The Virtual Meditative Walk: An Immersive Virtual Environment for Pain Self-modulation Through Mindfulness-Based Stress Reduction Meditation

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Abstract. One in five people in North America experience chronic pain. The primary non-pharmacological approach to treat chronic pain is to 'manage' pain by practices like Mindfulness-based Stress Reduction (MBSR) Meditation. Previous research shows the potential of mindfulness meditation to help foster patients' emotional wellbeing and pain self-modulation. Thus, the Virtual Reality (VR) system named "Virtual Meditative Walk" (VMW) was developed to help patients direct their attention inward through mindfulness meditation, which incorporates biofeedback sensors, an immersive virtual environment, and stereoscopic sound. It was specifically designed to help patients to learn MBSR meditation by providing real-time feedback, and to provide further training reinforcement. VMW enables patients to manage their chronic pain by providing real-time immersive visual signals and sonic feedback, which are mapped to their physiological biofeedback data. In the proof-of-concept study, this combination of immersive VR and MBSR meditation pain self-modulation technique proved to be effective for managing chronic pain.

Keywords: Virtual reality · Chronic pain · Mindfulness-based stress reduction meditation · Immersive environment

1 Introduction

It is estimated that 20 % of people in North America [1] and 15-20 % in industrialized nations [2] suffer from chronic pain. Defined as pain that lasts more than 6 months and persists beyond the healing of its putative cause, chronic pain usually involves neurobiological, psychological and social dimensions [3]. Chronic pain also lasts much longer than acute pain, and is not be associated with any observable bodily damage and might persist for a lifetime.

Although pharmacological approaches are the most common treatment method, they cannot address all aspects of the condition. Furthermore, analgesics such as opioids can have serious side effects, such as both dependency and addictive tendencies [4, 5]. Hoffman et al. demonstrated that immersive Virtual Reality (VR) is an effective

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way to manage attention in VR as a form of pain distraction for short-term, acute pain [7]. Therefore, VR can be used as a powerful pain control technique to manage and modulate pain [8]. However, it is not yet known if the immersive VR is helpful for managing chronic pain (CP) on a long-term scale.

For managing chronic or long-term pain, one of the standard supplementary or adjuvant approaches is mindfulness-based stress reduction (MBSR). MBSR meditation has been used for a long time to help CP patients to reduce their stress and improve their health via improvements in the maintenance of their psychological states [6], which is particularly important for chronic pain patients as the persistence of pain itself is stress-inducing and is known to have attendant emotional components. Therefore, the MBSR component and biofeedback mechanism were combined and incorporated when developing the virtual environment (VE).

The research described in this paper is our first phase towards studying how effective and efficient the immersive VR MBSR approach may be when combined with biofeedback for CP patients. Our prior research strongly suggested that it was effective in reducing stress among 411 healthy users, particularly among those who had never meditated before [14]. Subsequently, as preparation for building a VE specific to patients' needs and requirements, we studied numerous aspects of CP patients: Quality of Life (QoL), habits using technology, specific/variable problems and sequelae, sonic preferences and sensitivities [14], attitudes toward meditation practices, and what they imagined when they try to meditate or visualize to reduce their pain levels.

2 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 better manage their long-term pain and reduce its intensity.

Medical VR has emerged over the past two decades, including rehabilitation, surgical simulators, and telepresence surgery [10]. Researchers in 2003 [10] designed the Meditation Chamber, an immersive virtual environment to train participants to reduce their stress. Biofeedback sensors were adopted to monitor arousal, and this data in turn affected the VE's visual assets. The results indicated a positive influence of their VE: participants successfully managed their stress levels while observing the VE's continuously changing visual feedback, which was more effective than biofeedback alone in the control group.

VR has also proven to be an effective method to reduce acute pain resulting from wound care in burn patients [12]. Hoffman et al. designed a distraction-based VR study; the results showed up to a 50 % reduction in patients' perceived pain. Several other VR applications not built upon pain distraction were also developed to mitigate pain. Shiri et al. developed a VR system to treat pediatric headaches with biofeedback sensors [12]. In patients who had chronic headaches, galvanic skin response (GSR) levels were obtained over ten sessions, each lasting 30 min. The biofeedback data was then used to affect the environment that the participants were immersed in. After the participants were instructed to perform relaxation techniques (the more they relaxed, the happier their picture appeared in the VE), it was found that patients with migraines experienced a significant decrease in headache pain in the experiment [13].

Prior VR work offers 15 years of compelling evidence that VR is an "effective non-pharmacological analgesic" — for acute pain. Although the mechanism is not well understood, it is believed that VR is an especially strong instantiation of pain distraction because it involves numerous perceptual and motor senses. Though the length of those studies varied, most were 10-20 min in duration. In our earlier studies [10] for chronic pain, however, it was clear that many patients are not able to either sit or stand for more than 20 min. What is important here is that unlike traditional meditation training engaged in by healthy people, these patients' limitations require modification, not in the MBSR training content, but in their configuration via the length of time.

These works indicate that VR has been effective for treating acute pain; however, such VEs present limitations for managing chronic pain. Thus, our research focuses on utilizing immersive VR as an intervention to teach MBSR, a well-established pain management technique, which in turn may enable patients to more easily develop and adhere to an effective long-term pain management tool.

3 Virtual Meditative Walk

3.1 Environment Design

The Virtual Meditative Walk (VMW) incorporates a unique virtual environment with biofeedback for MBSR meditation training, and thereby addresses chronic pain patients' specific needs. The system is designed to directly generate a feedback loop of chronic pain patients' specific embodied conditions, bodily awareness, and potentially the sense of agency that they may develop by better coping with or reducing their persistent pain. We employ VR technologies for pain mitigation and management by controlling changes in 3D visual & sonic elements based on mindfulness-based stress reduction (MBSR) and biofeedback data in real-time to support their learning of mindfulness meditation techniques. 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 VR scene and its path design was showed in Fig. 1 below. Over time, patients learn to use this awareness outside of the VR.

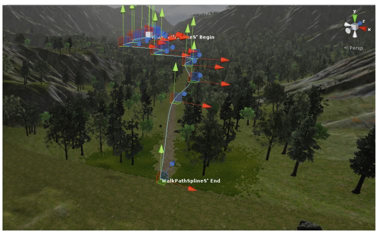

Fig. 1. Path design in VMW virtual environment

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 intentionally control 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 with subtle ambient breezes. The surrounding area is relatively mountainous, reminiscent of the trails found along the northwest coast of North America. The camera slowly moves along a flat, worn dirt pathway, as if the user is walking. The GSR sensors continuously track the patient’s changing arousal levels, and in turn modify the VMW’s atmospheric weather. The light fog in the forest, for example, recedes as a patient’s GSR levels start to stabilize, inferring 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. The two images in Fig. 2 show how the VE changes according to variable changes in the patients’ biofeedback data.

Fig. 2. As patients approach an inferred meditative state, the fog begins to dissipate (top to bottom), and sounds become more audible and spatial.

3.2 Focusing More Attention Inward with Outward VR Changes

During the system design process, we took into consideration patients' proprioceptive and interoceptive senses, which strongly shape human movement, interaction and experience, in order to bring embodied states—and how they are affected or transformed—into conscious awareness by mapping the changes in those embodied states (through biofeedback mechanisms such as galvanic skin response and heart rate variability) onto changes in visual and sonic qualities of VR environment.

It is important to note that pain distraction is NOT an appropriate strategy for long-term pain management; therefore, we developed a very different paradigm. Our new paradigm of "chronic pain self-modulation" builds on techniques known to be effective treatments for CP: MBSR and biofeedback. Pain doctors recommend them for self-managing CP, but they take significant effort to learn and to practice everyday. Our prior studies suggest that VR can help because it gives users immediate and immersive feedback. In this way, users can have a better sense of whether their efforts are actually producing any changes in stress levels.

4 User Proof-of-Concept Study

The study is a proof-of-concept designed to assess whether most CP patients are capable of 12-minute sessions, and if one session has measurable results that are comparable to prior studies with healthy people (i.e., are patients capable of focusing inward, and can they learn to change their GSR?).

4.1 Goals

A study was designed to test the minimal effectiveness of the Virtual Meditative Walk system. In the long term, the system is designed to be used over six sessions, which is an introduction parallel to learning MBSR in more traditional ways, such as FTF group lessons and recorded training sessions. For this VR approach, we wanted to determine if an immersive Virtual Environment, combined with MBSR training and biofeedback, helps pain patients better manage and self-modulate their pain by reducing perceived pain levels among chronic pain patients in the short term, using the minimal possible time period of one session.

4.2 Participants and Procedures

Thirteen patients ranging from 35 to 55 years of age (mean = 49, SD = 8.2) participated in the study in an established pain clinic. Each patient 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. Although 20 participants were originally recruited, 7 of them either chose not to complete the study because of pain, or failed to finish our questionnaires.

As for the patients' type of pain, it is crucial to understand that CP is considered to be a dysfunction of the pain response system. Therefore, categorization is often deemed to be counterproductive, since it draws researchers back into habitual ways of confusing the pain system dysfunction with acute pain; acute pain is the common understanding of pain that results from injury or infection, and functions in the short term as an alert to danger, injury or threat. While subcategories of pain type are used by a subset of health professionals and researchers who focus on CP, they are often categories of neuropathic, nociceptive and idiopathic pain. Also, while patients may cite the source of pain (such as in their lower back, legs, hips, neck, and shoulders), pain can be "referred". Moreover, chronic pain, as a systemic dysfunction, often leads to complex and distributed pain. For our readership, therefore, this complexity is beyond the scope of the paper (or page limits). More importantly, based on our prior publications in ACM fields, stating "which" category almost always derails the point of the research findings because readers return to habitual ways of thinking that CP is "just" acute pain, that it behaves in known ways, and that it can be cured.

4.3 Procedures

During meditation sessions, we monitored GSR levels of patients and used this data to drive the dynamics of the VE in real-time. This real-time biofeedback system allowed patients to become aware of their progress as they performed mindfulness and encouraged them to pursue the practice. During the session, the patient saw a foggy forest, with the fog representing the patient's GSR level. As patients intentionally reduced their stress level inferred from GSR data, the fog faded, and indicating that the patient was approaching or in a meditative state. The fog indicated the cause-and-effect mechanism of biofeedback in the VE. Based on early design tests and on one of our former studies [15], the fog animation was designed with abstraction in mind. The fog aimed to distribute the attention of the user while displaying the changes of GSR in real-time.

The participant was first informed of the whole study and procedures, and then the GSR sensors were attached to two fingers. In the control group, participants listened to the MBSR training audio. In the VR group, participants listened to the same MBSR training audio while immersed in the VMW environment. Both groups were given 12 min for the MBSR training (shown in Fig. 3).

4.4 Apparatus

The construction of the physical setup for the VMW required the use of a stereoscopic VR display. The display is mounted on a movable arm to ensure flexibility and to maximize patient comfort. 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. GSR data was used to control the biofeedback system in VR, but it was not adopted to compare pain levels. The assumption is: to immerse patients in the VE so that their GSR data were not displayed as a 2D graph, but rather had a major influence

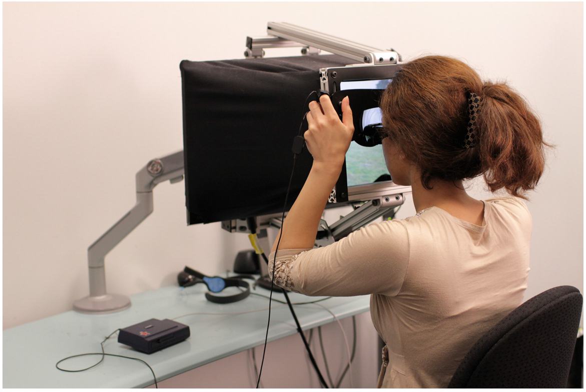

Fig. 3. The participant is learning MBSR in VMW

on the VE that is consistent with VR's immersive capabilities. Consequently, the raw GSR data was not used for comparing two groups.

A pain questionnaire was given to the patients both before and after the study session in order to compare perceived reported pain levels. The 11-point Numerical Rating Scale (NRS) was used as the instrument for patients to self-report their pain levels between the numerical values 0 and 10 (10 means the worst pain possible and 0 means no pain at all). The NRS instrument is standard in pain research in the health domain. For patients, NRS is simple in terms of understanding and ease of use; therefore, it was used to avoid distressing the pain patients with complex and lengthy questionnaires, which are commonly and repeatedly used in pain clinics.

4.5 Results and Analysis

A two-way mixed ANOVA was run to analyze the collected data. Time and condition were two independent variables. Time was the within-subjects factor, and the subjects design was between-subjects design – a participant either belonged to the VR group or to the control group.

We found a significant main effect of Time, $F(1, 11) = 10.44$, $p < .01$. The main effect of Condition was not significant, $F(1, 11) = 1.53$, $p > .05$. This indicated that when the time at which the 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, $F(1, 11) = 8.16$, $p < .05$, 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, $t(6) = 2.86$, $p < .05$, but a very weak drop in the control group, $t(5) = 1.24$, $p > .05$. 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.

4.6 Discussion

In the clinical pain clinic settings, we taught participants to learn a basic level of MSBR in the study with our VR system. We also imported VMW to mobile terminals as a software application for reinforcement for regular practice outside of the clinic, and to capture and track adherence to regular MBSR practice. Therefore, in our next phase, we plan to strengthen patients' self-care and management skills: (1) through VR therapy by providing six VR sessions in the doctors' clinic; and (2) providing mobile APP training so they can keep learning and practicing pain self-management in the same context.

Although the single trial outlined does not speak to the effectiveness of potential long-term capabilities for VR chronic pain self-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, and potentially to afford patients with a greater sense that they are able to self-manage their pain to some degree. This is an important factor since many CP patients report a sense of hopelessness [1].

For the past two decades, research on VR for pain has been focusing on interventions for acute pain. However, our focus is on how to utilize VR as a technology that could also benefit patients who live with long term chronic pain. By implementing an effective non-pharmacological analgesic approach—MBSR meditation—we believe the VR is more suitable for chronic pain patients and that such pain self-modulation may provide a more appropriate approach useful over the long term than short term pain distraction. Our immersive VR project, the Virtual Meditative Walk, and the study results demonstrate its potential positive effect.

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 chronic pain patient experience, studied within the context of the clinic to ensure that patients' comfort and stamina are not negatively impacted by the time and effort that would be required if patients needed to travel elsewhere, such as to a research lab.

5 Conclusion

In this paper, we briefly discussed how an immersive Virtual Environment, the Virtual Meditative Walk, could be designed for chronic pain patients to learn pain self-modulation. By designing a VR system that incorporates biofeedback mechanisms to support learning MSBR meditation, this technological intervention may be an effective and long term non-pharmacological approach, compared to traditional pain management. Further, by teaching MBSR to chronic pain patients in this context, we believe that their pain self-modulation ability can be improved and Potentionally sustained by long-term practice. Moreover, although this VR intervention is designed to address a difficult, complex and long-term condition of chronic pain, it is not limited to chronic pain patients; health practitioners, nurses, and patients suffering from acute pain symptoms can benefit from learning MBSR to foster psychophysiological attentiveness as well as pain, stress and anxiety-modulation capabilities.

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