Medicine Meets Virtual Reality 22
J.D. Westwood et al. (Eds.)
IOS Press, 2016

doi:10.3233/978-1-61499-625-5-154

A Virtual Reality Game for Chronic Pain Management: A Randomized, Controlled Clinical Study

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Abstract. Although Virtual Reality (VR) applications have been shown to reduce many forms of acute pain, such research of VR applications and their effects on chronic pain is still at its infancy. In this study, we designed a VR game *Cryoslide*, and examined its analgesic effect on chronic pain patients, its end users, in a clinical setting. In this randomized, controlled crossover clinical study of 20 chronic pain patients, *Cryoslide* significantly reduced perceived pain compared to the baseline and the control group. The results demonstrate that *Cryoslide* can be effectively used as an analgesic intervention for chronic pain management to lessen pain intensity during short-term symptom spikes.

Keywords. Virtual reality; serious games; chronic pain; pain management.

1. Introduction

The analgesic effects of immersive Virtual Reality (VR) technology have been studied in patients suffering from acute or short-term pain. For instance, VR interventions have been used to reduce acute pain in dental procedures[1], physical therapy[2,3], phantom limb pain[4], wound dressing[5] and experimental pain in healthy populations[6]. Despite the promising effect of VR on acute pain, limited research has been conducted for the use of VR in chronic or long-term pain management.

Chronic pain or persistent pain is pain without apparent biologic value that has persisted beyond the normal tissue healing time of at least 3 months[7]. It arises from maladaptive changes in the central nervous system and goes beyond the underlying disease or injury which triggers it, therefore many evidences now support that chronic pain is a disease entity, rather than a symptom[8]. In North America, Statistics Canada reported that approximately 5.6 million Canadians suffered from chronic pain in 2011/2012[9]; and about 100 million Americans have chronic pain, more than those affected by heart disease, diabetes and cancer combined[10]. Distinct from acute pain, chronic pain is always the interactive results of biological, psychological and social processes, which makes it difficult to tackle[7]. It is often treated with opioid analgesics. The long-term treatment with opioids, however, may result in problematic side effects,

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such as physical dependence and addiction[11]. During this long-term suffering, chronic pain patients also may undergo pain intensity fluctuations, including short-term pain spikes[12].

Although the nature of chronic pain poses significant differences, the pain-attenuation effect of VR from acute pain studies is nevertheless favorable for chronic pain management. Because of its immersive characteristic and analgesic effect, VR may serve as a potential non-pharmacological intervention to fulfill the treatment gap of chronic pain from either long-term management or short-term relapse control. There are still too few research papers available to confirm VR's effectiveness for chronic pain relief[13,14]. Therefore, our study adapts what was learned from previous research on the analgesic effects of VR for acute pain, and builds on these findings specifically for chronic pain patients. We designed an immersive virtual reality game called *Cryoslide*, and conducted a clinical study to determine if it may prove effective as a short-term intervention for chronic pain management. The findings may contribute to better understanding the specific content of chronic pain, and to more rapid improvements in VR design research.

2. Methods & Materials

2.1. Virtual Reality Game Design

In the game design of *Cryoslide*, we employed pain distraction strategies. The immersive VR experience in *Cryoslide* consists of 4 minutes' sliding in the icy cave and 6 minutes' sliding in the outdoor icy world (Figure 1). In the game, the player could interact with different creatures in the icy environment by hitting them with snowballs. The player's aim is to calm down these agitated creatures with snowballs to earn as many points as possible.

Figure 1. The track of *Cryoslide* (top-down view).

Four main creatures in the game (Figure 2) serve as key components of cognitive distraction.

- **Booshis** are red spherical creatures with neuron-like dendrites. They can hover and fly, which provide a variation of difficulties for the player to progress in the virtual environment.
- **Moths** are rare creatures that fly quickly in predefined circular patterns. If the player hits one, s/he will earn a large number of points as the moth disappears into a ball of light. Moths are designed to blend in with surrounding environment, encouraging the player to pay close attention to them.

- **Miniature neuron trees** are chest-high spherical creatures with neuron-like dendrites. Capable of chasing the player, they are coded with a simple AI pathfinding script.
- **Adult neuron trees** are unfriendly, agitated creatures programmed to chase the player unless many snowballs hit them in quick succession.

These creatures were introduced sequentially, allowing the players to adapt to certain difficulties corresponding to their own gameplay skills while simultaneously maintaining the game "flow". Considering that most of the players of this game are unlikely to be described as the hardcore gamer, the player will not get punished for missing any of the creatures.

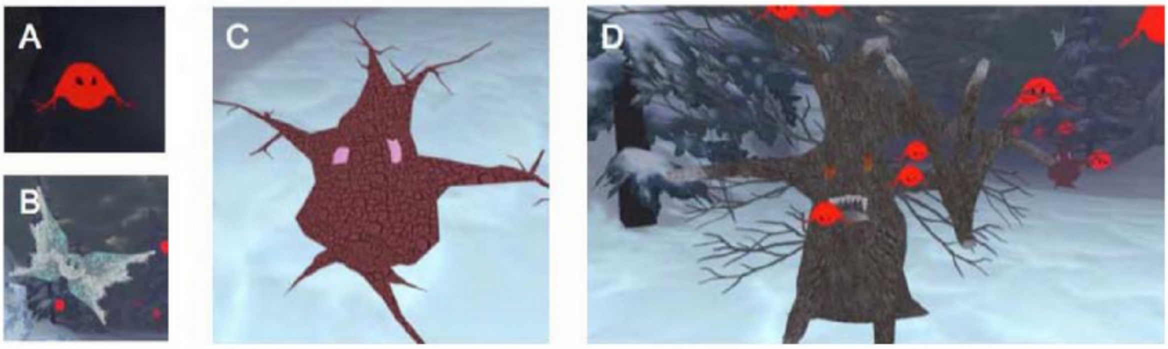

Figure 2. Character design: A: Booshi, B: Moth, C: Miniature neuron tree, D: Adult neuron tree.

To heighten the amount of cognitive occupation and distraction while maintaining a sense of fun in the game, *Cryoslide* incorporates an entertaining version of the "n-back task". This task derives from neuroscience and was implemented to encourage more cognitive engagement (Figure 3). The player earns large amounts of points by memorizing a sequence of n-back (n = 2) visual patterns, and identifying a recurrent one by throwing a snowball at it.

Figure 3. Example of a n-back tasks in *Cryoslide*. The image on the block (shown as a fish) changes to a different image every three seconds.

In terms of hardware, the player wears the Oculus Rift DK2 head-mounted display (HMD) and noise-cancelling headphones. The input devices of the game are two-fold: the HMD and a standard computer mouse. The player aims at targets via the HMD's head tracking system, throws a snowball by left clicking the mouse, and pauses/restarts the game by right clicking.

2.2. User Study of Chronic Pain Patients in Clinical Settings

We performed a randomized, controlled crossover clinical study to evaluate the analgesic effect of *Cryoslide* on patients with chronic pain. Subjects who were 18 years of age or older with the diagnosis of chronic pain were eligible for enrollment. Chronic pain was diagnosed by the pain specialist with the following criteria: ongoing pain lasting longer than 3 months. Participants who had a high risk of motion sickness, or severe pain around the HMD contact regions were excluded from the study. Subjects were recruited from a complex pain clinic in Vancouver.

The study was conducted in a private room at the clinic. We used Visual Analog Scale (VAS) questionnaire to collect pain intensity data (score from 0 to 100, with 0 representing no pain and 100 representing the excruciating pain). Additional questions regarding distraction experience were also incorporated into the questionnaire. Subjects who were eligible for the study first filled out the Intro Questionnaire which collects the baseline data. They then were randomly assigned to undergo either the VR intervention or the self-mediated control group for 10 minutes, followed by a washout period of 5 minutes. After that they crossed over to the other group for another 10 minutes. In the VR intervention group, subjects spent 10 minutes playing *Cryoslide* using the Oculus Rift DK2 and noise-cancelling headphones. In the self-mediated control group, subjects were asked to spend 10 minutes engaging in the daily pain-distracting activities that they used to, such as meditating, reading, playing mobile games or listening to audiobooks. During the washout period, subjects filled out the Post-Intervention Questionnaire, which was used to collect pain intensity data at present and during the past 10 minute. The entire study session lasted for 35-45 minutes per subject.

3. Results

Of the 23 eligible subjects enrolled, 3 subjects dropped out because of personal time constraints or nausea. The statistical analysis was performed on data of 20 subjects. Four were male (20%) and 16 were female (80%). Their age varied from 30 to 75-years-old.

3.1. Effect of Interventions on Chronic Pain Alleviation

Pain intensity during and after the interventions was measured. For pain intensity after the interventions, the two groups of the VR intervention and self-mediated control were not significantly different using repeated measures ANOVA ($F(2, 38) = 1.377$, $p = 0.265$). However, for pain intensity during the intervention, there was a significant difference between the VR intervention and control groups ($F(2, 38) = 21.473$, $p < 0.001$, $r = 0.505$). Mauchly's sphericity test was not violated ($\chi^2(2) = 3.726$, $p = 0.155$).

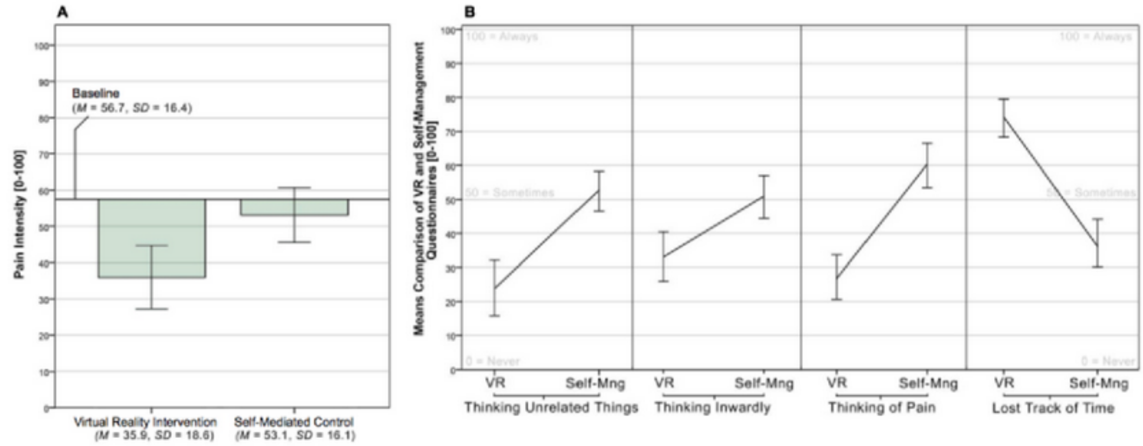

Figure 4. Means and 95% CI comparisons between the VR intervention and the control groups on pain intensity (A) and distraction (B).

Compared to the baseline, there was a 36.7% reduction in pain intensity during the VR intervention using Bonferroni post hoc tests (95% confidence interval [CI], -31.443 to -11.657; $p < 0.001$). Compared to control group, the VR intervention group also had a significant reduction in pain intensity (95% confidence interval [CI], -27.397 to -6.953; $p = 0.001$). There was no significant difference between the baseline and control group in pain intensity ($p = 0.336$) (Figure 4A).

3.2. Effect of Interventions on Pain Distraction

In comparison to the control group, subjects in the VR intervention group reported a 56% reduction in the amount of time thinking specifically about their pain ($p < 0.001$, $r = 0.75$); subjects also reported a statistically significant effect on losing track of time ($p < 0.001$, $r = 0.78$) in the VR intervention compared to the control condition. Subjects also found themselves less frequently thinking unrelated things ($p = 0.07$, $r = 0.57$) and thinking inwardly ($p = 0.47$, $r = 0.48$) in the VR intervention, but their differences with the control group did not show a statistical significance (Figure 4B).

4. Discussion

The user study result demonstrated that during the VR session, *Cryoslide* could significantly reduce the perception of pain intensity for chronic pain suffers in comparison to the baseline. Compared with self-mediated interventions such as reading, listening to music, or playing mobile games, our VR game gained more analgesic effect on chronic pain patients' suffering; it also significantly distracted patients' attention from their daily pain.

The analgesic effect of *Cryoslide* for chronic pain results likely from the complex interplay of immersion, interaction, emotional engagement, cognitive distraction tasks, and transported presence experience. In our present study, it is unknown which of these elements in *Cryoslide* was more dominant in leading to the pain-attenuation effect. Although "attention distraction" is currently the major explanation for such "VR analgesia" phenomenon, as the distracting cognitive tasks of VR demonstrates top-down modulation of pain signaling via frontal cortical processes[15], some neurocognitive research showed that other cognitive experiences, such as embodiment[16], emotion[17], perceived controllability[18] and expectancy[19], were also associated with cognitive analgesic effects. These elements, which also mingle in the gameplay of *Cryoslide*, may act on the pain modulation mechanisms in ways beyond "attention distraction". Therefore, built on our present discoveries, it is worthwhile to elaborately identify the effects of those contributions respectively in the future work, in order to elucidate the underlying mechanisms of "VR analgesia", and to guide the future design of VR systems for chronic pain management.

In this study, the analgesic effect of *Cryoslide* did not last beyond the VR session. One possibility may be that the 10-minute duration of the VR experience may not be long enough to evoke long-lasting neural analgesic effects, since ample studies on neuroplasticity have suggested that the intensity, frequency and duration of stimuli are all important factors in determining the extent of neural reorganization[20]. Furthermore, Rutter et al. demonstrated that the analgesic effect of VR after repeated exposure remained stable in healthy volunteers, implicating for the long-term use of VR as a non-pharmacological analgesic[6]. Even if the long-lasting perceptions of reduced pain is weak or difficult to evoke, the study results were still encouraging enough to provide an applicable, cost-effective non-pharmacological tool for the short-term control of chronic pain, especially during symptom fluctuation. It offers patients an effective alternative beyond opioids to control symptoms of this long-term condition, and may thereby help to lessen a sense of hopelessness. Besides the short-term symptom attenuation using VR games, other VR applications were also examined to achieve the long-term modulation for chronic pain, including motion control using VR for pain-related kinesiophobia[21], VR-mediated mindfulness[22] and progressive muscle relaxation[23]. These research studies, together with findings of this paper, provide evidence that virtual reality is a promising and viable tool for chronic pain management.

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