The Virtual Meditative Walk: Virtual Reality Therapy for Chronic Pain Management

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ABSTRACT
Because the nature of chronic pain is complex, pharmacological analgesics are often not enough to achieve an ideal treatment plan. Virtual Reality (VR) technologies have emerged within medical research in recent years for treating acute pain, and proved to be an effective strategy based on pain distraction. This paper describes a VR system designed for chronic pain patients. The system incorporates biofeedback sensors, an immersive virtual environment, and stereoscopic sound titled the "Virtual Meditative Walk" (VMW). It was designed to enable chronic pain patients to learn Mindfulness-based stress reduction (MBSR), a form of meditation. By providing real-time visual and sonic feedback, VMW enables patients to learn how to manage their pain. A proof-of-concept user study was conducted to investigate the effectiveness of the VR system with chronic pain patients in clinical settings. Results show that the VMW was more effective in reducing perceived pain compared to the non-VR control condition.

Author Keywords
Virtual Reality; Chronic Pain; Biofeedback; Mindfulness Meditation.

INTRODUCTION
An estimated 20% of people in North America [1] and 15-20% in industrialized nations [2] suffer from chronic pain. Chronic pain is defined as pain that lasts more than 6 months and persists beyond the healing of its putative cause. The complexity of this condition involves neurobiological, psychological and social dimensions, and as such, no universal treatment exists [3]. Although pharmacological approaches are the most common treatment method, they cannot address all aspects of the condition. Moreover, analgesics such as opioids can have serious side effects, including dependency and addictive tendencies [4], and misuse of opioids is a fast-growing problem among certain patient demographics [5].

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One of the standard supplementary or adjuvant approaches to managing chronic pain is MBSR. The primary goal of MBSR is to enable patients to reduce stress and improve their health via improvements in the maintenance of their psychological states [6]. This is particularly important for chronic pain patients, as the persistence of pain itself is stress-inducing. Moreover, because there is currenty no known cure, and because current treatments present limitations, many patients are left with a sense of hopelessness [2].

Hoffman et al. convincingly demonstrated that immersive Virtual Reality (VR) is an effective way to manage attention in computer-generated virtual places as a form of pain distraction [7]. Thus, VR can be used as a powerful pain control technique and tool for patients to manage and alleviate their acute or short-term pain [8]. However, it is not yet known if the analgesic effects of VR persist beyond the VR sessions. No peer reviewed user studies have yet been published to investigate whether VR is helpful for managing chronic pain on a long-term scale.

This paper outlines a novel approach constructed for managing chronic pain using VR, biofeedback technology and the MBSR technique. The results of this research suggest that learning MBSR while immersed in a virtual environment can lead to further decreases in perceived pain in contrast to learning MBSR without VR.

RELATED WORK
While treatment of severe chronic pain solely by pharmacological approaches is limited and problematic [9], there are alternatives and adjuvant approaches that help patients manage their long-term pain and reduce its intensity.

Medical applications of VR have begun to emerge over the past decade, including rehabilitation, surgical simulators, and telepresence surgery [10]. In 2003, researchers at the Georgia Institute of Technology designed an immersive virtual environment (VE) — the Meditation Chamber — to train participants to reduce their stress [10]. The researchers used biofeedback sensors to monitor arousal; this data in turn affected the visual assets in the VE. Participants were able to successfully reduce their stress levels while observing the VE's continuously changing visual feedback, and the VE was more effective than biofeedback alone.

VR has also proven to be an effective method to reduce perceived pain during burn wound care [12]. Hoffman et al. designed a series of distraction-based VR studies in which patients reported up to 50% reduction in perceived pain. Although these studies were small, they have been replicated and extended since 1999. Several other VR applications not built upon pain distraction were developed to mitigate pain. Drawing upon the well-known "mirror therapy" espoused by neuroscientist V.S. Ramachandran, Murray et al. deployed VR as a solution to treat phantom limb pain [11]. Although this study was preliminary, the users reported they felt sensation in their phantom limb and reported a decrease in phantom pain.

In 2013, Shiri et al. created a VE and biofeedback system to treat pediatric headaches [12]. They obtained galvanic skin response (GSR) levels of patients with chronic headaches over ten sessions, each lasting 30 minutes. The GSR data was processed and used to affect the VE that the users were exposed to. The users were instructed to perform relaxation techniques; as they became more relaxed, the VE showed a happier picture of them. The researchers reported that during the intervention, patients with migraines experienced a significant decrease in headache pain using Visual Analog Scale [13]. E. Hudlicka also designed and evaluated a virtual mindfulness coach for patient education and health behavior training. Results suggested that coach-based training was more effective compared to self-administered approaches for mindfulness practices [14].

These works indicate that VR has been effective for treating acute pain; however, such VEs present limitations for managing chronic pain. We must consider the inherent approach in the use of VR for acute pain is based on pain distraction. It is impossible to distract chronic pain patients in a VE for significant and frequent periods of time, or whenever their pain begins to flare. Thus, our research focuses on utilizing VR as a therapeutic intervention to teach MBSR, a well-established pain management technique, which in turn may enable patients to more easily develop an effective long-term pain management tool.

VIRTUAL MEDITATIVE WALK: USER STUDY DESIGN AND METHOD

Virtual Meditative Walk

MBSR, a form of mindfulness meditation, is a technique that takes time and effort to learn. Initially, it requires a focus on one's internal states, rather than on the world. The design of the Virtual Meditative Walk (VMW) provides a peaceful, non-distracting and safe environment for users to immerse themselves in as they learn to achieve a stable meditative practice as they learn to control (or exert agency over) the physiological aspects that are necessary to achieve the positive effects of MBSR. The VMW is a VE where participants immersed in the virtual reality find themselves "walking" in a beautiful forest composed primarily of a deciduous forest and undergrowth. The surrounding area is relatively mountainous, reminiscent of the trails found along the northwest coast of North America. The camera slowly moves along a worn dirt pathway, as if the user is walking. This allows patients to explore the forest without requiring physical distractions or attention in order to achieve further passage. (Figure 1.)

The GSR sensors continuously track the patient's changing arousal levels, and in turn modify the VMW's weather. The light fog in the forest, for example, recedes as a patient's GSR levels start to stabilize in favor of a mindful state. Alternatively, the fog thickens and draws closer when the patient's arousal levels increase. This serves as seamless visual feedback for patients immersed in the VMW. Figure 2 shows how the VE changes according to variabile changes in the patients' biofeedback data.

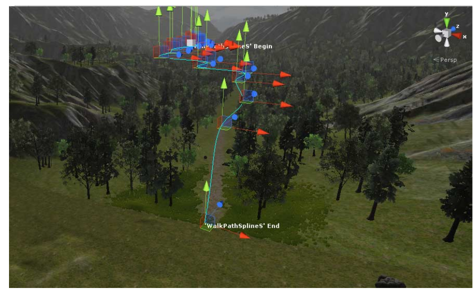

Figure 1. Path design in VMW virtual environment.

Figure 2. As patients approach an inferred meditative state, the fog begins to dissipate (left to right), and sounds become more audible and spatial.

Study Intent

This proof-of-concept study was designed to determine if a Virtual Environment, combined with MBSR training and biofeedback, helps pain patients better manage their long-term chronic pain, given the limitations of VR pain distraction. Will patients fare better using the VMW to learn MBSR, compared to patients who learn MBSR without immersive VR? If such a VR intervention is able to reduce perceived pain levels among chronic pain patients in a clinical setting, it may be possible that the *long-term* benefits for patients learning MBSR to better manage their long-term persistent pain could be significantly improved.

Our focus groups and participatory design sessions made it clear that the use of VR itself may impose limitations that require greater investigation. For example, we found that some patients cannot sit for more than 20 minutes, that others cannot tolerate the weight or pressure of a head-mounted display (HMD) like the Oculus Rift, and that the planned use of a treadmill was too problematic to use in this initial stage. And so the study not only served as a proof-of-concept experiment, but it provided us further insight into how future studies can be better designed to accommodate customized patient needs.

Participants & Procedures

Initially, the study included twenty participants. However, because seven participants refused to fill out the pain assessment forms, their data was excluded. The participants who were included comprised thirteen patients from the Greater Vancouver area, ranging from 35 to 55 years of age (mean = 49, SD = 8.2); each had a diagnosis of chronic pain. Six participants (3 male, 3 female) were randomly assigned to the control group, and the other seven (3 male, 4 female) were assigned to the VR group. The experimenter introduced each participant to the study, and then attached the GSR sensors. Participants in the control group were required to listen to the MBSR training audio track. Participants in the VR group listened to the same MBSR training audio track while immersed in the VMW. Firsthand Technology's DeepStream VR viewer was used. Patients in both groups participated in the MBSR training for twelve minutes.

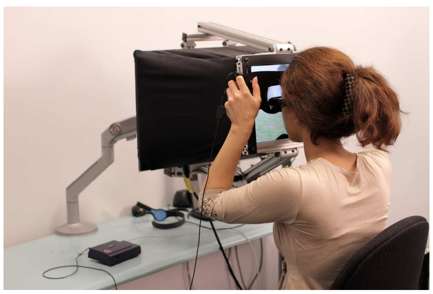

Figure 3. A participant in the VMW study using the DeepStream stereoscopic viewer.

Apparatus

The construction of the physical setup for the VMW required the use of the DeepStream VR viewer, which was installed in a room in a pain clinic for the study. The DeepStream is a stereoscopic VR viewer compatible with PC or Mac computers; it is mounted on a movable arm to ensure flexibility and to maximize patient comfort. The DeepStream rests directly in front of the participant's eyes and does not grip the head, unlike HMDs such as the Oculus Rift, which may cause unnecessary discomfort or pain with this particular participant demographic. The GSR sensors, which are small clips, were gently put onto two of the patient's fingertips; none of the participants reported discomfort from their use.

Instruments

A simple statistical analysis was conducted before and after the study session in order to compare perceived reported pain levels. Study investigators used an 11-point Numerical Rating Scale (NRS) in which patients self-report their pain levels between the numerical values 0 and 10; 10 equates to the worst pain possible and 0 equates to no pain felt. The NRS instrument was chosen because of its simplicity of understanding and ease of use, and because the investigators wanted to avoid distressing the pain patients with complex and lengthy questionnaires. Prior experience taught us that these participants, who may already be feeling some discomfort, end studies prematurely when confronted with the same lengthy questionnaires that they are compelled to fill out for most of their clinical visits.

RESULTS AND ANALYSIS

In this study, time and condition were two independent variables. Time was a within-subjects factor, as every participant was measured before and after their MBSR experience. The study used a between-subjects design; a participant either belonged to the VR group or to the control group. Therefore, a two-way mixed ANOVA was run to analyze the collected data. We found a significant main effect of Time, $F(1, 11) = 10.44$, $p < .01$, $r = .61$. The main effect of Condition was not significant, $F(1, 11) = 1.53$, $p > .05$, $r = .25$. This indicated that when the time at which NRS was measured is ignored, the initial pain level in the VR group was not significantly different than that in the control group. There was a significant Time x Condition interaction (as shown in Figure 4), $F(1, 11) = 8.16$, $p < .05$, $r = .54$, indicating that the changes in the pain level in the VR group were significantly different compared to the change in the control group. Specifically, there was a significant drop in NRS ratings in the VR group, $t(6) = 2.86$, $p < .05$, $r = .57$, but a very weak drop in the control group, $t(5) = 1.24$, $p > .05$, $r = .26$. These findings indicate that the VMW (VR paired with biofeedback for MBSR training) was significantly more effective than MBSR alone at reducing reported pain levels among participants. LS Means test results are shown in Figure 4.

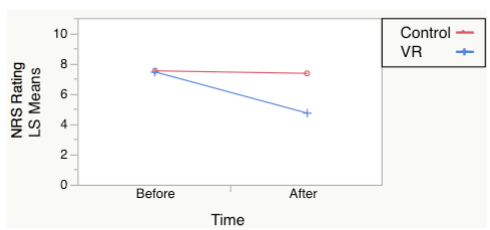

Figure 4. VR and Control Groups NRS Rating LS mean value before and after experiment

DISCUSSION

It is promising to examine the pain reduction reported by participants in the VMW study, as the impact the VR had on chronic pain patients occurred after such a short amount of time. Compared to the control group, the VR group experienced a reduction of pain, on average, equalling 2.6 on the NRS scale. One must also consider that the patients themselves were only immersed in the VR for twelve minutes, which is a short amount of time for an MBSR session. Future studies with longer immersion times and a focus on how long the analgesic effect may linger after the meditative session is the natural next step in continuing this line of inquiry. The introduction of more detailed reporting methods of perceived pain, such as the use of the McGill

Pain Questionnaire, could also yield new insights into the details surrounding perceived reported pain after the VR intervention. This will require greater effort put towards the understanding of pain patient experience within the context of the clinic to ensure their comfort and stamina are not negatively impacted.

Although the single trial outlined does not speak to the effectiveness of potential long-term capabilities for VR chronic pain management, the VMW enables chronic pain patients to consider that their pain experiences could be further managed through MBSR practiced over the long-term. By multiple training sessions and regularized practice, patients can learn to more easily situate the psychophysical mediation of their internal experiences into everyday life. The pain reduction reported by the NRS data is an early step in proving that VR and biofeedback systems may be an effective first step in promoting this behavioural change.

The VMW was designed using a cross-platform game engine that enables researchers or patients to run the VMW on a wide variety of devices, including handheld phones and tablets. These could enable patients to enhance their MBSR skills in a more easily accessible manner outside of clinical settings. This would also allow researchers and health practitioners to extend the use of VR technology from research and clinical settings to patient homes. To achieve this goal, a key approach would be to migrate the current VE to devices patients already own. Smaller, portable stereoscopic viewers could also be used with mobile devices such as Google Cardboard or the FOV2GO, both of which are low-budget stereoscopic viewing devices; this approach is currently being investigated by the study investigators for future work.

CONCLUSION

In this paper, we discussed how a VR intervention, in conjunction with MBSR and biofeedback, was better able to invoke positive results in chronic pain patients, compared to MBSR alone. This approach could be an effective non-pharmacological alternative or supplementary method to existing pain management strategies. By teaching mindfulness meditation to patients in this context, we believe that pain patient health may be improved over time.

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