

Virtual Reality Game Design for the Reduction of Chronic Pain Intensity in Clinical Settings

by

Amber Choo

B.F.A, University of British Columbia Okanagan, 2012

Thesis Submitted In Partial Fulfillment of the
Requirements for the Degree of
Master of Arts

in the

School of Interactive Arts and Technology
Faculty of Communication, Art and Technology

© Amber Choo 2015

SIMON FRASER UNIVERSITY

Summer 2015

All rights reserved.

However, in accordance with the *Copyright Act of Canada*, this work may be reproduced, without authorization, under the conditions for "Fair Dealing." Therefore, limited reproduction of this work for the purposes of private study, research, criticism, review and news reporting is likely to be in accordance with the law, particularly if cited appropriately.

Approval

Name: Amber Choo

Degree: Master of Arts

Title of Thesis: Virtual Reality Game Design for the Reduction of Chronic Pain Intensity in Clinical Settings

Examining Committee: **Chair:** Wolfgang Stuerzlinger
Professor

Diane Gromala
Senior Supervisor
Professor

Chris Shaw
Co-Supervisor
Associate Professor

Bernhard Riecke
Supervisor
Assistant/Associate/Professor

Peter Gorniak
External Examiner
Adjunct Professor

Date Defended/Approved: July 2nd 2015

Ethics Statement



The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

- a. human research ethics approval from the Simon Fraser University Office of Research Ethics,

or

- b. advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University;

or has conducted the research

- c. as a co-investigator, collaborator or research assistant in a research project approved in advance,

or

- d. as a member of a course approved in advance for minimal risk human research, by the Office of Research Ethics.

A copy of the approval letter has been filed at the Theses Office of the University Library at the time of submission of this thesis or project.

The original application for approval and letter of approval are filed with the relevant offices. Inquiries may be directed to those authorities.

Simon Fraser University Library
Burnaby, British Columbia, Canada

update Spring 2010

Abstract

Virtual reality applications have been shown to reduce discomfort and pain in acute pain patient demographics including dental patients, chemotherapy patients and burn patients. Currently little research literature exists on the effectiveness of virtual reality applications for chronic pain patients, who suffer from longer-term persistent pain experiences. This thesis outlines the testing of virtual environments designed to distract chronic pain patients from their embodied pain experiences. Their designs are influenced by contemporary game design theory, cognitive psychology and immersion frameworks. In a randomized crossover clinical study, twenty chronic pain patients spent ten minutes in *Cryoslides*, a virtual environment, using a head-mounted display, and ten minutes in a control condition. *Cryoslides* significantly reduced perceived pain intensity in chronic pain patients in the experimental condition. This shows that *Cryoslides* can be effectively used as an analgesic activity by chronic pain patients to lessen chronic pain intensity in short-term durations. The immersive design of *Cryoslides* contributes to the pain research community by directly addressing the lack of virtual reality research for chronic pain patients in the research literature. The results of *Cryoslides*'s clinical testing encourage future research inquiries into virtual reality applications designed for chronic pain patients with kinesiophobia, and virtual reality applications on mobile devices for at-home patient use.

Keywords: Virtual reality; games for health, pain management, chronic pain

Acknowledgements

I would like to thank my senior supervisor, Dr. Diane Gromala; my co-supervisor, Dr. Chris Shaw; and Dr. Bernhard Riecke for keeping me fed and adopting me into their home bases in SIAT. I thank the Faculty of Communication, Art and Technology as well as the School of Interactive Arts and Technology for supplying me with multiple graduate fellowships, support of which I am extremely grateful. I would like to thank Dr. Bernhard Riecke (again) for helping me find the missing pieces to my multidisciplinary thesis work, and for his patience during this process. I would also like to thank my parents for their ongoing positivity and complete lack of skepticism in my research activities. Lastly, I would like to thank my peers Xin Tong, Özgün Eylül İşcen and Mehdi Karamnejad for their cheerleading and moral support.

Table of Contents

Approval.....	ii
Ethics Statement	iii
Abstract.....	iv
Acknowledgements	v
Table of Contents.....	vi
List of Figures.....	viii
List of Acronyms.....	ix
1. Introduction	1
1.1. What is Chronic Pain?	2
1.2. What are Mobius Floe and Cryoslide?	4
2. Literature Review.....	5
2.1. Introduction	5
2.2. Games Research	5
2.3. Cognitive Sciences and Health.....	8
2.3.1. Burn Patients and Physical Therapy	8
2.3.2. Medically Induced Pain	9
2.3.3. Anxiety and Stress	9
2.3.4. Chronic Pain	10
2.3.5. Cognitive Distraction	11
2.4. Immersion	12
2.4.1. Challenge.....	14
2.4.2. The Imaginary	15
2.4.3. The Sensory	15
2.4.4. Stages of Immersion	16
2.4.5. Influence on Questionnaires.....	17
3. Design and Gameplay	18
3.1. Gameplay Walkthrough	18
3.2. Interface	22
3.2.1. Head Mounted Displays	23
3.3. Optimization for Split-Screen Stereo Rendering	24
4. Mobius Floe (Alpha) Testing.....	25
4.1. Materials.....	25
4.1.1. Mobius Floe	25
4.1.2. Chilling Space	26
4.1.3. Soundself	26
4.2. Apparatus	26
4.3. Participants	27
4.4. Design	28
4.5. Procedures	28
4.6. Results	29
4.7. Discussion	30

4.8. Limitations	31
5. VR Chronic Pain Reduction in Clinical Settings.....	33
5.1. Materials and Revisions	33
5.2. Apparatus	34
5.3. Participants	34
5.4. Experimental Design	34
5.4.1. Introductory Questionnaire	36
5.4.2. Post-Self Management Questionnaire.....	37
5.4.3. Post-Virtual Reality Questionnaire.....	38
5.5. Procedure.....	39
5.6. Results	42
5.7. Patient Feedback	46
5.8. Discussion.....	49
5.8.1. Duration of effect.....	49
5.8.2. Impact of cognitive immersion and presence	50
5.8.3. Anxiety.....	51
5.9. Limitations	52
Future Work.....	53
5.10. 53	
5.11. Conclusion	54
References.....	57
Appendices.....	64
Appendix A. Video Files.....	65
Appendix B. N-back task instruction sheet	66
Appendix C. Pain intensity questionnaires (all)	67
Appendix D. Study script	70

List of Figures

Figure 1.	The appearance of the n-back tasks in Cryoslide. The image on the block (shown as a fish) changes to a different image (such as a triangle) every three seconds. All n-back tasks were 2-back.	11
Figure 2.	The linear track of Cryoslide (top-down view). The virtual track features four minutes in a cave, and six minutes outdoors.	18
Figure 3.	The ice cavern and snow sled as seen in Cryoslide, with Booshi (red spherical creatures).	19
Figure 4.	Small neuron tree (left) and moth creature close-up (right).	20
Figure 5.	The adult neuron tree surrounded by 'Booshi'. Players can calm it down by hitting it with snowballs, earning them additional points.	20
Figure 6.	The clip applied (left) and the Oculus Rift by Sergey Galyonkin (cc).	27
Figure 7.	Pain intensity during exposure to three different virtual environments. Error bars depict 95% confidence intervals.	29
Figure 8.	A design diagram for the clinical study.	39
Figure 9.	Pain intensity reported retroactively after both conditions in comparison to pre-treatment pain intensity. Error bars depict 95% confidence intervals.	42
Figure 10.	Bar chart showing means of three immersion related questions. Error bars depict 95% confidence intervals.	44
Figure 11.	Means comparisons of questions posed in both experimental and control conditions. Error bars depict 95% confidence intervals.	45

List of Acronyms

FPS	Frames Per Second
HMD	Head-mounted display
PI	Pain Intensity
PPI	Present Pain Intensity
VE	Virtual Environment
VR	Virtual Reality

1. Introduction

Virtual reality (VR) is “an artificial world that consists of images and sounds created by a computer and that is affected by the actions of a person who is experiencing it” (“Virtual Reality | Definition” 2003). The virtual realities discussed in this thesis are virtual environments accompanied by stereoscopic head-mounted displays, pieces of hardware which occlude the visual senses from outside stimuli in favor of immersing the user in the simulated reality they convey. A virtual environment paired with a head-mounted display was once used in combination with a standard opioid treatment to manage the wound care of thirty-six burn patients over a period of several days (Faber, Patterson, and Bremer 2013). These patients underwent painful wound cleaning and debridement sessions while simultaneously immersed in virtual reality. The researchers who introduced the virtual reality simulation were curious as to whether or not this virtual reality treatment (in combination with pharmacological analgesics) would lessen the perceived pain of the burn patients during their wound care procedures over several days. They discovered that patients in the control condition (without VR) reported higher pain levels than on their days with exposure to the VR treatment.

Faber’s study is one of many examining the analgesic effects of VR on acute pain patients. There is already research literature which shows that virtual reality simulations are effective at reducing acute pain in various situations, such as in patients undergoing dental procedures (Hoffman et al. 2001), physical therapy (Hoffman, Patterson, and Carrougher 2000)(Schmitt et al. 2011), phantom limb pain (Perry et al. 2014), and wound dressing (Maani et al. 2008). In contrast, there is very little research pertaining to chronic pain patient treatment using virtual reality. The results of these acute pain studies, however, are especially promising when considering pharmacological analgesic medications are the default treatment for acute and chronic pain management, but have serious drawbacks which could be addressed with VR treatment. Examples include the development of physical tolerances to opioids after prolonged use, or developing dependencies on pharmacological analgesics like Oxycontin (Carise et al. 2007) to an

unhealthy degree. This can lead to prolonged stays in hospitals and decline in chronic pain patient well-being. By examining the research literature pertaining to virtual reality design for acute pain patients, and by refining the immersive spaces used to invoke these distractive experiences, this thesis paper aims to examine the potential components of virtual reality pain treatment design and determine if they could be effective for chronic pain patients. To do so not only addresses a serious gap in the research literature pertaining to the validity of chronic pain virtual reality treatments, but the findings also contribute to the rapid improvements of VR design research.

The key area of exploration in this thesis is the role of virtual reality treatments and their use with chronic pain patients. Although previous pain-related virtual reality studies provide valuable insight into the potential health applications of virtual reality for acute pain, chronic pain remains widely unexplored in the research literature (Garrett et al. 2014). Chronic pain costs economies billions of dollars worldwide due to its impact on the quality of life of those affected, decreasing patient productivity and generating additional costs to maintain services and medical care for chronic pain patients (Richard 2012)(Barham 2012). If virtual reality treatments are found to be successful for chronic pain relief, they could be used to increase patient well-being and quality of life.

The thesis' primary contribution is the design and evaluation of *Cryoslide*. *Cryoslide* (cryo: "a combining form meaning "icy cold," "frost," used in the formation of compound words") is a pain distraction virtual environment meant for use with chronic pain patients and developed at Simon Fraser University. Patients immersed in the virtual environment 'slide' forward on a sled in an icy environment, throwing snowballs in an attempt to cool down agitated, enflamed surreal creatures and solve simple cognitive memory tasks. Game mechanics and design decisions incorporated in *Cryoslide* are discussed with perspectives including but not limited to HCI, cognitive psychology and digital immersion research.

1.1. What is Chronic Pain?

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 knee. 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. Rather, chronic pain persists well beyond the time expected for an injury to heal and may continue to exist for the course of a lifetime (Russo and Brose 1998). Chronic pain can manifest as a result of an injury to the body, or it can manifest without a clear 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” (Treede et al. 2008).

Chronic pain experience is also influenced by psychosocial influences and factors which interact with brain processes and patient perception of pain (Gatchel et al. 2007). While pain fades with 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 additional decreases in social interaction and psychological health (Gilmour 2015). For example, there is a statistical association between the presence of CP and depression (Fishbain et al. 1997). Opioids are commonly prescribed for chronic pain, but they pose a notable risk of addiction, even in patients considered to be low-risk (Wasan et al. 2012). Craving opioids in this manner negatively impacts patient mood, invoking urges for more medication and pre-occupying patients with thoughts of the next dose (Wasan et al. 2012).

Approximately 29% of the population of Canada suffered from chronic pain in 2004 (Boulanger et al. 2007). Statistics Canada reported that approximately 5.6 million Canadians suffered from chronic pain in 2011/2012 (Gilmour 2015). Any form of help virtual reality treatment could provide to this demographic would be beneficial to those affected. For these reasons, this thesis paper focuses on research and design for the chronic pain patient demographic.

1.2. What are Mobius Floe and Cryoslide?

Mobius Floe and *Cryoslide* are virtual realities designed at Simon Fraser University to reduce the intensity of pain experiences in pain patients. Both virtual realities attempt to cognitively distract the patient from physical pain. This tactic has already been shown to be useful for short-term pain experiences, such as during painful medical treatments (Hoffman, Patterson, and Carrougner 2000). People who play games may be able to relate to this distractive experience when thinking back to a time where they may have had some type of injury or headache and played a video game, drawing their attention outward and away from their injury. Some individuals become completely immersed in other realities while playing something they enjoy, blocking out other sensory stimuli for potentially lengthy periods of time (Porter et al. 2010)(Fakhruddin 2012).

The designs of these virtual realities were inspired by a previous VR for acute pain patients titled *SnowWorld* (Hoffman 2015). *SnowWorld* was a virtual environment viewed through a head mounted display (HMD) which demonstrated that VR treatments can work in tandem with pain medications to further reduce perceived instances of pain in patients with combat-related burn injuries (Maani et al. 2008). Unfortunately, the specifics behind how to approach virtual environment design for pain treatment vary in the research literature. Some research studies use hypnotic environments (Patterson et al. 2006) while others use VR with distracting gameplay, such as *SnowWorld* (Faber, Patterson, and Bremer 2013). Some studies state an immersive VR was used, but do not discuss what the VR experience was like in any detail (Das et al. 2005)(Mosso-Vazquez et al. 2014). What was clear from previous literature, however, was the invocation of virtual presence would be necessary in reducing perceived pain intensity with virtual reality (Hoffman et al. 2004). To invoke virtual presence, digital immersion frameworks were utilized to help the chronic pain patients immerse themselves into virtual spaces. Game mechanics were also implemented in order to help increase patient engagement and heighten cognitive distraction. The resulting combination of these ideas and frameworks were translated into the virtual realities discussed in this thesis paper, with *Cryoslide* being introduced to chronic pain patients at a complex pain clinic in Vancouver, B.C after production. The virtual reality treatment dramatically reduced patient's pain levels in the clinical setting.

2. Literature Review

2.1. Introduction

The technical and theoretical inspirations behind the design of *Cryoslide* and its earlier manifestations are diverse because the virtual environment exists to serve health research, but improves in effectiveness by drawing on research from other fields including game design theory, immersion frameworks and cognitive psychology.

2.2. Games Research

Cryoslide took inspiration from various design frameworks pertaining to player experience. Lazzaro's study titled "Why We Play Games: Four Keys to More Emotion without Story" is an influential examination into four types of fun that can be observed in video game players (Lazzaro 2004). Her study attempted to discover if video games could generate emotions without storytelling, and the results were split into four fun 'keys' or types of fun observed. Forty-five individuals' gameplay experiences were recorded using various methods, including interviews, surveys, videos of their facial expressions and audio recordings. They observed that games could indeed draw various types of emotions using gameplay mechanics without story. They separated all of the emotions they witnessed into the four fun keys: Hard Fun, Easy Fun, Serious Fun (or Altered States), and People Fun. Hard Fun manifests from challenge-based experiences, whereby the player a difficult obstacle and attempts to overcome it, invoking great satisfaction when they do so. Easy Fun emerges from more imaginative gameplay such as exploration-based experiences and simulator games, such as farming simulators or life-sims.

Serious Fun explores real-life meaning and the socio-political side of gaming, comprising educational games or games with specific messages they wish to convey. Games that teach their players something new, or propose they try and think in different ways belong to the Serious Fun category. People Fun comprises multiplayer experiences where players communicate and generate a wide array of emotion from those interactions. People Fun can also encompass feelings that players develop for virtual characters, such

as well written characters in narrative-based games. These fun keys are important to understanding why individuals play games and continue to come back and play more, considering a fun experience is often the key to persistent play. It is also safe to assume that a game with many fun keys will appeal to a broader range of players. The higher the appeal of the game, the more likely we will be able to maintain pain patient interest and maintain a state of cognitive immersion.

It is worth noting that the concept of 'Hard Fun' shares many similarities with Csikszentmihalyi's Flow framework. Flow explains an ideal psychological state which applies to many disciplines and practices in which an individual has engaged in a task and obtained the correct balance of challenge in relation to their skill (Csikszentmihalyi 2004); this ideal state is important to maintaining virtual immersion, for flow "can be positively associated with degrees of the cognitive phenomenon of immersion and telepresence" (Faiola et al. 2003) and is also considered to be an important part of games user experience (Takatalo et al. 2010). *Cryoslide* challenges the player by encouraging patients to throw virtual snowballs at creatures in the virtual space; some creatures are harder to hit than others and award the player more points for doing so. At the same time, the surrealist gameplay combined with the stereoscopic head mounted display encourages feelings of wonder, awe and mystery, invoking the casual experiences correlated with "Easy Fun" which relies heavily on curiosity. Lazzaro also notes that "Serious Fun" is concerned with games for real-world purposes and 'games as therapy' whereby the game enables the player to change their affective state in a meaningful way or conduct an activity that is meaningful outside of the context of the game. Patients who underwent an experience in *Cryoslide* were acutely aware they were participating in a research study that was meant to benefit chronic pain research, and one would assume many volunteers found 'serious fun' satisfaction in being able to contribute to the cause through their participation. Although Serious Fun does not contribute to digital immersion, it invokes a longer-term interest in the patient's perspective on the virtual treatment.

Lenticular design is a game design philosophy that was also an important factor in the development of *Cryoslide*, as it stresses the importance of designing a game for many types of users, all of whom have varying skill levels and interests. Lenticular design, when implemented correctly, provides additional degrees of complexity for players who are searching for it, but blends into the gameplay in such a manner as to not intrude or

discourage new or casual players (Grieco 2015). For example, casual players can glide through *Cryoslide* doing very little without penalty. They can choose to observe the graphics and going-ons of the virtual environment instead if they feel the other gameplay is too stimulating. Other players who want a little more challenge can attempt to earn a high score by hitting as many creatures as possible with snowballs, including the hardest-to-hit creatures, invoking a more challenge-based experience. There are also small optional cognitive challenges in the game in the form of n-back tasks which these users can engage in to earn more points. At its essence, lenticular design allows players to choose their own difficulty level by enabling players to choose what activities they are most interested in pursuing in the virtual environment.

The idea of uncertainty or the sense of not knowing what will happen next was crucial to maintaining patient interest in *Cryoslide*. Uncertainty in games can be broken down into two forms: “on a macro-level relating to the overall outcome of a game, and on a micro-level relating to specific operations of chance within the designed system” (Zimmerman and Salen 2004). It is important in all games to ensure that the player feels somewhat uncertain about what happens next in order to maintain their interest, but not to create so much uncertainty that the player feels lost or without agency. This is a key reason why *Cryoslide*’s creatures were designed to be surreal in appearance, appear gradually over time, and behave differently from other creatures in the virtual environment; creature design is discussed in detail in section 3.1. The player is uncertain what creatures will appear next, and what the creatures will initially attempt to do. When they meet these creatures for the first time, players learn their behaviours, and the creatures become more familiar and predictable. At this time, another new creature the player hasn’t seen before can then be introduced, maintaining a degree of micro-uncertainty. On a larger scale, the player is also uncertain as to where they are being led to in the virtual environment. Uncertainty is also an important part of maintaining imaginative immersion as discussed in section 2.4.

2.3. Cognitive Sciences and Health

2.3.1. *Burn Patients and Physical Therapy*

There is already research available in regards to the effectiveness of virtual reality for burn patient pain reduction, including successful applications of virtual reality treatment in burn patients of varying ages (Hoffman et al. 2014)(Maani et al. 2008)(Hoffman, Patterson, and Carrougher 2000)(Hoffman et al. 2000)(Faber, Patterson, and Bremer 2013)(Das et al. 2005). For example, in a randomized control trial study, 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) (Das et al. 2005). A different study concerned with severe burn injuries and physiotherapy used virtual reality as a distraction tool while twelve burn patients underwent physical therapy to prevent their bodies from healing inadequately during their recovery process (Hoffman, Patterson, and Carrougher 2000). They found that virtual reality 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. They also reported that the analgesic effect was maintained with repeated usage of virtual reality therapy over multiple sessions (Schmitt et al. 2011).

The key virtual environment that inspired *Cryoslide* was a VR titled *SnowWorld*, which drew patient's attention away from their embodied experience of pain and toward the virtual 3D environment. It was used to curb the wound care pain of U.S. soldiers injured with significant burns at the U.S. Army Institute of Surgical Research (USAISR). *SnowWorld* featured a snowy landscape where the patient could throw snowballs at snowmen in the virtual space. This experience, combined with analgesic medications, served to improve the soldier's pain experiences in regards to "time spent thinking about pain" and experienced "pain unpleasantness", both of which declined significantly with the introduction of VR to their standard wound care routine (Maani et al. 2008).

2.3.2. *Medically Induced Pain*

Although burn patients primarily encompass the small amount of literature that is available, other types of acute pain have been examined. Hoffman has also reported reduced levels of pain in dental patients undergoing scaling and root planing in those who were immersed in cognitive distraction via a virtual reality simulation over patients who were asked to watch a movie and those who had no distraction present during their procedures (Hoffman et al. 2001).

Wint et al. examined the feasibility of using virtual reality glasses on thirty children receiving lumbar punctures during their cancer treatments to distract them from the painful procedure in the hopes their pain experiences would be lessened (Wint et al. 2002). They found a slight analgesic effect, but it was not statistically significant. A limitation of this study that wasn't discussed in the paper is the glasses themselves. 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 (Vidyarthi 2012). The children in the study had several distractions, including their parents who were attending the LP procedures. 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 (Hoffman, Patterson, and Carrougner 2000)(Maani et al. 2008). Additionally, the children were asked to watch a 3D movie, which would not have provide any tasks to encourage further engagement and strengthen the immersive experience. The importance of sensory and challenge-based immersion (task oriented) is discussed in greater detail further in the literature review.

2.3.3. *Anxiety and Stress*

There are very few studies examining the effect of virtual reality on stress reduction. One study introduced virtual reality to sixty-seven postoperative patients who underwent cardiac surgery; the researcher's intent was to reduce patient postoperative distress. 88% of the participants reported a decreased level of pain, while 37.3% experienced lower heart rates, 52.2% experienced reduced arterial pressure, and 64% experienced reduced respiratory rates (Mosso-Vazquez et al. 2014); the VR successfully

reduced patient 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 (Schneider and Workman 2009). This distress reduction did not extend outside of the VR, but was maintained strongly while the children were at play.

Virtual realities have been known to encourage meditative practices in pain patients to reduce pain intensity (Gromala et al. 2015). 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. Galvanic skin response sensors were worn by the patients, 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 (Gromala et al. 2015). The benefit of a strategy such as this is that the virtual reality experience teaches the patient MBSR over time, providing visual feedback in response to the patient's current physical state.

2.3.4. Chronic Pain

Chronic pain patients, although requiring long-term pain reduction strategies, also suffer from shorter-term spikes in pain intensity (Baliki et al. 2006) during which they may also benefit from non-pharmacological treatment practices. In a study using a relaxing virtual environment, forty chronic pain patients experienced a VR in an attempt to reduce their pain intensities. The researchers found that patient's 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 (B. Wiederhold et al. 2014). Unfortunately, there is insufficient literature to show that chronic pain patients can benefit from immersive virtual reality applications in the same ways as their acute 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 (Shahrbanian et al. 2009)(Garrett et al. 2014). In order to fill this



Figure 1. *The appearance of the n-back tasks in Cryoslides. The image on the block (shown as a fish) changes to a different image (such as a triangle) every three seconds. All n-back tasks were 2-back.*

research gap, this thesis adapts what was learned from previous virtual reality analgesics for acute pain, and applies these findings to chronic pain patients in an attempt to determine if pain reduction can also be achieved with the CP demographic in this manner.

2.3.5. Cognitive Distraction

Cryoslides incorporates techniques from the cognitive sciences by introducing n-back tasks, attentional switching and dual-task paradigms which work in tandem to invoke cognitive load, continuous action and heighten arousal (Herff et al. 2013)(Wickens 2002). These techniques encourage cognitive engagement, which is necessary to invoke psychological immersion (Ermi and Mayra 2005; Takatalo et al. 2010; Brown and Cairns 2004), a key user experience goal of *Cryoslides*. Patients are encouraged to perform tasks such as n-back puzzles for large amounts of points by memorizing n-back ($n = 2$) visual patterns, such as triangles, fish, trees and other simple images. Participants interact with the images using a throwing mechanic to identify the correct image in the sequence. The image shown in Figure 1 would rotate to a new image every three seconds. When the

image repeated the same image shown two images earlier (two-back) in the sequence (an example being Square, Circle, then Square) participants were instructed to hit the image to complete the n-back task. Participants who hit the n-back task at the correct moment spawned a large green checkmark with a positive sound effect to inform them the task had been completed correctly. There was approximately one visual n-back task per minute in the outdoor area, therefore increasing the amount of cognitive load on the player later in the game.

Attentional switching and dual-task paradigm examples from *Cryoslide* include player interactions with said puzzles and creatures, often in a simultaneous fashion. Occasionally, the n-back tasks and an abundance of differently behaving creatures would be in the proximity of the player at the same time, encouraging attentional switching and dual-task paradigms. The players had to switch their attention between the creatures' locations and the n-back task memorization to score the most points, fully engaging their cognitive load. For example, the player may find themselves fending off neuron trees, trying to stay focused on the n-back images while simultaneously considering a snowball assault on a nearby moth-creature. N-back tasks are known to increase cognitive load (Herff et al. 2013) as are attentional switching and dual-task paradigms. Such tasks also improve gameplay experience in regards to challenge-based immersion (Ermi and Mayra 2005) which emphasizes player investment through implementing challenge and potential for emotional reward.

2.4. Immersion

In order to create and improve upon the user experience effects witnessed in previous virtual reality pain studies, we must first understand what about the virtual reality experiences was causing the analgesic effect. 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 (Hoffman et al. 2004). All participants attempted to immerse themselves in the same virtual reality, but some used the low-tech rig, which was a pair of stereoscopic virtual reality glasses without a player controller or audio output, while others used the high-tech rig which consisted of a head-

mounted display with 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 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.

Immersion within the context of game-playing is a critical affective element to ensure players will be drawn into the gamespace and ideally decide to stay there. Introducing specific terms in an attempt to better describe individual immersive experiences allows for more coherent discussion about the affective impact that games press upon their players and how that impact is constructed. Ermi and Mayra outline three types of immersion (Ermi and Mayra 2005) which are directly applicable to game-playing experiences, all of which informed the game's design. Oftentimes terms such as 'immersion' are used in contexts where the specific experience behind the immersion attempting to be conveyed requires further clarification, for the immersive experience can manifest in highly variable ways. Ermi and Mayra proposed three terms to describe three variations of immersion which can co-exist or manifest individually from a design perspective. They describe challenge-based immersion as a feeling that is most strongly evoked when the player is faced with well-balanced and satisfying challenges of skill. Imaginative immersion is described as the phenomenon where players are encouraged to use their own imaginations in tandem with the virtual space by becoming absorbed in the narrative, its characters, and the settings shown in the game space. Lastly, sensory immersion involves immersing the human senses, most commonly with visual and audible stimuli. This is more easily done by using immersive technologies such as noise-cancelling headphones or stereophonic audio rigs, large high definition displays or stereoscopic equipment, all of which attempt to draw the focus of the player away from the real world.

2.4.1. Challenge

Challenge-based immersion (Ermi and Mayra 2005) has a definition which manifests similarly to Csikszentmihalyi's "flow" framework. Here challenge-based immersion encompasses the positive feelings a gamer experiences when they are presented with a coherent challenge and are able to apply their skills to it in such a manner as to not allow them to complete the challenge easily, but instead work toward victory and obtain 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 (Lazzaro 2004) whereby her definition for 'Hard Fun' manifests as the direct result of challenge-based activities. In other words, this type of fun is produced when players complete challenging activities. However it should be noted that the 'fun key' terminology is a bit misleading when considering the full breadth of challenge-based games. Not all challenge-based games produce 'fun' in players in a conventional sense. Rather, many games do not necessarily translate directly to a 'fun' experience but are intentionally designed as stressful experiences, such as *Papers Please*, a popular indie game where the player becomes an immigration officer on the border of a dystopic fictional country (Cobbett 2013), or games such as *Outlast* or *Amnesia: The Dark Descent* where the player intentionally subjects themselves to extremely frightening, anxiety-laden horror-based situations (Todd 2010).

The fact that *Cryoslides* is not meant to be played for hours on end informed the design decision to add challenge-based immersion with mechanics concerned with short-term activities. *Cryoslides* does not try to impress upon the player long-term goals to solve. Rather, it focuses on the survivability of the now by continually ambushing the player with enemies they must thwart. However, the mechanics to respond to these challenges are extremely simplistic and uncomplicated in order to design for the chronic pain patient demographic, many of whom do not play games. Players are never punished for failing to do something, and they do not have to worry about controlling self-propelled movement. At the same time, challenge-based immersion manifests through the creatures and the n-back tasks in the environment, which can be tackled at each patient's individual pace. And so *Cryoslides* does not delve deeply into difficult, complex activities as expertly as many other contemporary games have thus far. It does not need to. By introducing simple,

minimalist mechanics, *Cryoslide* becomes much more accessible to the patient demographic.

2.4.2. *The Imaginary*

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 and allowing them to absorb their avatar's experience within it, including interactions with fictional characters and with the environment. Many types of games rely heavily on this world-focused immersive gameplay with story-based narratives; some examples include the beautiful landscapes and mysterious lore in *Diablo III* (Ingenito 2014) and in the *Dragon Age* series (Hamilton 2014).

Cryoslide capitalizes on imaginative immersion through its surreal representations of 'neuron trees', 'booshi' dendrites, and its beautiful snowy landscape setting, which allows for a familiar environment for the player to situate themselves in while simultaneously providing curious characters to investigate.

2.4.3. *The Sensory*

We would not be able to convey narrative situations or feats of challenge very easily without some sort of stimuli to convey this information. Sensory immersion oftentimes plays an important part in immersing gamers into contemporary virtual spaces. All parts of the game which stimulate the physical senses of sight, of sound, and of touch are generally encompassed in the discussion of sensory immersion within this context. For example, a large television screen coupled with comfortable seating and stereo sound could be considered an ideal immersive sensory rig within the home. Vidyarthi also asserted that 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 (Vidyarthi 2012). For example, the voices of others in the room adjacent to yourself, the sunlight streaming through the window and onto the television, or internal nociceptive pain could all be considered unwanted distractions deterring the player from becoming fully immersed within the virtual world. And so in order to properly cater to sensory immersion

one must not only consider the internal graphics and sound within the game but how they are conveyed to the player within the physical space.

Cryoslide sports stereo sound which were be used with noise-cancelling headphones to occlude external stimuli. *Cryoslide* also relies on a stereoscopic (three-dimensional) HMD, the Oculus Rift DK2 to encompass the participant's field of vision. The spectacle of the viewer seeing and experiencing the Rift for the first (or third, or fifth) time is often enough to get participants excited about how tangibly real the virtual environment feels around them. *Cryoslide* was played in a quiet clinical setting in a private room, which was necessary in order to prevent external stimuli from drawing the player away from the sensory experience.

2.4.4. Stages of Immersion

Brown and Cairns also attempted a proposal of new terminology to better clarify descriptions of immersion experience. The authors investigated cognitive psychology from an evolutionary perspective and focused on three 'levels' of immersion instead of three separate manifestations: engagement, engrossment and total immersion (Brown and Cairns 2004) whereby users can transition between them, total immersion being the highest form of immersive experience. Engagement is the lowest level and is concerned with intent and ease of use, including the interface and control systems, the argument being that if participants cannot engage well with the system, it will inhibit their ability to become immersed in what the system has to offer. Engagement also encompasses the participant's intentions: if they do not want to play the game or spend the necessary time to do so, they will not be engaged. When 'engagement' has been achieved, engrossment is the next immersive step, whereby the game must directly affect the gamer's emotions, whether that manifests directly as a 'fun' experience or even through a sense of respect for the game's construction. Regardless, the emotional investment must translate to the player wanting to continue play. Engrossment also encompasses physical symptoms of digital immersion, such as the gamer being less aware of their surroundings. Once engrossment is achieved, 'total immersion' is possible, which primarily encompasses embodied presence. Participants are "cognitively cut off from reality", and the game becomes their only focus.

2.4.5. *Influence on Questionnaires*

The three stages of immersion as proposed by Brown and Cairns and the three types of immersion introduced by Ermi and Mayra also influenced various immersion-related questions on the questionnaires used in the clinical study. For example, the question “I felt like I lost track of time in the snow world” is drawn from Brown and Cairns’ notion of ‘engrossment’ as well as Csikszentmihalyi’s Flow framework. “I found the controls were easy to use” correlates to Brown and Cairns’ ‘engagement’ and the Flow framework. “I was focused on collecting as many points as I could” draws from all discussed immersion frameworks, specifically Ermi and Mayra’s challenged-based immersion and Brown and Cairns’ ‘engrossment’ and ‘total immersion’. All questions discluding the pain intensity questionnaires were concerned with one or more immersion frameworks. By including questions on several aspects of how one can engage with immersive virtual worlds, we are able to survey patients’ immersive experiences in a holistic and specific manner. The full list of questions on the user experience questionnaires are available in the appendix.

3. Design and Gameplay

Before reading this section, it may be easier to understand the discussion by viewing the short video of *Cryoslide* available in the Appendix.

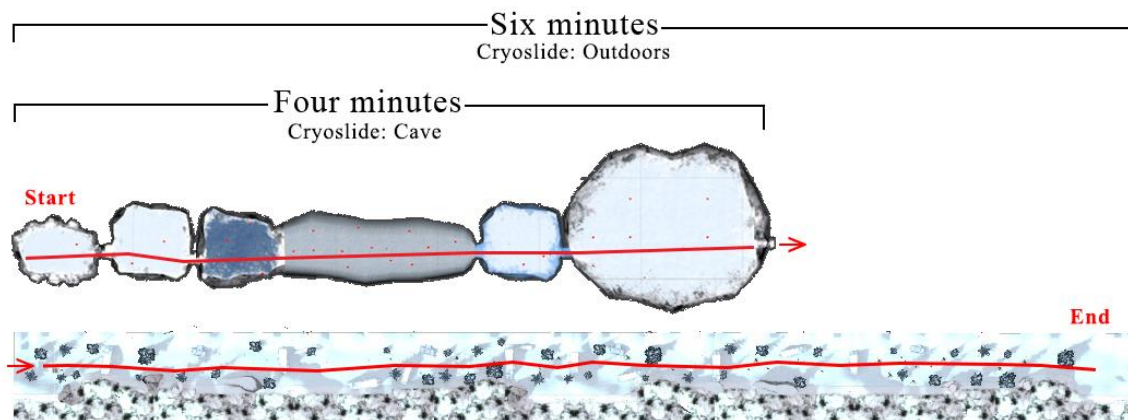


Figure 2. *The linear track of Cryoslide (top-down view). The virtual track features four minutes in a cave, and six minutes outdoors.*

3.1. Gameplay Walkthrough

Cryoslide's construction was finished in January 2015. Made in the Unity game engine (Helgason 2015), it sports various distraction-based gameplay strategies in different areas of the virtual space which gradually intensify over a ten minute duration. It is designed to be played with the Oculus Rift head-mounted display (HMD), which is worn in a way similar to a pair of ski goggles. The Rift provides an immersive visual display which refreshed at 75 frames per second, allowing for greater depth of embodied immersion within the virtual space.

The *Cryoslide* virtual environment first transports players into an ice cave (Figure 2). The player is automatically drawn forward through the virtual space on a 'rail' system, or pre-determined linear pathway. Wearing the Oculus Rift, the patient can physically look down to find themselves on a wooden snow sled being pulled through the ice cavern (Figure 3). The player can read how to play or view their current 'score', or number of points accrued for their actions, which is shown on a piece of paper at the front of the sled.

The patient can start and stop the sled at any time with a click of the right mouse button. Patients are told to throw snow balls using the left mouse button while aiming with the position of their head, which was made possible by the Oculus Rift's head-tracking camera.

The patients encounter many creatures, some of which are more difficult to hit with snowballs than others, creating varied degrees of challenge. Patients first encounter floating red spherical creatures (called Booshi) with neuron-like dendrites (Figure 3). The Booshi are bright and easily seen against the snowy backdrops of the virtual environment. Most Booshi don't move, which provide ideal targets for participants who are learning how to control the virtual environment. After several minutes in the virtual environment however, small clusters of four Booshi appear in the ice caves and fly in circles between and around one another. These are slightly harder to hit, providing for a slight increase in challenge. Creatures also invoke further player involvement, an important aspect of games user experience (Takatalo et al. 2010).

Upon hitting Booshi with a snowball, they turn cyan in color (a visual representation of the Booshi 'cooling down') and emit a happy squeak and disappear, earning the patient one point per creature hit. The points are updated in real time on a virtual paper on the wooden sled to ensure the patients can actively keep track of their progress.



Figure 3. *The ice cavern and snow sled as seen in Cryoslide, with Booshi (red spherical creatures).*

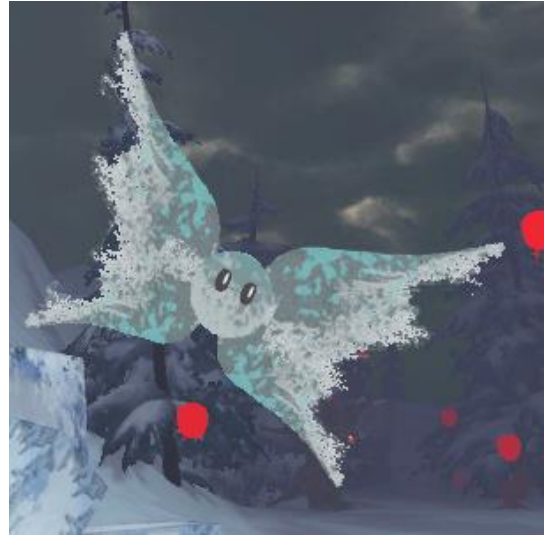
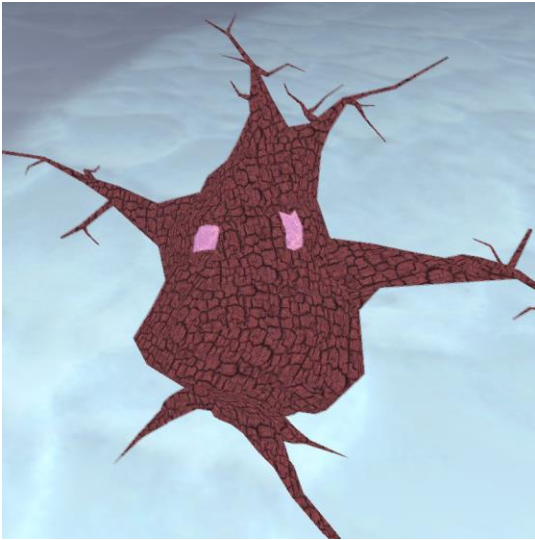


Figure 4. *Small neuron tree (left) and moth creature close-up (right).*



Figure 5. *The adult neuron tree surrounded by 'Booshi'. Players can calm it down by hitting it with snowballs, earning them additional points.*

The software does not punish patients for missing any Booshi or other creatures in regards to gameplay mechanics. The patient's aim in the virtual space is to cool down or calm the agitated characters in the *Cryoslide* space to obtain the most amount of points possible.

After six minutes of gameplay in the ice cavern, players are visually transported to a new outdoor environment in order to maintain their imaginative interest. The outdoor area consisted of a linear path through the snow surrounded by snowy hills and trees. The Booshi are placed here in abundance to distract the pain patients.

Moth characters are seen rarely in the snowy outdoor area and fly quickly in pre-defined circular patterns. If the participant can hit the moth with a snowball, they earn a large sum of points, and the moth disappears into a ball of light. The moth is designed to blend in with the surrounding environment, encouraging participants to pay close attention to spot them when one appears and furthering their attentional concentration toward the virtual environment. The moths also move at a quick enough speed that participants will have to shoot ahead of the moth's trajectory to hit it successfully, making them a little more challenging to hit than the Booshi.

Outdoors, the patients also find themselves under threat from new chest-high spherical creatures with neuron-like dendrites (Figure 4). These miniature 'neuron trees' are capable of chasing the player's sled when the sled draws close. The miniature neuron trees are meant to surprise the player when they first approach the player's sled, as the player has not seen this type of behavior before from any of the previous creatures. The miniature neuron trees take three snowballs instead of one to defeat, and use a simple AI pathfinding script to avoid obstacles to reach the player successfully.

Introducing new characters is done over time in order to increase challenge to help maintain 'flow' state. The final creatures to appear on the linear track is the adult neuron tree. These 'neuron trees' are circled by the red spherical Booshi creatures and are designed with unfriendly, agitated expressions. They are programmed to chase the player when s/he is close, but fall asleep and disappear when hit with many snowballs. The neuron tree design is inspired by the neurological systems in the human body causing the pain experience. In particular, the trees are designed to be the 'scariest' creature, and

serve as a key mode of cognitive distraction as they coerce the player with their angry expressions into taking defensive actions against them in a strategic and time sensitive manner. Although the neuron trees appear intimidating, there is no negative effect on the player if they fail to subdue a neuron tree. However, the neuron trees are the most challenging to defeat, as they take the most time and snowballs to deter. Like their smaller counterparts, the trees are programmed to understand where they can walk and where they cannot to ensure they are able to glide around the virtual environment without colliding into snow walls or other obstacles, optimizing their ability to chase the player's sled.

The four creatures as discussed increase in difficulty and behavior, with the easiest creatures to 'cool down' with snowballs appearing first, and the most difficult creatures appearing last. This decision was informed by the flow framework as discussed in the literature review, which strongly emphasizes maintaining a level of challenge befitting the player at all times, lest they become too bored or too frustrated (Cowley, Charles, and Black 2008).

3.2. Interface

The team considered various types of interactive hardware which could be used by patients to control their experience within *Cryoslide*. Production and testing was done via mouse and keyboard. Because we were designing for pain patients, it was strongly advised we keep controls simple and as minimalist as possible in order to avoid overwhelming non-gamer patients, while simultaneously keeping the gestural aspect of controls to a minimum to maintain optimal patient comfort. This is in conflict with industry standards, which put heavy emphasis on multi-button controllers often seen paired with console devices or PCs (Machkovech 2015). We decided to use a simple two-button computer mouse during clinical testing, as the interface was familiar to most patients, and was not over-complicated in appearance.

3.2.1. Head Mounted Displays

We are many years away from achieving the ideal technologies for virtual reality simulations. Nechvatal in his paper in *Leonardo* speculates on what would be required from a philosophical perspective of the truest digital immersion, whereby the technology used would have to immerse us in such a manner as to render itself invisible during use (Nechvatal 2001). The ontological separation between one's body and one's presence in the virtual space would be resolved and the participant's sense of presence and self-awareness would be truly immersed within the VR. Current HMDs for use with VR software are extremely promising for immersive experiences and are improving at a rapid pace. The use of HMDs or other virtual reality viewers is critical to the pain distraction intent underlying the design of *Cryoslides*, and can of course be used for other purposes aligned with participant immersion for future research projects.

The Oculus Rift produced by Oculus VR® is a well-known HMD manufactured by Oculus VR and was used in the *Cryoslides* study. A key critique of the device thus far has been resolution (Hutchinson 2014), which has been somewhat resolved in the Oculus DK2 (also known as Crystal Cove) which has a resolution of 960 x 1080p per eye. The Valve Corporation ("Valve" 2015) is also taking fast technological strides in regards to their research collaboration with HTC into head mounted displays – the HTC Vive has two OLED screens with a resolution of 1200 x 1080 each, with a refresh rate of 90hz. Both devices perform well in regards to the positional tracking of one's head in real-time by allowing the user to physically look around the virtual space and have the stereoscopic imagery update appropriately. Valve's HMD however allows the user to wander around the small room that the HMD is situated in (Orland 2015). This is especially interesting when participants realize that they are able to physically walk up to virtual objects. This technology in particular would be extremely useful in a research study involving chronic pain patients with kinesophobia (fear of movement) as it has the ability to actively encourage full-body participant movement. The Oculus Rift was successfully used in a study involving burn patients by Hoffman et al. with further recommendations of its use for further pain related studies (Hoffman et al. 2014).

For the VR sub-study and primary clinical study outlined in this paper, we chose the Oculus Rift DK2 after user testing studies were conducted by members of the

Transforming Pain Research Group in clinical settings. A previous graduate student examined the Oculus Rift against a different stereoscopic viewer titled the Deepstream 3D, made by Firsthand Technologies (Karamnejad 2014). Although the Deepstream was found to be more comfortable and produced fewer physical symptoms, the Oculus was found to encourage a more immersive experience and was not considered to be significantly taxing on its participants. Considering how important immersion is to a distractive *Cryoslide* experience, we chose to use the Oculus Rift with emphasis on patient well-being. If participants found the experience to be too physically demanding or uncomfortable at any time, they were to inform the study investigator immediately and would be withdrawn from the study. The patients were also given the ability to stop motion in the virtual environment at any time using the right mouse button whenever they desired.

3.3. Optimization for Split-Screen Stereo Rendering

The Oculus Rift DK2 runs at a refresh rate of 75 Hz. Lower frame rates are associated with higher probabilities of nausea (Pose and Regan 1994), which would be inappropriate to use with patients if the issue could be prevented. When drawing for split-screen stereo virtual reality, we are in essence drawing two screens instead of one, and so optimization is especially critical to ensure the images stream as cleanly as possible without lag. Low frames per second (FPS) can cause disruptive feelings of nausea in virtual environments, and has been used in the past to intentionally generate feelings of nausea for research purposes (Russell et al. 2014). Low FPS or Hz could disrupt feelings of sensory and embodied immersion within the digital space due to the feelings of nausea it could produce.

In regards to preventing this issue, several aspects that influence frame rate optimization were addressed. How many polys are we drawing? Are the textures mapped onto sheets or being called separately? How can we construct the design of the scene in such a way as to help reduce draw calls using occlusion culling? These types of issues are considered at the start of production and continually re-evaluated during the development process.

4. Mobius Floe (Alpha) Testing

In this pilot study, we examined if perceived pain would be significantly reduced in healthy volunteers who engaged with an alpha version of *Mobius Floe* in comparison to healthy volunteers engaged in an ordinary immersive title not designed for pain reduction (the control condition). If *Mobius Floe* is unable to reduce perceived pain reduction in comparison to its control condition, it would indicate that the software requires revisions before its usage with pain patients and help identify where those revisions are required.

4.1. Materials

4.1.1. *Mobius Floe*

The stimulus materials used in the experiment consist of three different VR experiences. The first was *Mobius Floe* in its alpha stage; *Mobius Floe* is the precursor to *Cryoslides*. A short video of the *Mobius Floe* software is available here: <http://bit.ly/1BOe0fH>. *Mobius Floe* consists of simple rail-based gameplay whereby the player is propelled forward automatically on an invisible track. Players throw different analgesic drugs (visualized as colorful spinning spheres) at anthropomorphic trees in the virtual environment to make them fall asleep. For this study, a modified rail system was used, which leads the player into smoke at the end of the finite track, and has them re-appear at the start of the track, looping the rail system infinitely. There is a health point system visualized on an on-screen GUI, although it was modified to ensure even if the players did poorly, the game would still run and not end prematurely. These adjustments ensured players would play *Mobius Floe* for ten minutes, as the alpha rail was originally six minutes long. The linear track is fairly curvy, veering unexpectedly in various directions at different parts of the track, including up and down a mountainous area.

4.1.2. Chilling Space

The second VR, *Chilling Space* (“Rift Away - Oculus Rift Experiences” 2015), allows participants to float slowly in outer space and shoot at asteroids rendered in a realistic aesthetic. Participants can move the right arm of the avatar from first-person perspective and use it to aim projectiles at asteroids. The asteroids pose no threat to the avatar, and no tasks are introduced or asked of the participant.

4.1.3. Soundself

The last VR allowed participants to immerse themselves in a meditative, virtual trance-space titled *Soundself* (Arnott 2013), which was created for use with a head-mounted display. The visual spiral inside of *Soundself* is the only feature of the virtual environment. The spiral changes chromatically over time through mesmerizing animations which pulse and swirl. *Soundself* does have a single mode of interactivity which is audio-based, encouraging players to hum along with the ambient sound which influences the spiraling visuals. For the purposes of this study we did not allow participants to engage with the software in this way, instead choosing to use *Soundself* as a no-interactivity control measure against the interactivity in the other virtual environments.

4.2. Apparatus

All participants wore the Oculus Rift DK2 for the first time. The Oculus is a head-mounted-display used to immerse persons into virtual spaces by immersing their visual senses. The Oculus Rift straps to the participant’s head similar to a pair of ski goggles. Participants wore a noise-cancelling headset on top of the Oculus Rift.

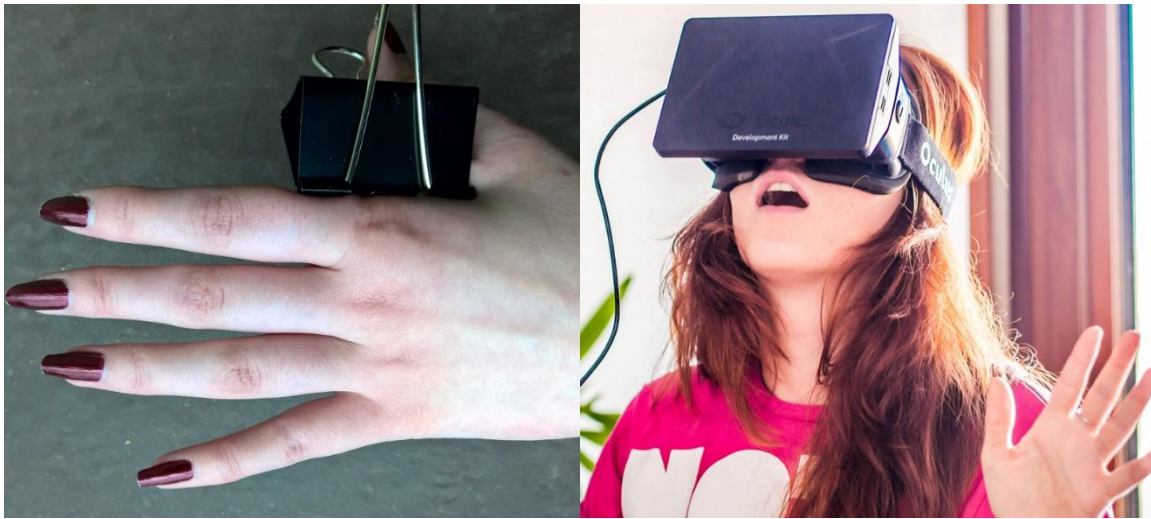


Figure 6. ***The clip applied (left) and the Oculus Rift by Sergey Galyonkin (cc).***

A 50mm plastic clip was applied to the first dorsal interosseous muscle on the participant's non-dominant hand (the soft flesh on the side of the hand, see Figure 6) to exude a minor but persistent, constant pressure. The clip simulated the experience of temporary acute pain in the healthy participants, allowing them to maintain their full range of movement. The ease of use of the clip also enabled participants to remove it on their own at any time if they wished to stop participating in the study.

4.3. Participants

The sub-study for the sake of participant accessibility was done with healthy participants using controlled induced acute pain. Twenty-six healthy participants between 20 and 30 years of age volunteered for this study. All participants were recruited at one of two social events hosted by the study investigator. Participants who considered themselves to be especially sensitive to nausea or motion sickness were not eligible for the study. One participant dropped out of the study early because symptoms of nausea and did not have his data included in the statistical analysis. Participants were randomly allocated to one of three VR groups. *Mobius Floe* had nine participants while the Soundself and *Chilling Space* groups had eight participants each contribute to the statistical analysis.

4.4. Design

The study used a between-subjects design consisting of three randomized groups; the difference between these groups was a single independent variable (one of three VR experiences.) There were two control groups including one with interactivity (*Chilling Space*) and one without interactivity (*Soundself*).

One-paged visual analog scale questionnaires were used to record the dependent variable, or the participant's reported pain level, a zero being 'no pain', a five being 'somewhat painful' and a ten being 'very painful'.

4.5. Procedures

Participants were first given a copy of the consent form and briefed on what they would be doing during the study. After signing the consent form, participants would wear the steel clip as detailed in section 4.2. Participants would then fill out the first VAS questionnaire to rate their current acute pain experience. The study investigator would then draw a slip of paper from a bowl at random, which would determine which virtual environment the participant would experience. The study investigator explained what to expect in the virtual environment, and then then discussed key pieces of the consent form including risk of nausea and the participant's ability to leave at any time at no risk or detriment to the participant. After three minutes with the clip applied, the VAS questionnaire was filled out for a second time.

The Oculus Rift and headphones were then fitted onto the participant, and they began to immerse themselves in the virtual environment. The third VAS measurement was conducted five minutes after the participant was immersed in the VR. This was done by the study investigator gently lifting one side of the headset off of the participant's ear, and asking them to verbally rate their pain in the same manner they had done previously. The study investigator would write the number they reported on the VAS for them, as the participant would still be wearing the Oculus Rift over their eyes. The study investigator would then re-apply the headphones and allow the participant to continue their experience in the virtual environment for another five minutes. The last VAS measurement was done

immediately after the participant removed the HMD, or exactly ten minutes after first exposure to the VR. This last pain measurement concludes the study session.

4.6. Results

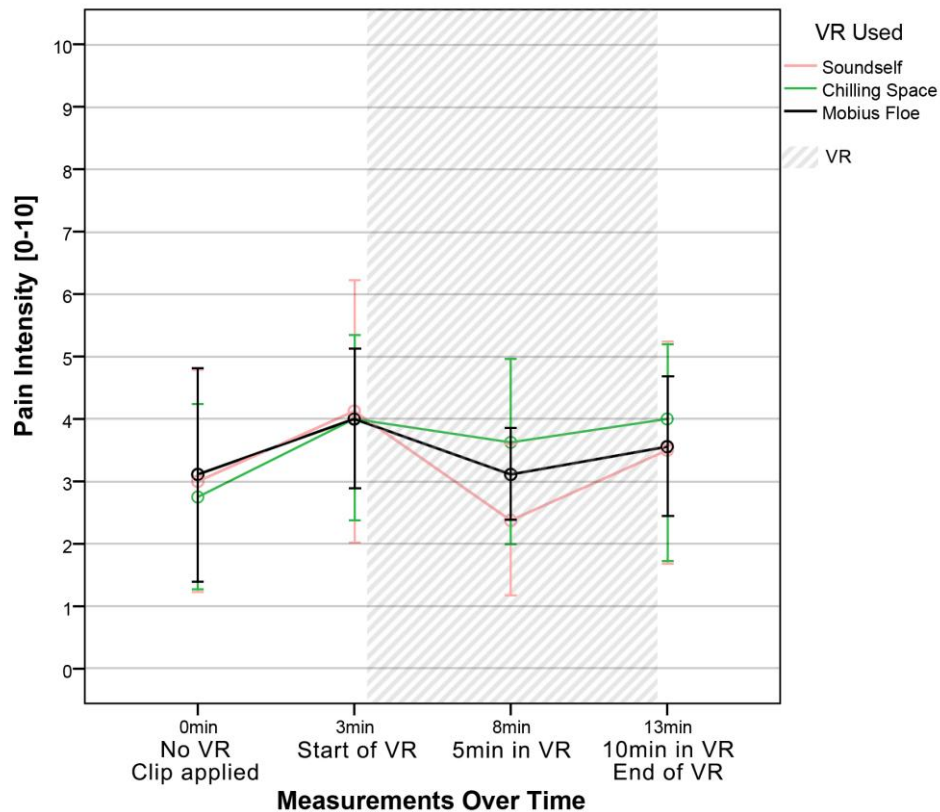


Figure 7. *Pain intensity during exposure to three different virtual environments. Error bars depict 95% confidence intervals.*

Figure 7 outlines the pain intensity data for each VR over time. While viewing Figure 7, note that the virtual reality was introduced immediately after the second measurement (three minute mark). The reported pain value between 0 and 10 (0 = 'no pain', 5 = 'somewhat painful', 10 = 'very painful') is displayed on the vertical axis up to six as no pain ratings were recorded above that level. The numerical values on the horizontal axis signify the four pain measurements taken over time.

A mixed ANOVA was used to analyze the pain intensity in each of the three VR groups over time. Mauchly's test of sphericity was not violated, $\chi^2(5) = 6.512$. $p =$

.260. The within-subjects effects VR x time interaction was not significant, $F(6, 66) = 1.25$, $p = .292$ and the main effect of VR on the pain intensity scores was non-significant, $F(2, 22) = .128$, $p = .067$, indicating that the virtual environment chosen did not have a significant effect on pain measurements taken over time. Only the within-subjects effect of time was statistically significant $F(3, 66) = 8.14$, $p < .001$, $r = 0.695$, showing that there was a significant effect on pain intensity across all groups over time.

Bonferroni post hoc tests show a significant effect of time on the pain intensity ratings at the zero minute mark and three minute mark, $CI_{.95} = -1.685$ (lower) $-.491$ (upper), $p < .001$, which shows that the clip on participant's hands increased pain over time over the three minute duration. There is also a significant effect of time on the pain intensity ratings between the three minute mark and eight minute mark, $CI_{.95} = .239$ (lower) 1.770 (upper), $p = .006$, showing that time had a significant effect on pain intensity during the first five minutes of VR exposure. There is no significant effect of time on the last five minutes of VR exposure, $CI_{.95} = -.1314$ (lower) -0.18 (upper), $p = .06$. This shows that although time had a significant effect on the reported pain reductions in the first five minutes of VR, the significant effect of time diminished by the ten minute measurement.

4.7. Discussion

There is a spike of pain intensity in the second pain measurement in all three virtual reality groups, which shows that wearing the clip over time increased the intensity of pain felt in most participants. This also implies the clip might have had a more intense effect over time. Despite this increase, there is a drop in pain intensity in the third measurement in all three groups despite the increase in measurement two, with Soundself being the only VR to show statistical significance in its ability to reduce pain intensity. However it must be noted that the *Soundself* group did not see a decline in perceived pain levels between measurements three and four, showing that the effect it did have on participants dwindled by the ten minute mark. We do not see a stable decline in perceived pain levels in the *Mobius Floe* and *Chilling Space* groups.

The study helped us glean preliminary data from *Mobius Floe's* design progress and provided suggestions for improvement as discussed in section 5.1. The study results show that the virtual environments chosen are not able to significantly reduce pain intensity experiences in healthy participants with artificially induced acute pain. Further research into designing for distractive VR pain experiences is required. Designing this preliminary study also helped inspire the design of the full repeated measures study conducted in a clinical setting discussed in section 5.

4.8. Limitations

The study procedures could have been improved in several ways. We should have used persons without simulated pain as our participant demographic. Chronic pain patient experience is much more significant in regards to the impact the disease has on their way of life. It impacts patients physically and psychologically so intensely that oftentimes chronic pain becomes a life-changing experience for those afflicted (Breivik et al. 2006). To say that a healthy person with a clip on their hand would accurately simulate a chronic pain experience is not true due to the psychological factor of chronic pain experience, which was missing in this study. This is a limitation of the study when considering the primary goal of the thesis is to eventually treat chronic pain patients.

The participant demographic was also entirely comprised of friends and friends of friends of the study investigator, and were recruited in two social gatherings. Although we controlled for participant bias by not telling the participants that one of the VRs had been created by our team, we were unable to accurately control for participants arriving to volunteer who had consumed alcohol, often in varying amounts. It is possible that those who had drunk alcohol also experienced a numbing of their simulated pain experience (Woodrow and Eltherington 1988).

We should have implemented a script for the study investigator to read from in order to control for investigator bias. An interview should have been added at the end of the study procedures which would have provided further insight into what aspect of the study experience worked well, what didn't work, and any issues (or positive outcomes) that the study investigator did not expect.

One of the disadvantages of using a between-subjects design is that it generally requires more participants than a within-subject design. The *Chilling Space* VR control group could have been removed from the study as it provided no real significance when compared to the *Soundself* control group, helping resolve this disadvantage. *Chilling Space* was too similar to *Mobius Floe* in its design, whereas *Soundself* was distinctly different and appealed to sensory immersion more strongly than *Chilling Space* was able to appeal to any distinct facet of digital immersion. The resulting statistics from the study would have been more powerful if we had not split up the few participants we had into three groups instead of two.

5. VR Chronic Pain Reduction in Clinical Settings

The research question for this study reads as follows: Can perceived pain be significantly reduced in pain patients who engage with *Cryoslide* in comparison to a pain patient control group that attempts to self-manage their pain experience?

5.1. Materials and Revisions

Cryoslide was used instead of *Mobius Floe* for this study. A short video of the *Cryoslide* software is available here: <http://bit.ly/1btJba3>. The gameplay is similar in the sense that players appear in an icy landscape on a forward-moving rail system running at a pre-set pace. Players still use the left mouse button to fire snowballs at creatures in the environment, and are encouraged to physically move their head inside of the Oculus Rift to move the camera in the virtual space. In regards to the changes implemented, the game now runs at 75 fps in contrast to the roughly 40 fps of the alpha of *Mobius Floe*. The rail system became a straight line in order to minimize any nauseous effects from the curved and bumpy track previously used. This was especially important considering feelings of nausea, although inherently unpleasant, will detract from the immersive quality of the game (Witmer and Singer 1998). A new enclosed area made of ice caverns was installed, which allowed for drastic frame rate improvements and a new change of scenery to maintain a sense of wonder and to keep the visual content engaging. The player now moves forward on a sled instead of floating in order to ground them in the space. The rail system was smoothed out in regards to y-axis movements, removing the mountain climb entirely. Previously the camera would gently bump up and down on the mountain; this caused feelings of unnecessary nausea and disorientation in some sub-study participants who reported these feelings during and after the study procedures. N-back tasks were newly introduced to increase the amount of cognitive load on the participant over time where $n=2$ in all instances. More information about the design of *Cryoslide* is available in section 3.

5.2. Apparatus

All equipment was provided by the iSpace Lab and Transforming Pain Research Group at Simon Fraser University. Participants wore the Oculus Rift DK2, the VR headset used to immerse persons into virtual environments in such a manner as to help them feel as though they are inside of *Cryoslide*.

Noise-cancelling headphones were worn over the Oculus Rift. Participants also used a standard computer mouse with left click and right click functionality.

5.3. Participants

Twenty adult pain patients (4 male, 16 female) of varying ages (30+) were recruited at a complex pain clinic in Vancouver. The clinic is run by Dr. Pamela Squire, a collaborating researcher with the Transforming Pain Research Group in conjunction with Dr. Pankaj Dhawan. The research study was conducted by the author in a private room at the clinic. Adult participants of all ages and genders were recruited either by Dr. Squire or her secretary. Participants who considered themselves to have a higher risk of motion sickness, participants who had severe pain in the regions where the Oculus Rift was expected to be fitted onto their person, and participants who did not have any physical pain at the time they volunteered to participate were not eligible for the study. Three patients who participated but did not complete the study because of personal time constraints or nausea were not included in the analyses.

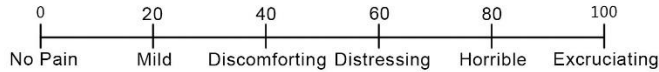

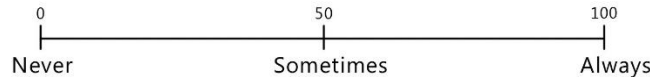
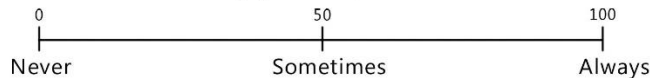
5.4. Experimental Design

The study design in comparison to the sub-study previously discussed minimized the amount of participant groups. This study uses a repeated-measures design whereby each patient participated in the experiment group and control group in an order randomly determined by the flip of a coin. The primary independent variable was exposure to Cryoslide or the control condition; all participants' pain intensity levels were measured repeatedly over time. The primary dependent variable was pain intensity (PI) which was reported by patients filling out visual analog scale questionnaires throughout the study

procedures. Immersion was also a dependent variable which manifested in several questions on the VAS questionnaire. There were three different variations of the VAS questionnaires – one tailored for the beginning of the study, one for post-VR experience, and one for post-self-mediated (control group) experience. The questionnaires varied because certain questions were not appropriate at certain times – for example questions pertaining to the VR experience are not appropriate for post-control and the introductory questionnaire. Several questions repeat between the questionnaires such as the pain intensity ratings.

5.4.1. *Introductory Questionnaire*

Digital Immersion Questionnaire for Pain Experience Management
Amber Choo - Feb 2015

Participant #	Intro Questionnaire
<p>During the last ten minutes, my pain intensity was on average:</p> <div style="text-align: center;"></div>	
<p>How would you describe your Present Pain Intensity right now?</p> <div style="text-align: center;"></div>	
<p>The time I usually spend preoccupied with myself is:</p> <div style="text-align: center;"></div>	
<p>During the last ten minutes, the amount of time I spent thinking about my pain experience was:</p> <div style="text-align: center;"></div>	

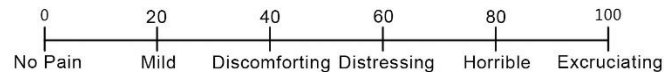
5.4.2. *Post-Self Management Questionnaire*

Digital Immersion Questionnaire for Pain Experience Management
Amber Choo - Feb 2015

Participant # _____

Post-Self Management Questionnaire

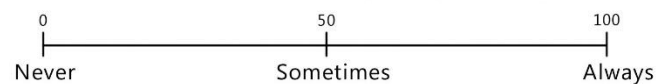
How was your Pain Intensity in the ten minutes before this questionnaire?



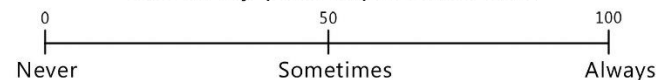
How would you describe your Present Pain Intensity **right now**?



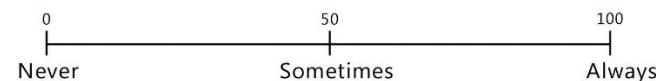
During the last ten minutes, the time I spent preoccupied with **myself** was:



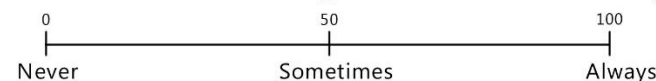
During the last ten minutes, the amount of time I spent thinking about my pain experience was:



During the last ten minutes, I felt like I lost track of time:



During the last ten minutes, I thought about unrelated everyday things:





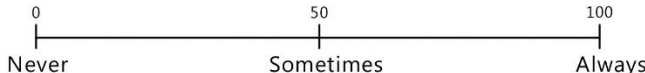
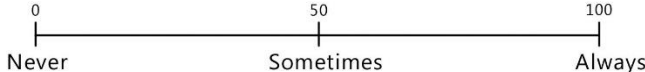
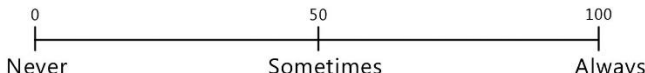
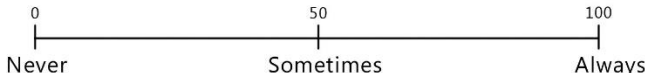
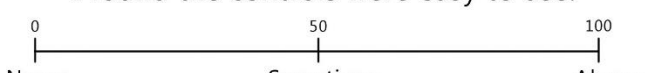
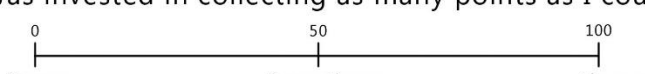
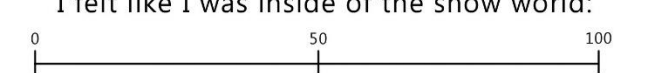
What was the primary activity you engaged in during the last ten minutes?

☐ Meditating ☐ Sitting in a resting state ☐ Reading

Something else (please describe): _____

5.4.3. Post-Virtual Reality Questionnaire

Digital Immersion Questionnaire for Pain Experience Management
Amber Choo - Feb 2015

Participant #	Post-VR Questionnaire
<p>How was your Pain Intensity when you were inside the snow world?</p> <div style="text-align: center;"></div>	
<p>How would you describe your Present Pain Intensity right now?</p> <div style="text-align: center;"></div>	
<p>The time I spent preoccupied with myself in the snow world was:</p> <div style="text-align: center;"></div>	
<p>The time I spent thinking about my pain experience in the snow world was:</p> <div style="text-align: center;"></div>	
<p>I felt like I lost track of time in the snow world:</p> <div style="text-align: center;"></div>	
<p>Inside the snow world, I thought about unrelated everyday things:</p> <div style="text-align: center;"></div>	
<p>I found the controls were easy to use:</p> <div style="text-align: center;"></div>	
<p>I was invested in collecting as many points as I could:</p> <div style="text-align: center;"></div>	
<p>I felt like I was inside of the snow world:</p> <div style="text-align: center;"></div>	

5.5. Procedure

After reading and signing the consent form, all participants filled out a short introductory questionnaire at the beginning the study, which asked them to rate their present pain intensity (PPI) as well as their retroactive pain intensity, or their pain intensity felt in the last ten minutes. These two pain measures were on all questionnaires (See Figure 8) to accommodate for a potential drop in analgesic effect when patients remove the VR gear later in the study. Patients also reported how often they thought about their current experiences (thinking inwardly) and how often they thought about their pain experiences.

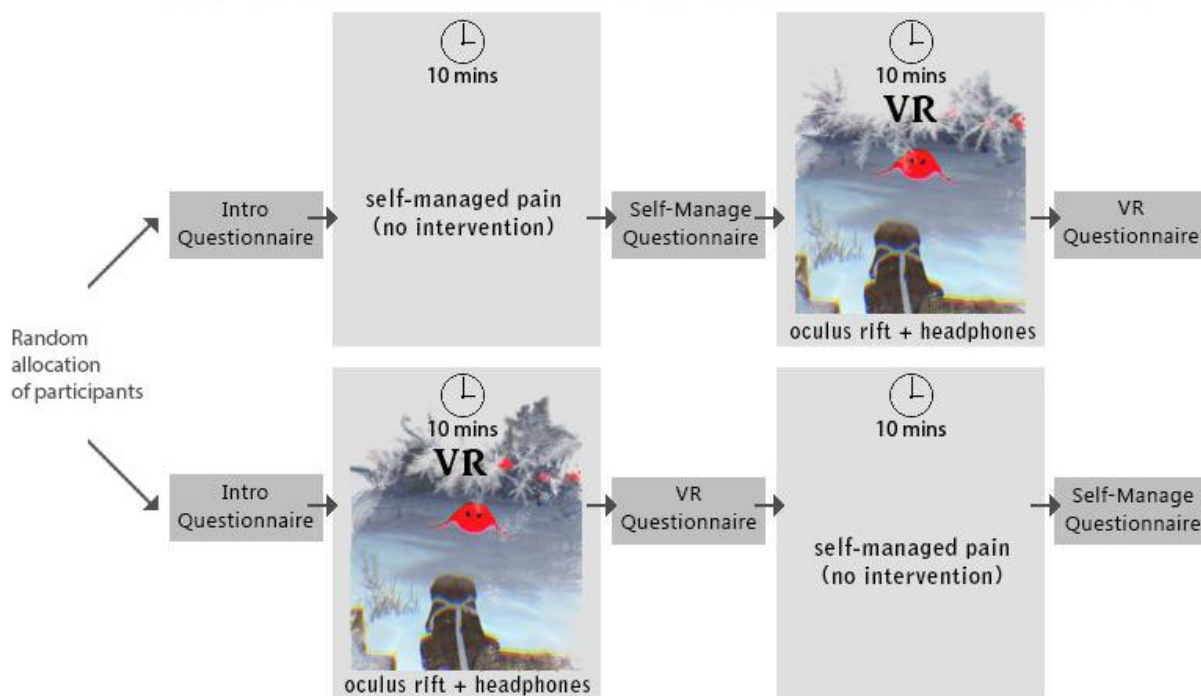


Figure 8. A design diagram for the clinical study.

Once the initial questionnaire was complete, participants first took part in either the control or experimental condition by way of a coin toss (Figure 8). The experimental condition consisted of participants spending ten minutes immersed in a VR in the Oculus Rift DK2 in the immersive rail shooter titled *Cryoslide*. The control group consisted of ten minutes of time relaxing, meditating, reading or conducting another form of self-mediated

pain experience without *Cryoslide* or the Oculus Rift. More specifically patients were asked to pick an activity they would use on an average day to help minimize their perceived pain intensity in an everyday setting. Many patients relaxed in a sitting position during this time, while others read, played phone games, or listened to audio books. Another questionnaire was given to patients after the control group which is viewable in section 5.4.2. Questions only applicable to digital immersive experiences were removed.

The coin toss to randomly determine condition order was critical, as some participants would arrive to participate after seeing the doctor and may have been medicated during their appointment, resulting in lower (and sometimes higher) pain intensity than patients normally experienced. Randomization helped balance effects from external outliers between the VR and control conditions.

The experimental condition had patients experience ten minutes in the *Cryoslide* virtual environment. Before entering the virtual space, they were instructed how to use the controls, including physical head movement to look around and aim, the left mouse button to fire snowballs, and the right mouse button to start and stop the sled. The study investigator also provided example visuals on paper and an explanation of the n-back tasks before VR immersion so participants would understand how to recognize and complete the 2-back tasks for additional points. Inside of the VR, the instructions on how to interact with the mouse interface were posted again on the front of the sled in case the patient forgot any of the controls.

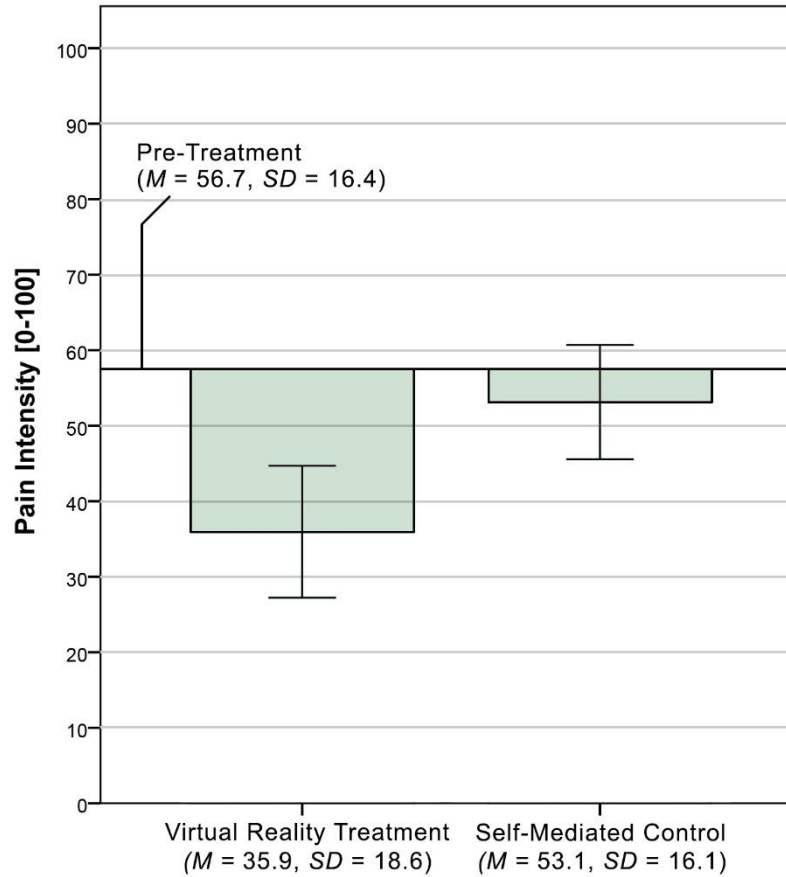
After the ten minutes in virtual environment passed, the software would inform participants that they were finished. Participants then removed the gear with the help of the study investigator. They immediately filled out a one paged questionnaire containing the same questions from the introductory questionnaire, but with several additions (viewable in section 5.4.3). Patients were asked to rate their present pain intensity (PPI) as well as their retroactive pain intensity (pain felt over the last ten minutes in the experimental condition). This was to accommodate for the possibility that the analgesic effect would be present in virtual reality, but diminish immediately after the head-mounted-display was removed. Other questions were influenced by the Flow framework, Ermi and Mayra, and Brown and Cairns' immersion frameworks, and focused on how immersive the participant's digital experience was and in what capacities they would have deemed it

immersive; more details on how these immersion frameworks influenced the questionnaires are available in section 2.4

At the end of these study procedures in all participant groups, patients were encouraged to partake in a semi-structured interview with the study investigator, the results of which are detailed in section 5.7. The questions were primarily concerned with their experience in *Cryoslide* in regards to attention, immersion and their suggestions for future improvements.

5.6. Results

Figure 9. *Pain intensity reported retroactively after both conditions in*



comparison to pre-treatment pain intensity. Error bars depict 95% confidence intervals.

Present pain intensity and retroactive pain intensity (pain intensity felt in last ten minutes) were both measured separately before treatment, after the virtual reality, and after the self-mediated control condition. Present pain intensity was analyzed using a repeated measures ANOVA and was found to not be statistically significant $F(2, 38) = 1.377$, $p = .265$. However, comparing pain intensity felt retroactively, or in the last ten minutes before treatment, during virtual reality, and during the control condition was statistically significant, $F(2, 38) = 21.473$, $p < .001$, $r = 0.505$ (see Figure 9).

Mauchly's test of sphericity was not violated, $\chi^2(2) = 3.726$, $p = .155$. Bonferroni post hoc tests showed there was a statistical difference between the pain intensities of participants' experience in the VR in relation to their initial pain intensities, $CI_{.95} = -31.443$ (lower) -11.657 (upper), $p < .001$ where pain intensity in the VR was significantly reduced in comparison to patient's pre-treatment pain intensity. More specifically, virtual reality exposure reduced retroactive pain intensity by 36.7% in relation to pre-treatment pain intensity ratings. The retroactive pain intensities reported in the VR in relation to retroactive pain intensities reported in the control condition were also significant; pain was reduced much more in the VR condition, $CI_{.95} = -27.397$ (lower) -6.953 (upper), $p = .001$. More specifically, the control condition (self-mediated pain experience) reduced retroactive pain intensity by 6.3%. This shows that the patients had significantly lower pain intensity in VR than in the control condition, and that the virtual reality reduced retroactively reported pain intensity in a statistically significant manner. The difference in retroactive pain intensity between the control and initial pain intensity was not significant ($p = .336$).

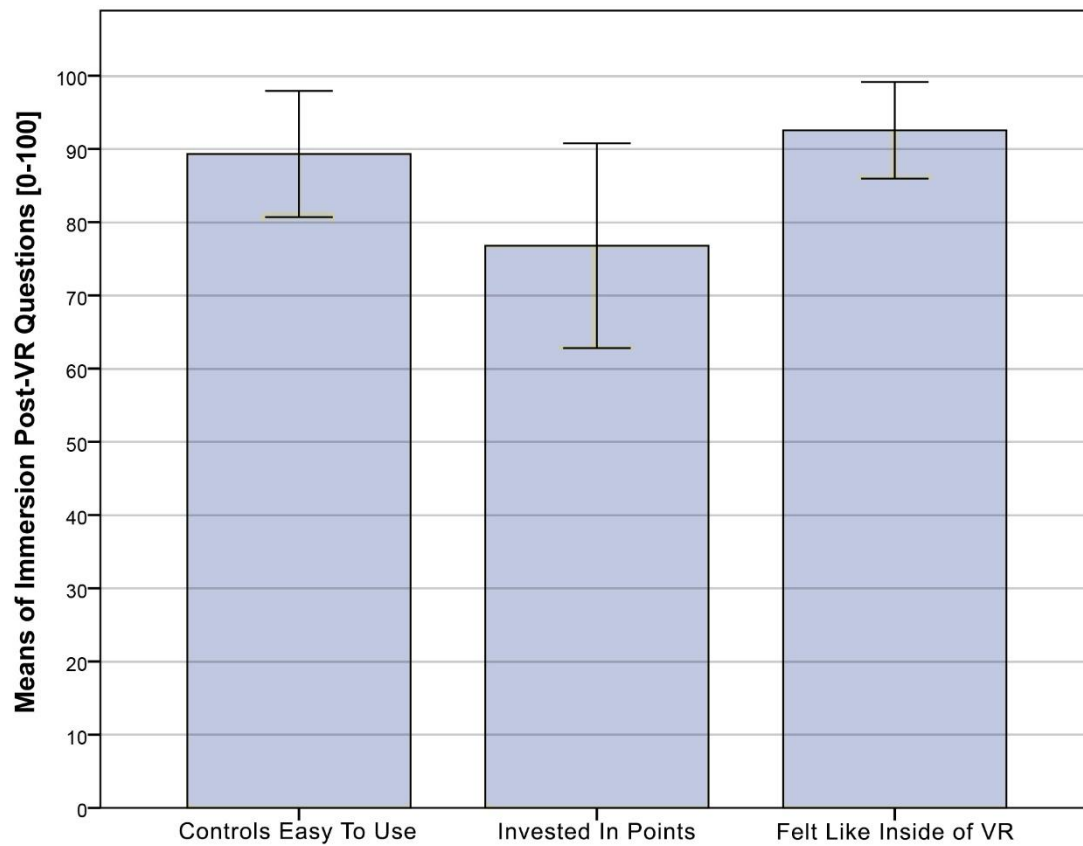


Figure 10. Bar chart showing means of three immersion related questions. Error bars depict 95% confidence intervals.

Participants found the controls in the virtual environment were easy to use ($M = 89.3$, $SD = 18.9$). Most participants found themselves invested in collecting as many points as possible ($M = 76.8$, $SD = 30.7$). Participants overwhelmingly reported feeling like they were physically inside of the virtual environment ($M = 92.5$, $SD = 12.4$) (Figure 10).

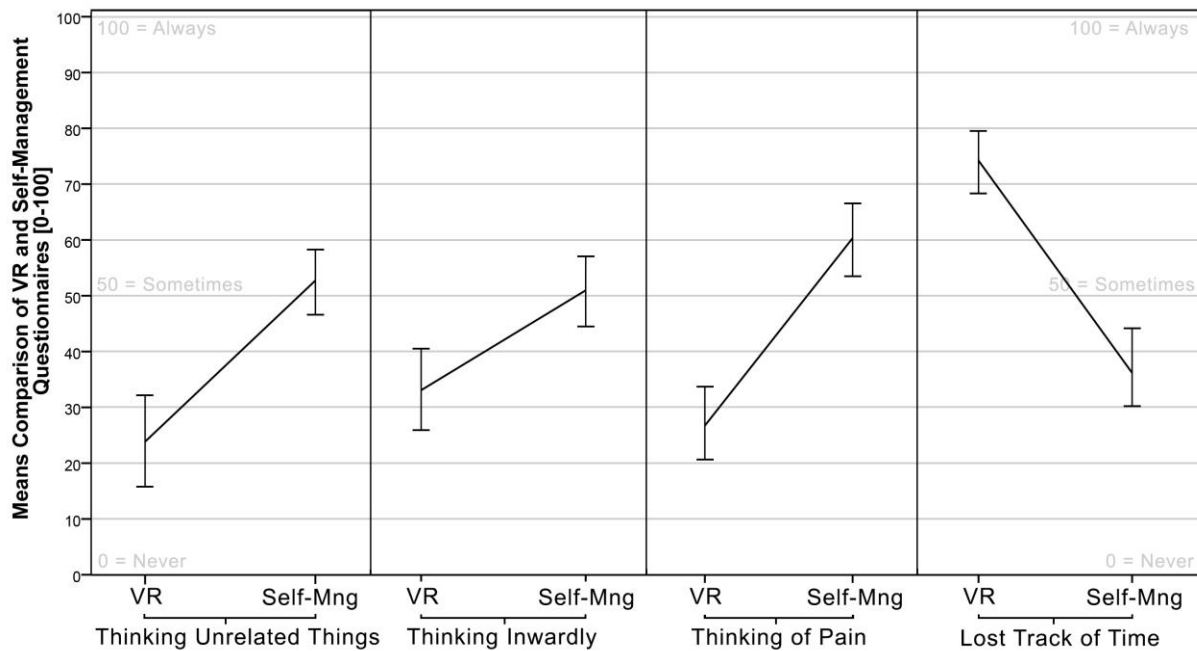


Figure 11. Means comparisons of questions posed in both experimental and control conditions. Error bars depict 95% confidence intervals.

Participants reported that the amount of time they spent thinking about themselves (thinking inwardly) was decreased in the VR ($M = 25.1$, $SE = 5.99$) in comparison to the self-mediated condition ($M = 50.4$, $SE = 5.89$), $t(19) = 4.18$, $p = 0.47$, $r = .48$ (Figure 11). Participants also reported that the amount of time they were thinking specifically about their pain was decreased in the VR ($M = 26.34$, $SE = 6.2$) than in the self-mediated condition ($M = 60$, $SE = 6.1$), $t(18) = 4.784$, $p < .001$, $r = .75$. More specifically, ten minutes in VR exposure reduced the amount of time patients spent thinking about pain by 56% in comparison to the control condition (self-mediated pain reduction). Participants reported losing track of time in the VR condition ($M = 73.9$, $SE = 4.93$) more than in the self-mediated condition ($M = 35.850$, $SE = 8.10$), $t(19) = 5.477$, $p < .001$, $r = .78$. They also found themselves less frequently thinking of unrelated, everyday things in the VR ($M = 23.8$, $SE = 8.1$) than in the control condition ($M = 52.7$, $SE = 6.4$, $t(19) = 3.0$, $p = 0.07$, $r = 0.57$). The effect sizes for all of these measurements are large, meaning the amount of variance between these variables is largely accounted for by the experiment model (Cohen 1988).

5.7. Patient Feedback

Participant names in the following section have been changed to anonymize patient identity.

Participant feedback was extremely diverse in nature and contradictory in many areas in regards to suggestions for future improvements, how the virtual environment is (or should be) experienced, and what pieces of the virtual environment require improvement. The semi-structured interview was conducted to promote discussion between the researcher and participant, and reveal insights that the researchers may not have considered by encouraging the patients to express their thoughts about what occurred from their unique perspectives.

Two participants informed the study investigator that the virtual environment was inducing feelings of claustrophobia, specifically in the ice caves region where the walls of the cave can generate very close to the player camera; they claimed this feeling contributed toward feelings of nausea, which caused them to end the VR session prematurely.

One participant stayed for the duration of the VR but later explained that she felt agitated and disoriented afterward. Unexpectedly, she seemed to enjoy the gameplay, smiling and moving the mouse in the air like a weapon to fire, and exclaiming thoughts such as 'I'll wait for them to come to me!' and "Those clouds look so real! Oh my god!". When asked to explain where the feelings of agitation and disorientation occurred from, she explained that although the gameplay was engaging, there 'was too much stimuli.' Several patients explained they had increased sensitivity to audible and visual stimuli because the nature of their chronic pain.

One participant, Dee, was one of the participants who withdrew from the virtual environment early because feelings of nausea, and provided similar feedback in regards to sensory stimuli. During the virtual environment she had been commenting on how satisfying it was to hit the creatures with snowballs successfully, laughed and jeered at the creatures occasionally, and afterwards proclaimed 'that was awesome' despite the unwanted physical symptom of nausea. After inquiring in regards to why she thought the VR was enjoyable, Dee explained that in her everyday life, there are far too much stimuli

for her own personal experience. Before she had entered the pain clinic, there had been sirens outside and the blaring noise was enough to cause her emotional distress. “I need to get to another place. Outside is just too overwhelming. I need this,” she added, gesturing to the head mounted display. “The world in there was beautiful until [the walls] got closer.” She also explained she was not normally a claustrophobic person, but it was likely ‘too much stimuli’ – the visuals and audio combined - that caused the nausea.

Other participants requested that the snowballs fire farther, the sled should move faster, or that there should be an option to move faster if they would like to. Allowing them to do so would provide further player agency. One of the participants who suggested this, named Danny (again, note that all names have been changed to protect patient identity), commented afterward that he doesn’t usually play games, but when he did he would play ‘star wars’ with his son, and he would usually not do very well, but the memory of doing so was a positive experience for him. His anecdotes bring up an interesting point in regards to the place of games in the household, and how not all games are designed for single player use. A potential future avenue of research exploration could involve virtual reality treatments becoming a multi-person activity, whereby the patient could, if they wished, also play in the distractive virtual space with friends or family. This could serve as an additional cognitive distraction and infuse the experience with social fun and feelings of togetherness.

Another participant named Sarah, a woman in her sixties, considered the virtual environment to be ‘a riot’ in regards to her user experience inside the device. She explained, ‘I was in command. I need to be distracted, and this is more engaging than TV.’ She explained the virtual reality experience ‘transported her out of herself’ and that she still had a “hangover from it... I’m feeling that winter wonderland thing, you know?” After asking her what she meant by needing to be distracted, Sarah explained that in her everyday life she usually cooks, or watches television or plays solitaire because she “need[s] a coping mechanism... I need to be distracted” from the pain experience. Sarah commented that she’d like ‘one of these’ at home, but also suggested that in order for such a device to work for her, there should be more content, as playing in the same virtual environment over and over again would be less stimulating.

When interacting with the virtual world, most participants sat in a relaxed position in the chair with the mouse resting on their thigh. One fibromyalgia patient named Lin did not behave in this manner. Rather, Lin used the mouse in a similar way as one would use a toy gun at the arcade, holding it forward, arm raised, and changing its position quickly and in dramatic arms-length strides, shooting with the left mouse button often. She would comment occasionally about the creatures 'getting away'. Unable to see the real physical space around her, Lin almost hit the study investigator and the head tracking camera multiple times with her hand throughout the session. Two other participants also interacted with the virtual environment using similar arms-length gestures. Their eagerness to move in such a fashion, despite the mouse's inability to actually locate itself within physical space suggests that these first-person shooting games could be an excellent candidate for chronic pain patients who suffer from kinesiophobia. In this instance, the mouse could be replaced with the Razer Hydra or other device whose location could be physically tracked within virtual space to encourage meaningful movement. Theoretically, patients with kinesiophobia could easily be encouraged to move using a similar setup, in clinical or in home settings. It is also worth mentioning that a third participant named Sam reported neck pain, but also noted that 'even though my neck was very stiff, it encouraged me to turn to the [left and] right.' Sam considered it a fun and positive experience and was smiling throughout most of the virtual reality experience. She reported enjoying the fact that the virtual environment "encouraged [her] to move." Further research exploration of VR first-person shooting games for treatment of kinesiophobia is highly recommended by the author.

In regards to use of controls, five users expressed frustrations. One woman explained that it wasn't clear when the monsters were being hit, and that the snowballs were not firing straight. However, the snowballs fire to the center of the screen at all times, and this was not changed prior to her participation; there were no other verbal complaints about aiming or inadequate visual feedback from other participants. It is possible that the participant found the controls too difficult to use or found the controls to be non-intuitive. In regards to how easy it was to use the VR controls in the Post-Virtual Reality Questionnaire, the participants reported ($M = 89.3$, $SE = 4.1$) where 100 = always easy to use, and 0 = never. Five patients reported a rating below 80/100. Fourteen participants rated the controls 100/100. Although the controls were easy to use for almost all of the

participants, it is important to note that there are outlier patients who may require a different control interface in order to accommodate their use of interactive VR more easily. These participants may be unfamiliar with computer and digital interfaces, which could explain their difficulties with the mouse controls. For example, motion tracking may be a suitable candidate to replace the *Cryoslide* mouse controls when working with patients who are not familiar with human computer interaction.

5.8. Discussion

The intent behind the *Cryoslide* study was to analyse *Cryoslide*'s effectiveness in regards to the purpose it was designed for – significant pain reduction in pain patients. We hypothesized based on the literature review that a high degree of immersion would be present in a virtual reality that can reduce perceived pain intensity (M. Wiederhold and Wiederhold 2007; Hoffman et al. 2014; Karamnejad 2014). We then hypothesised that *Cryoslide* would be able to invoke a high degree of immersion and reduce perceived pain intensity in chronic pain patients. The immersion-based questions were added to the VAS questionnaires in order to measure what facets of different immersion frameworks were presented most strongly in *Cryoslide*.

5.8.1. Duration of effect

The statistical differences between chronic pain patient's reported present pain intensity (pain felt now) and their pain intensity reported retroactively after the control and experimental conditions (pain felt in the last ten minutes) varied because the VR could only reduce chronic pain intensity while the VR was being used. In other words, the VR did not produce any lasting effects outside of the virtual experience. When patients recalled their pain experiences, they recalled drastically reduced pain levels in the virtual environment which were statistically different from their present pain levels at the time of reporting. Considering the timing of the questionnaires was immediate after both the experimental and control groups, we can conclude the reduction in pain intensity from use of the *Cryoslide* software does not extend after its usage is concluded, removing the analgesic effect immediately upon removal of the VR gear. Rather, the *Cryoslide* virtual reality treatment had a significant effect on reduction of perceived chronic pain experience

while in use. An effect hypothesized to be caused by virtual presence and cognitive immersion that lasts beyond the immersive period would have been difficult to explain.

When considering the duration of effect of *Cryoslides* 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 (Gilmour 2015). There is a statistical association between the presence of CP and depression (Fishbain et al. 1997) and feelings of helplessness (Skevington 1983). By adding *Cryoslides* to a pain patient's arsenal of tools to help combat and control their chronic pain experience, the introduction of a VR treatment into patient lives could help negate feelings of helplessness and contribute positively to the psychological aspect of CP patient life.

Lastly, chronic pain patients are known to suffer from spikes of pain intensity where their chronic pain intensity is worse than normal (Baliki et al. 2006), which can cause the patient to catastrophize over the experience, causing it to spiral further out of their control. It is also possible that the introduction of an analgesic treatment like *Cryoslides* could help patients remove themselves from cycles of pain catastrophization by moving their sense of presence away from their embodied experience into the virtual world and reducing their pain levels to a more manageable intensity.

5.8.2. *Impact of cognitive immersion and presence*

We also hypothesized that immersion would have a strong role in the reduction of pain. During the difficult moments when a chronic pain patient's pain experience is flaring into higher intensities, immersing themselves in a virtual reality game like *Cryoslides* enables chronic pain patients to re-direct their attention away from an inward focus and toward the digital space. Their ability to remove their attention from their embodied selves and their pain experience was a key part of the distraction-based strategy we hypothesized would help decrease their pain intensity. Cognitive immersion was expected to play a critical role in mediating patient pain reduction because of the importance of pulling patient attention away from pain experience and toward another space entirely. We measured cognitive immersion using various questions pertaining to symptoms of immersive experience, such as losing track of time, usability of controls and virtual

presence. The study results show that participants experienced a high degree of psychological and embodied immersion during their VR pain reduction experience in contrast to the control condition. The time they spent thinking about themselves (thinking inwardly), losing track of time, and thinking of everyday unrelated things were all reduced significantly in the VR condition, implying a psychologically immersive effect. They also overwhelmingly reported feeling as though they were inside of the virtual environment. This shift in embodied presence is a key symptom of total immersion as discussed in Brown and Cairn's paper on the three stages of immersion in games (Brown and Cairns 2004). Participants felt the controls were easy to use, which is important to achieve for adequate game-based interactive experiences (McGloin, Farrar, and Krcmar 2013)(Brown and Cairns 2004). Lastly, they were often invested in collecting as many points in the game as they could, suggesting that Cryoslide invokes challenge-based immersion as defined by Ermi and Mayra (Ermi and Mayra 2005). All of the immersion questions posed to participants overwhelmingly supported the original hypothesis that a high degree of immersion would be present in the successful reduction of pain intensity. This hypothesis has already been proposed by several authors working with acute pain (Hoffman et al. 2001; Faber, Patterson, and Bremer 2013)(M. Wiederhold and Wiederhold 2007) and in existing literature review (Garrett et al. 2014).

However, we cannot claim that immersion directly causes pain reduction, as *Cryoslide* offers more than digital immersion – it was created to invoke digital presence and cognitively distractive mechanics. In other words, *Cryoslide* is a concoction of many frameworks and design variables put together which combined causes an analgesic effect. In other words, patients were immersed, and pain reduction was achieved, but we cannot assert there is a causal effect between immersion and pain reduction.

5.8.3. *Anxiety*

In regards to the patient feedback, our findings support a claim by Jennett et al. that anxiety felt by participants in immersive game spaces would not necessarily detract from quality of immersion. They theorized that games which generate anxiety often do so because of a challenge posed from the game to the player. 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 (Jennett et al. 2008).

This claim resonates particularly strongly in our own participants who rated their experience in the game as highly immersive despite any stresses that they reported during the semi-structured 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 (Gatchel et al. 2007). The existence of chronic pain patient anxiety sensitivity strongly emphasizes the importance of finding an ideal balance of challenge without invoking significant amounts of anxiety for the VR chronic pain patient demographic.

5.9. Limitations

It would have been ideal to have a different individual besides the creator of *Cryoslides* testing the virtual reality's effectiveness with chronic pain patients, as it is entirely possible that creator bias could have influenced the results. This was controlled for with an introductory script which was read to the participants by the study investigator to introduce the study, including the study procedures, ensuring that no dialogue implying any sort of expected result would be accidentally introduced.

Some of the chronic pain patients coming into the study on that day had already been seen by Dr. Squire for pain treatments, including injections. These treatments would have influenced their reported pain levels in all measurements. This was controlled for by randomizing the order of study procedures, where half of the participants conducted the virtual reality session first while others conducted the control condition first. There were no questions in the questionnaires asking patients if they had been seen by Dr. Squire before or after their participation.

The gender distribution of the participant population was heavily skewed in the direction of women; only four men participated while sixteen women participated. Women are two to three times more likely to report chronic pain than men (Smith 2003) which was apparent in the patient population visiting the clinic. Insufficient data on the participants themselves was collected; only gender was recorded and not participant age. Ideally we should have also taken information about what types of chronic pain the patients were suffering from, as some of our findings including the potential for virtual reality to be used

with patients with kinesiophobia were only brought to attention when patients took the initiative to volunteer that information to the study investigator.

Lastly, *Cryoslide* was made with a combination of design frameworks and ideas fused together, including immersion frameworks, game design mechanics and cognitively distracting techniques such as n-back tasks. We cannot ascertain which design ingredients contributed the most or the least to virtual reality pain reduction. It is also entirely possible that some of these ingredients do not contribute at all. Rather, what we know is that the blueprint for *Cryoslide*, or the accumulation of all of these different facets of research fused together created an analgesic experience. In order to determine which aspects of the design contributed to analgesic effect, future studies would need to examine and isolate each of these design decisions. For example, it would be possible to test what impact game mechanics had on *Cryoslide* by creating a control condition with that design ingredient missing, and the experimental condition would consist of the current version of *Cryoslide*.

5.10. Future Work

Accessibility for continued exposure to *Cryoslide* should be disseminated to chronic pain patients in an accessible manner. If we can secure additional funding, the virtual environment could easily be ported to mobile phones for use with devices such as the Google Cardboard, or other stereo viewers like the FOV2GO which introduce simple and easily affordable hardware for viewing stereoscopic content to consumer bases. The software itself could be made available on the Google Play or Apple 'App' stores and relevant websites, enabling patients to install the software on their phones and enabling them to access VR in home settings. A potential area of future research is the role of mobile virtual realities and their place in pain patient care. Could pain patients use their phones in combination with products like Google Cardboard to self-medicate at home, at the workplace, or elsewhere? Taking these non-pharmacological analgesic alternatives out of the clinical setting and into accessible spaces for pain patients would be a positive step in an attentive direction. It would also lead into the potential for further research studies into VR for pain patient use in home and personal settings, and encourage

scientific inquiry into how to design VR for pain reduction when the VR is expected to be used multiple times by the same patients.

Fear of movement is an understandable psychological phenomenon familiar to many pain patients who have been living with long-term pain. Future work must examine the use of virtual reality treatments for kinesiophobia including how to design virtual reality software to encourage certain types of bodily movement. Hoffman has also suggested that VR could be used for “indirectly treating chronic pain via motion therapy” (Hoffman et al. 2008). The *Cryoslide* clinical study in particular made it very apparent that a virtual environment designed without motion controls can still encourage energetic movement. If one imagines what a virtual environment with motion controls could do in contrast, the results are understandably very exciting. A preliminary study by Chen et al. used the Oculus Rift with kinesiophobia patients to try and manipulate the just noticeable difference (JND) of certain neck movements to encourage bolder patient movement with some degree of success (Chen et al. 2014). 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 kinesiophobia on a regular basis. A search for relevant literature reveals very little research in regards to games for kinesiophobia treatment; however, there does appear to be at least one clinical trial underway (“Using an Interactive Game to Reduce Fear and Increase Spine Motion in Low Back Pain” 2015).

5.11. Conclusion

With some trial and error, we were able to successfully create a virtual reality that reduced perceived pain intensity in chronic pain patients. Influenced by the previous virtual environments created in the past, such as *SnowWorld*, we designed several prototypes of our own VR analgesic for chronic pain patients titled *Mobius Floe* with the help of our undergraduate researchers and Ari Hollander from Firsthand Technology. The first study comparing the alpha version of *Mobius Floe* to other virtual realities revealed that a variety of virtual reality experiences do encourage a minor analgesic effect, but the effect of *Mobius Floe* itself was not significant enough to maintain a strong analgesic effect. We revisited the literature surrounding digital immersion frameworks and cognitive distraction,

and created a new software titled *Cryoslides* which offered an immersive and distractive experience. *Cryoslides* was able to significantly reduce perceived pain intensity in chronic pain patients in a clinical setting. The reductions in pain intensity we saw with *Cryoslides* were far greater than we saw in the initial *Mobius Flow* alpha testing study.

Although we have shown that *Cryoslides* creates an analgesic effect in chronic pain patients immersed in the virtual environment, there are also ways in which the virtual reality may benefit the chronic pain patient demographic outside of virtual reality. Feelings of helplessness and depression are common in chronic pain patients (Baliki et al. 2006)(Fishbain et al. 1997), and so the introduction of a tool like *Cryoslides* could help patients maintain a sense of control in relation to their CP experiences. Chronic pain can also experience sudden spikes in pain intensity, causing patients to catastrophize the painful experience, which can cause the pain experience to increase to higher degrees of intensity (Baliki et al. 2006). *Cryoslides* may be able to treat these cycles of pain spikes by helping the chronic pain patients move their embodied attention away from the pain experience and toward digital presence, ideally reducing their pain intensities to more bearable levels.

In the future, *Cryoslides* should be converted to a mobile format and tested in a second clinical study using a mobile viewer feasible enough for participants to be able to use in home settings. The cost of doing so is very little, as the software is already optimized to run on mobile devices. The limitation of using mobile devices would likely include a reduced field-of-view and by extension, reduced sensory immersion. However, if we are able to detect a statistically significant result in the perceived pain reduction of patients using *Cryoslides* in mobile viewers, at-home usage may be a viable locale for future longitudinal research experiments. If mobile viewers are found to be effective, the impact of this would be significant to all pain patients interested in virtual reality treatments. In particular, the consequences of chronic pain can result in depression, anger, anxiety, self-preoccupation, isolation and demoralization (Gatchel et al. 2007), but portable VR software could offer a new tool to chronic pain patient's analgesic arsenals, offering a sense of control to CP patients combating these psychological symptoms. With an accessible self-management tool, VRs such as *Cryoslides* could make significant differences in chronic pain patient lives: VR software can be made accessible online, and patients could take control anywhere with a smartphone.

For now, *Cryoslide* serves as an effective virtual reality analgesic which could be used in clinics and hospital settings for short-term durations in the future. It has limitations, however: the analgesic effect does not last outside of the VR experience. Our research will continue to improve virtual reality analgesics' intensity and duration alongside quickly developing virtual reality technologies to continue pushing forward the existence of VR analgesics and their wide-ranging applications for the future.

References

- Arnott, Robin. 2013. *Soundself*. Virtual Reality.
- Baliki, Marwan, Dante Chialvo, Paul Geha, Robert Levy, and Norman Harden. 2006. "Chronic Pain and the Emotional Brain: Specific Brain Activity Associated with Spontaneous Fluctuations of Intensity of Chronic Back Pain." *The Journal of Neuroscience* 26 (47): 12165–73.
- Barham, Leela. 2012. "Economic Burden of Chronic Pain Across Europe." *Journal of Pain & Palliative Care Pharmacotherapy* 26 (1): 70–72.
- Boulanger, Aline, Alexander Clark, Pamela Squire, and Edward Cui. 2007. "Chronic Pain in Canada: Have We Improved Our Management of Chronic Noncancer Pain?" *Pain Research and Management* 12 (1): 39–47.
- Breivik, Harald, Beverly Collett, Vittorio Ventafridda, Rob Cohen, and Derek Gallacher. 2006. "Survey of Chronic Pain in Europe: Prevalence, Impact on Daily Life, and Treatment." *European Journal of Pain* 10 (4): 287.
- Brown, Emily, and Paul Cairns. 2004. "A Grounded Investigation of Game Immersion." In *Extended Abstracts of Human Factors in Computing Systems*, 1297–1300. New York: ACM.
- Carise, Deni, Karen Dugosh, Thomas McLellan, Amy Camilleri, and George Woody. 2007. "Prescription OxyContin Abuse Among Patients Entering Addiction Treatment." *The American Journal of Psychiatry* 164 (11): 1750–56.
- Chen, Karen, Kevin Ponto, Mary Sesto, and Robert Radwin. 2014. "Influence of Altered Visual Feedback on Neck Movement for a Virtual Reality Rehabilitative System." In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 58:693–97.
- Cobbett, Richard. 2013. "Papers, Please Review." *IGN*. June 12. <http://ca.ign.com/articles/2013/08/12/papers-please-review>.
- Cohen, Jacob. 1988. *Statistical Power Analysis for the Behavioral Sciences*. Second. Lawrence Erlbaum Associates Publishers.
- Cowley, Ben, Darryl Charles, and Michaela Black. 2008. "Toward an Understanding of Flow in Video Games." *ACM Computers in Entertainment* 6 (2).
- Csikszentmihalyi, Mihaly. 2004. *Mihaly Csikszentmihalyi: Flow, the Secret to Happiness*. Lecture. Monterey, California: TED2004.

- Das, Debashish, Karen Grimmer, Anthony Sparnon, Sarah McRae, and Bruce Thomas. 2005. "The Efficacy of Playing a Virtual Reality Game in Modulating Pain for Children with Acute Burn Injuries: A Randomized Controlled Trial." *BMC Pediatrics* 5 (1).
- Ermi, Laura, and Frans Mayra. 2005. "Fundamental Components of the Gameplay Experience: Analysing Immersion." In *Changing Views: Worlds in Play*.
- Faber, Albertus, David Patterson, and Marco Bremer. 2013. "Repeated Use of Immersive Virtual Reality Therapy to Control Pain during Wound Dressing Changes in Pediatric and Adult Burn Patients." *Journal of Burn Care Research* 34 (5): 563–68.
- Faiola, Anthony, Christine Newlon, Mark Pfaff, and Olga Smyslova. 2003. "Correlating the Effects of Flow and Telepresence in Virtual Worlds: Enhancing Our Understanding of User Behavior in Game-Based Learning." *Computers in Human Behavior* 29 (3): 1113–21.
- Fakhruddin, Mufaddal. 2012. "Man Dies after Playing Diablo III for 72 Hours." *IGN*, May 24. <http://bit.ly/1F58FmB>.
- Fishbain, David, Robert Cutler, Hubert Rosomoff, and Renee Rosomoff. 1997. "Chronic Pain-Associated Depression: Antecedent or Consequence of Chronic Pain? A Review." *The Clinical Journal of Pain* 13 (2): 116–37.
- Garrett, Bernie, Tarnia Taverner, Wendy Masinde, Diane Gromala, and Chris Shaw. 2014. "A Rapid Evidence Assessment of Immersive Virtual Reality as an Adjunct Therapy in Pain Management." *Clinical Journal of Pain* 30 (2).
- Gatchel, Robert J, Yuan Bo Peng, Madelon L Peters, Perry N Fuchs, and Dennis C Turk. 2007. "The Biopsychosocial Approach to Chronic Pain: Scientific Advances and Future Directions." *Psychological Bulletin* 133 (4): 581–624. doi:10.1037/0033-2909.133.4.581.
- Gilmour, Heather. 2015. "Chronic Pain, Activity Restriction and Flourishing Mental Health." *Statistics Canada*. <http://www.statcan.gc.ca/pub/82-003-x/2015001/article/14130-eng.htm>.
- Grieco, Gino. 2015. "Lenticular Design." *First Person Scholar*. January 5. www.firstpersonscholar.com/the-game-design-holy-grail/.
- Gromala, Diane, Xin Tong, Amber Choo, Mehdi Karamnejad, and Chris Shaw. 2015. "The Virtual Meditative Walk: Virtual Reality Therapy for Chronic Pain Management." In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 521–24. Seoul, Korea: ACM.

- Hamilton, Kirk. 2014. "A Beginner's Guide To All Things Dragon Age." Entertainment. *Kotaku*. November 13. <http://kotaku.com/a-beginners-guide-to-all-things-dragon-age-1658487212>.
- Helgason, David. 2015. "Unity." *Unity - Game Engine*. Accessed July 4. <http://unity3d.com/>.
- Herff, Christian, Dominic Heger, Ole Fortmann, and Johannes Hennrich. 2013. "Mental Workload during N-Back Task—quantified in the Prefrontal Cortex Using fNIRS." *Frontiers in Human Neuroscience* 7: 935.
- Hoffman, Hunter. 2015. "Virtual Reality Pain Reduction." Research Projects. *HITLab*. March 16. www.hitl.washington.edu/projects/vrpain/.
- Hoffman, Hunter, Patterson David, Carrouger Gretchen, and Furness Thomas. 2000. "Virtual Reality as an Adjunctive Pain Control during Burn Wound Care in Adolescent Patients." *Pain* 85 (1): 305–9.
- Hoffman, Hunter, Azucena Garcia-Palacios, David Patterson, and Mark Jensen. 2001. "The Effectiveness of Virtual Reality for Dental Pain Control: A Case Study." *Cyberpsychology & Behavior* 4 (4): 527–35.
- Hoffman, Hunter, Walter Meyer, Ramirez Maribel, and Linda Roberts. 2014. "Feasibility of Articulated Arm Mounted Oculus Rift Virtual Reality Goggles for Adjunctive Pain Control During Occupational Therapy in Pediatric Burn Patients." *Cyberpsychology, Behavior and Social Networking* 17 (6).
- Hoffman, Hunter, David Patterson, and Gretchen Carrouger. 2000. "Use of Virtual Reality for Adjunctive Treatment of Adult Burn Pain During Physical Therapy: A Controlled Study." *The Clinical Journal of Pain* 16 (3): 244–50.
- Hoffman, Hunter, David Patterson, Eric Seibel, and Maryam Soltani. 2008. "Virtual Reality Pain Control During Burn Wound Debridement in the Hydrotank." *The Clinical Journal of Pain* 24 (4).
- Hoffman, Hunter, Sam Sharar, Barbara Coda, John Everett, Marcia Ciol, Todd Richards, and David Patterson. 2004. "Manipulating Presence Influences the Magnitude of Virtual Reality Analgesia." *Pain* 111 (1): 162–68.
- Hutchinson, Lee. 2014. "Oculus Rift Dev Kit 2 Launches with 960x1080 Resolution, Lower Latency." *Ars Technica*, March 19, sec. Product News and Reviews.
- Ingenito, Vince. 2014. "Diablo 3: The Shiniest Hell." Entertainment. *IGN*. August 14. <http://ca.ign.com/articles/2014/08/14/diablo-3-reaper-of-souls-ultimate-evil-edition-review>.

- Jennett, Charlene, Anna Cox, Paul Cairns, Samira Dhoparee, Andrew Epps, Tim Tijs, and Alison Walton. 2008. "Measuring and Defining the Experience of Immersion in Games." *International Journal of Human-Computer Studies* 66: 641–61.
- Karamnejad, Mehdi. 2014. "Virtual Reality and Health Informatics for Management of Chronic Pain." Simon Fraser University.
- Lazzaro, Nicole. 2004. "Why We Play Games: Four Keys to More Emotion Without Story."
- Maani, Christopher, Hunter Hoffman, Peter DeSocio, Michelle Morrow, and Chaya Galin. 2008. "Pain Control During Wound Care for Combat-Related Burn Injuries Using Custom Articulated Arm Mounted Virtual Reality Goggles." *Journal of CyberTherapy & Rehabilitation* 1 (2): 193–98.
- Machkovech, Sam. 2015. "Steam Controller, SteamVR, Steam Machines: Valve's Hardware Push in Photos." *Ars Technica*, March 4, sec. Gaming and Entertainment.
- McGloin, Rory, Kirstie Farrar, and Marina Krcmar. 2013. "Video Games, Immersion, and Cognitive Aggression: Does the Controller Matter?" *Media Psychology* 16 (1): 65–87.
- Mosso-Vazquez, Jose Luis, Gao Kenneth, Brenda Wiederhold, and Mark Wiederhold. 2014. "Virtual Reality for Pain Management in Cardiac Surgery." *Cyberpsychology, Behavior, and Social Networking* 17 (6): 371–78.
- Nechvatal, Joseph. 2001. "Towards an Immersive Intelligence." *Leonardo* 34 (5): 417–22.
- Orland, Kyle. 2015. "Hands-on: Valve/HTC Opens up the Virtual Reality Experience." *Ars Technica*, March 5, sec. Gaming and Entertainment.
- Patterson, David, Shelley Wiechman, Mark Jensen, and Sam Sharar. 2006. "Hypnosis Delivered Through Immersive Virtual Reality for Burn Pain: A Clinical Case Series" 54 (2).
- Perry, Briana, Catherine Mercier, Steve Pettifer, and Jonathan Cole. 2014. "Virtual Reality Therapies for Phantom Limb Pain." *European Journal of Pain* 18 (7): 897–99.
- Porter, Guy, Vladan Starcevic, David Berle, and Pauline Fenech. 2010. "Recognizing Problem Video Game Use." *Australian & New Zealand Journal of Psychiatry* 44 (2): 120–28.

- Pose, Ronald, and Matthew Regan. 1994. "Techniques for Reducing Virtual Reality Latency with Architectural Support and Consideration of Human Factors." In *Selected Papers from the First International Conference on Hypermedia, Multimedia, and Virtual Reality: Models, Systems, and Applications*, 117–29. London: Springer-Verlag.
- Richard, Patrick. 2012. "The Economic Costs of Pain in the United States." *Journal of Pain* 13 (8): 715.
- "Rift Away - Oculus Rift Experiences." 2015. *Rift Away*. www.riftaway.com.
- Russell, Matthew, Brittney Hoffman, Sarah Stromberg, and Charles Carlson. 2014. "Use of Controlled Diaphragmatic Breathing for the Management of Motion Sickness in a Virtual Reality Environment." *Applied Psychophysiology and Biofeedback* 39 (3): 269–77.
- Russo, Cathy, and William Brose. 1998. "Chronic Pain." *Annual Review of Medicine* 49: 123–33.
- Schmitt, Yuko, Hunter Hoffman, David Blough, David Patterson, Mark Jensen, Maryam Soltani, Gretchen Carrouger, Dana Nakamura, and Sam Sharar. 2011. "A Randomized Controlled Trial of Immersive Virtual Reality Analgesia, during Physical Therapy for Pediatric Burns." *Burns* 37 (1): 61–68.
- Schneider, Susan, and M.L Workman. 2009. "Effects of Virtual Reality on Symptom Distress in Children Receiving Chemotherapy." *CyberPsychology & Behavior* 2 (2): 125–34.
- Shahrbanian, Shahnaz, Xiaoli Ma, Nicol Korner-Bitensky, and Maureen Simmonds. 2009. "Scientific Evidence for the Effectiveness of Virtual Reality for Pain Reduction in Adults with Acute or Chronic Pain." 7, 40–43.
- Skevington, Suzanne. 1983. "Chronic Pain and Depression: Universal or Personal Helplessness?" *PAIN®* 15 (1-4): 309–17.
- Smith, A.A. 2003. "Intimacy and Family Relationships of Women with Chronic Pain." *Pain Management Nursing* 4 (3): 134–42.
- Takatalo, Jari, Jukka Häkkinen, Jyrki Kaistinen, and Göte Nyman. 2010. "Presence, Involvement, and Flow in Digital Games." In *Evaluating User Experience in Games*, edited by Regina Bernhaupt, 23–46. Human-Computer Interaction Series. Springer London. http://link.springer.com.proxy.lib.sfu.ca/chapter/10.1007/978-1-84882-963-3_3.

- Todd, Brett. 2010. "Amnesia: The Dark Descent Review." *Gamespot*. September 30. <http://www.gamespot.com/reviews/amnesia-the-dark-descent-review/1900-6280302/>.
- Treede, R, T Jensen, J Campbell, G Cruccu, J Dostrovsky, J Griffin, and P Hansson. 2008. "Neuropathic Pain: Redefinition and a Grading System for Clinical and Research Purposes." *Neurology* 70 (18): 1630–35.
- "Using an Interactive Game to Reduce Fear and Increase Spine Motion in Low Back Pain." 2015. Proposed Clinical Trial NCT02301741. Ohio: Ohio University.
- "Valve." 2015. *Valve*. Accessed July 4. <http://www.valvesoftware.com/>.
- Vidarthi, Jay. 2012. "Sonic Cradle: Evoking Mindfulness through Immersive Interaction Design." MSc Thesis, Surrey, BC, Canada: Simon Fraser University. <https://vimeo.com/55230632>.
- "Virtual Reality | Definition." 2003. *Merriam-Webster's Collegiate Dictionary*. Springfield, MA: Merriam-Webster.
- Wasan, Ajay, Edgar Ross, Edward Michna, Lori Chibnik, and Shelly Greenfield. 2012. "Craving of Prescription Opioids in Patients With Chronic Pain: A Longitudinal Outcomes Trial." *The Journal of Pain* 13 (2): 146–54.
- Wickens, Christopher. 2002. "Multiple Resources and Performance Prediction." *Theoretical Issues in Ergonomics Science* 3 (2): 159–77.
- Wiederhold, Brenda, Kenneth Gao, Camelia Sulea, and Mark Wiederhold. 2014. "Virtual Reality as a Distraction Technique in Chronic Pain Patients." *Cyberpsychology, Behavior and Social Networking* 17 (6): 346–52.
- Wiederhold, Mark, and Brenda Wiederhold. 2007. "Virtual Reality and Interactive Simulation for Pain Distraction." *Pain Medicine* 8 (s3): S182–88.
- Wint, Suzanne Sander, Debra Eshelman, Jill Steele, and Cathie E. Guzzetta. 2002. "Effects of Distraction Using Virtual Reality Glasses During Lumbar Punctures in Adolescents With Cancer." *Oncology Nursing Forum* 29 (1): E8–15.
- Witmer, Bob, and Michael Singer. 1998. "Measuring Presence in Virtual Environments: A Presence Questionnaire." *Presence: Teleoperators and Virtual Environments* 7 (3): 225–40.
- Woodrow, Kenneth, and Lorne Eltherington. 1988. "Feeling No Pain: Alcohol as an Analgesic." *Pain* 32 (2): 159–63.
- Zimmerman, Eric, and Katie Salen. 2004. "Games as Systems of Uncertainty." In *Rules of Play: Game Design Fundamentals*. MIT Press.

This page left blank in original

Appendices

Appendix A.

Video Files

Cryoslide example video. Length: 50 seconds. 23.8 MB.

Filename: cryoslidecompressed.mp4

Video URL to Cryoslide example video on Google Drive: <http://bit.ly/1btJba3>

Moebius Floe example video. Length: 1 minute 25 seconds. 36.2 MB.

Filename: mfalphacompressed.mp4

Video URL to Mobius Floe example video on Google Drive: <http://bit.ly/1BOe0fH>

Appendix B.

N-back task instruction sheet

Instructions

Use the **left mouse button** to throw snowballs.

Use **your head** to look around and **aim** your snowballs.

You can press the **right mouse button** to start and stop moving forward.

You may pass by some large snow blocks with rotating images on them.



To score additional points, hit the rotating image with a snowball when it turns into **the image you saw two images ago**.

For example:

Imagine we see one image at a time. First the star, then triangle, then yin-yang symbol etc...



2-back!

When you see the image you saw two images ago, you would throw a snowball at it. In this example, you would hit the rotating image when it showed the triangle after the yin-yang, because it's appearing twice (**one two images ago**, and once now).

A checkmark will appear if you are correct.

If you see a green screen please let me know - it means the application has minimized and needs attention.

Appendix C.

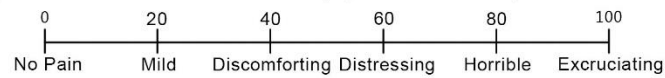
Pain intensity questionnaires (all)

Digital Immersion Questionnaire for Pain Experience Management
Amber Choo - Feb 2015

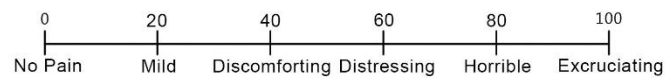
Participant #

Intro Questionnaire

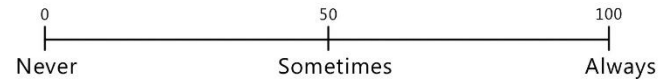
During the last ten minutes, my pain intensity was on average:



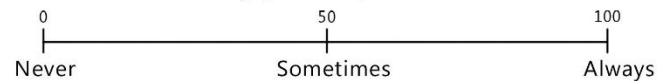
How would you describe your Present Pain Intensity **right now**?



The time I usually spend preoccupied with **myself** is:



During the last ten minutes, the amount of time I spent thinking about my pain experience was:



Digital Immersion Questionnaire for Pain Experience Management
Amber Choo - Feb 2015

Participant #

Post-Self Management Questionnaire

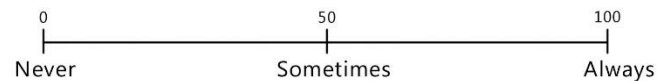
How was your Pain Intensity in the ten minutes before this questionnaire?



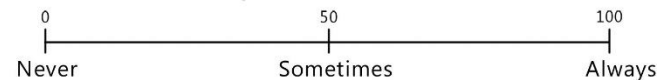
How would you describe your Present Pain Intensity **right now**?



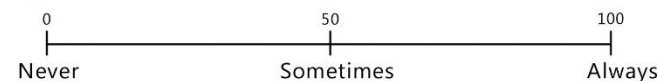
During the last ten minutes, the time I spent preoccupied with **myself** was:



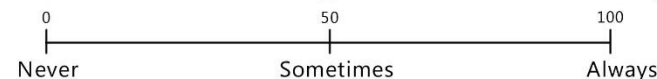
During the last ten minutes, the amount of time I spent thinking about my pain experience was:



During the last ten minutes, I felt like I lost track of time:



During the last ten minutes, I thought about unrelated everyday things:



What was the primary activity you engaged in during the last ten minutes?

☐ Meditating ☐ Sitting in a resting state ☐ Reading

Something else (please describe): _____

Digital Immersion Questionnaire for Pain Experience Management
Amber Choo - Feb 2015

Participant #

Post-VR Questionnaire

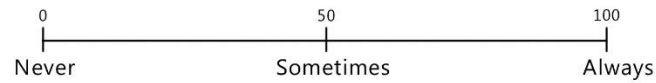
How was your Pain Intensity when you were inside the snow world?



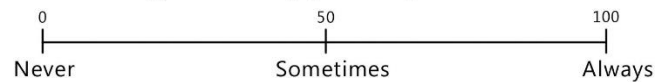
How would you describe your Present Pain Intensity **right now**?



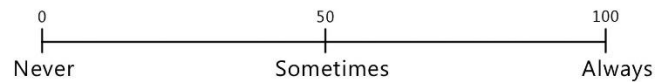
The time I spent preoccupied with **myself** in the snow world was:



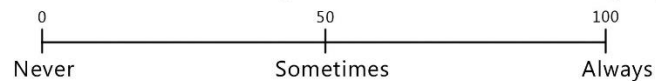
The time I spent thinking about my pain experience in the snow world was:



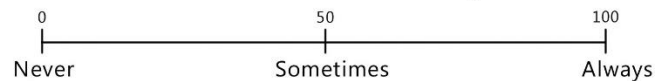
I felt like I lost track of time in the snow world:



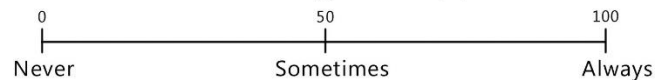
Inside the snow world, I thought about unrelated everyday things:



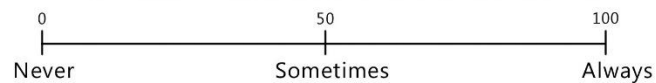
I found the controls were easy to use:



I was invested in collecting as many points as I could:



I felt like I was inside of the snow world:



Appendix D.

Study script

SIMON FRASER UNIVERSITY

Introductory script for User Testing of Virtual Realities for Pain Reduction

Title of Study: User Testing of Virtual Realities for Pain Reduction
Principal Investigator: Amber Choo
Senior Supervisor: Dr. Diane Gromala
Department: School of Interactive Arts and Technology
Ethics application number: [2014s0587]

Thank you for visiting us in Dr. Squire's pain clinic today. The user study you have volunteered for aims to collect data about a virtual reality game currently being designed for pain distraction at Simon Fraser University in order to improve it.

"Would you consider yourself easily susceptible to nausea or motion-sickness?" *(if they respond yes, they are not eligible for the study.)*

"Are you experiencing any chronic pain at this moment?" *(must respond yes.)*

In this study, you will play with the Oculus Rift, a head-mounted-display which immerses the visual senses. The Oculus Rift is known to cause feelings of nausea in some users. If you experience nausea and would like to stop, let me know immediately and we will take the Oculus Rift off and end the study.

We will ask you to spend ten minutes self-managing your pain before or after using the Oculus Rift; the order of activities is randomly determined by the flip of a coin. For example some participants may use the Oculus Rift first, and then spend ten minutes meditating or reading to self-manage their pain, while other participants will do same but in a reverse order. We are curious to see if the virtual reality treatment will have any effect on your perception of pain in contrast to more common self-management methods.

You have the right to withdraw from the experiment for any time for whatever reason. If you want your data removed from the study, we can do that for you too. The study investigator (Amber Choo) will be here if you have any questions. If you are called for your appointment with Dr. Squire and are in the virtual reality, I will remove your headphones and head mounted display immediately and you can go see her right away.

Let's get started by taking a look at the consent form. Please read it over and take your time. If you decide you would like to participate, we will flip a coin to decide which activity to do first.