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Mobile Devices as Adjunctive Pain Management Tools

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Abstract

Approximately 108 million people in North America and Europe suffer from chronic pain. Virtual reality (VR) is a promising method for pain management in a clinical setting due to the distracting properties of an immersive virtual environment. In this study, we demonstrated the potential use of mobile phones as a means of delivering an easily accessible, immersive experience. Thirty-one patients tested VR pain distraction. Objective measurements of heart rate correlated to decreased anxiety, while, subjectively, patients also reported reduced levels of discomfort. The positive results of this study indicate that mobile phones can provide an immersive experience sufficient to deliver pain management distraction. Because mobile devices are widely available, the potential for developing pain management programs that are accessible has become a realistic possibility.

Introduction

THIS PROJECT'S KEY TECHNOLOGY OBJECTIVES are developing virtual reality (VR) mobile phone software for the management of chronic, neuropathic pain, and proving its effectiveness in a study compared to pain focus.

Evidence shows that there is a clear need for adjunctive pain relief. Chronic pain is the most common reason for seeking medical care.[1] Recent studies show prevalence ranging from 13% to 53% in countries throughout the world,[2–5] and reaching up to nearly one-third of the adult population in the United States.[6] Chronic pain rises with age and affects a higher proportion of women than men.[2–4] Although the definition of chronic pain is pain that lasts for 3–4 months, long-term surveys show that 20% to 46% of chronic pain patients have experienced pain for 10 years or more.[3,7] Pain is of moderate to severe intensity for most patients, and other than opioid analgesics, few prescription pain drugs achieve acceptable pain relief in more than 50% of treated patients.[8] Even with the newer drugs, a 50% reduction in pain for 60% of patients is the best outcome achieved to date for patients with certain types of neuropathic pain.[9]

A review of the FDA's 510(k) database for pain relief devices shows only five alternatives to drug therapy: three are transcutaneous electrical nerve stimulator (TENS) devices, one uses infrared therapeutic heating, and another uses neuromodulation (U.S. FDA, 2006). These devices, while effective for various types of pain, are not inexpensive or easily portable. The inclusion of objective physiological measures during VR distraction will help to determine precisely the amount of physical relief being provided by this innovative new modality.

Advantages of using a mobile phone for pain management include:

- The mobile phone is an appliance with which the patient is familiar, thus requiring minimal instruction in its use for a noncall purpose.
- Graphics quality is improving continuously, and the software is completely portable, allowing anytime/anywhere use by the patient.
- No computer is required, because the software purchase is added to the patient's mobile phone bill, and the download to the mobile phone is accomplished via Short Messaging Service (SMS).
- Similarly, software upgrades can be performed automatically.

As more mobile phone subscribers opt for Internet service, new versions of software can be developed that allow patients to transmit real-time physiological data (e.g., heart rate, skin conductance) securely to their physicians while using the software. Along with that software, we can develop and package a set of mini-sensors for patients who wish to chart their physiological progress after using the pain management software over time. Physicians will be able to use these data to support insurance reimbursements based on objective evidence-based patient progress.

Brain imaging shows that being distracted has a real effect in decreasing the intensity of pain signals in the brain, and that VR actually changes how the brain physically registers pain, not just patients' perception of the incoming signals.[10–12]

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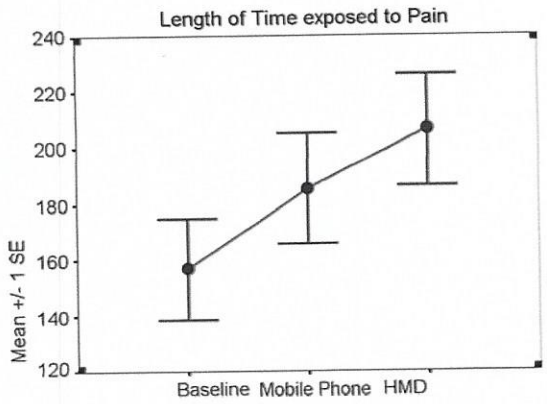

FIG. 1. Time of pain exposure comparison. HMD, head-mounted display.

Research on the effect of VR on pain shows a reduction of 30% in reports of "worst pain" (sensory component of pain), 44% in "time spent thinking about pain" (cognitive), and 45% in "pain unpleasantness" (emotional), as well as significant reductions in pain-related brain activity in all five brain regions of interest: the anterior cingulate cortex, the insula, the thalamus, and the primary and secondary somatosensory cortices.[13]

VR systems are available with 3D images, motion capture, and an 80° field of view. However, most systems today require headgear to stimulate the VR and are therefore found in hospitals or clinics. Since chronic pain can exist for months to years after patients are discharged from the hospital, VR software on a mobile platform can provide easily accessible, transportable pain relief with little equipment required.[14]

The challenge is proving that an easily portable pain management device with a small screen, such as that on a mobile phone, can be effective for pain relief in patients with chronic, neuropathic pain. To be effective, we believe that the virtual environment must be subjectively immersive.[15] Studies to date show that VR is effective at lessening distress, pain, and anxiety in burn wound care, chemotherapy, dental procedures, surgical procedures, phantom limb pain, physical therapy procedures, ulcer care, and venipuncture.[16–23]

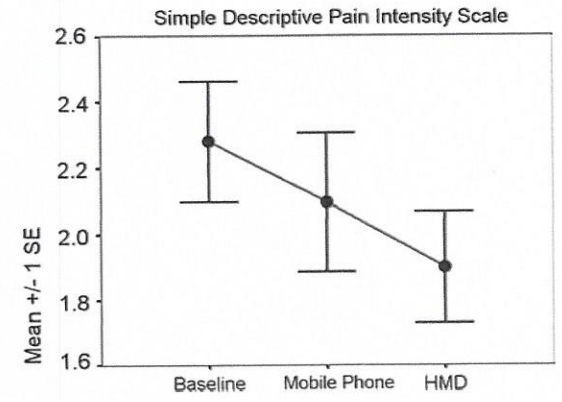

FIG. 2. Compared to baseline, the Simple Descriptive Pain (SDP) intensity scale decreased when patients used the mobile phone (mean score decreased by 0.3). The SDP scale decreased further when patients were using the HMD (mean score decreased by 0.355, $p<0.05$).

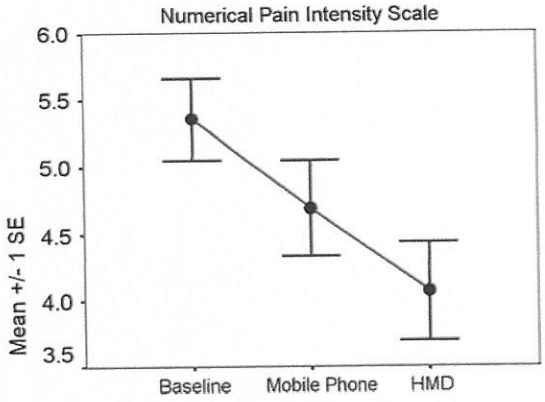

FIG. 3. The numerical pain scale decreased when subjects were using the mobile phone (mean score decreased by 0.66, $p<0.002$), and it further decreased by 0.32 when patients used the HMD.

Use of the mobile phone as a new platform for VR therapy has, however, now become an emerging research design (see Table 1).[24,25]

Methods

Procedure

Efficacy of mobile phone displays to deliver pain distraction VR was tested in comparison to two other methods of simulation delivery—the traditional head-mounted display (HMD), and a standard flat-panel display used as a baseline. Human factors testing was first done with controls, after which the VR was used with clinical chronic pain patients.

Controls

The VR distraction was first tested on a group of 20 participants with low daily pain intensity scores of <4 (0=no pain, 10=worst possible pain) to ensure that the distraction was of sufficient use to increase pain tolerance. In these studies, participants were asked to submerge their hand into a

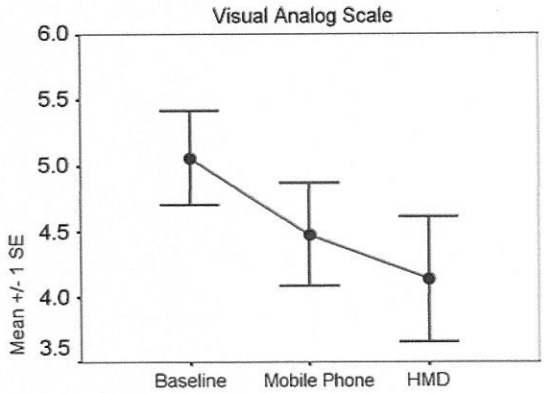

FIG. 4. The Visual Analog Pain Scale decreased when subjects were using the mobile phone pain distraction (mean score decreased by 0.58, $p<0.02$), and it further decreased by 0.445 ($p<0.04$) when the HMD was used.

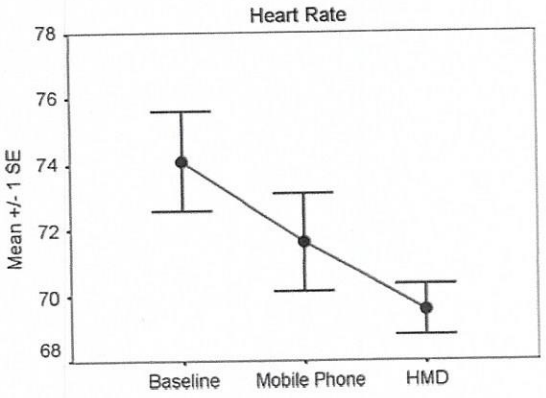

FIG. 5. At baseline, the mean heart rate was 74 beats per minute (bpm). When subjects used the mobile phone pain distraction, the mean heart rate decreased to 72 bpm, and then decreased to 70 bpm when subjects used the HMD.

bath of cold water. We measured the amount of time they were able to keep their hand submerged in the water during baseline, HMD, and mobile device measurements.

Chronic pain participants

Thirty-one patients, aged 18–65 years, with current non-cancer pain for at least 3 months and a daily average pain intensity score of ≥ 4 were exposed to virtual environments in a HMD or mobile device. These two conditions were compared to a baseline pain focus measurement. Data were collected during a 5 minute pain focus session, followed by either a HMD or mobile device VR exposure session of 20 minutes. Half the patients received the HMD exposure, while the other half was exposed to the mobile device first followed by the HMD exposure. During the exposure to the simulation, patients were instructed to interact with the simulation graphics and explore the virtual worlds.

Measures

A pain intensity scale questionnaire was the subjective measurement, which composed of a Simple Descriptive Pain Intensity Scale, Numerical Pain Intensity Scale, and Visual Analog Scale. During the exploration and during baseline, patients' physiological measures, including heart rate, peripheral skin temperature, respiration, and skin conductance, were continuously monitored. A paired t test was used to assess the differences in the pain intensity scale at baseline and during the mobile phone and HMD pain distraction treatments.

Results

Controls

Although VR has been successfully used for pain distraction for the past 15 years, we wanted to test the new mobile platform with controls to assure both safety and effectiveness. We did a number of studies, which included length of time exposed to an inflated blood pressure cuff and exposure to TENS unit (data not shown). In all these studies, the participants were able to withstand a greater degree of discomfort in both the mobile and HMD platforms.

For example, in the cold bath exposure study, at baseline, the mean length of time that participants tolerated the pain stimuli was 156 seconds, while the mobile phone pain distraction increased the mean length of time to 194 seconds, and the HMD condition increased it to 206 seconds (see Fig. 1). This initial study showed that pain distraction using these worlds on a mobile platform was effective. There were no adverse effects from using the simulation in controls. Specifically, there was no cybersickness, and the human factors analysis study revealed that the systems were easily operable.

Chronic pain patients

In this study, we wanted to ensure that patients could express their pain ratings in a reliable manner. Therefore, we used the Simple Descriptive Pain Intensity Scale (see Fig. 2), the Numerical Pain Intensity Scale (see Fig. 3), and the Visual Analog Scale (see Fig. 4). All scales showed a subjective decrease in pain experienced while using both the mobile device and the HMD. While the HMD was more effective in reducing subjective pain ratings, mobile devices also were able to achieve pain reduction effectively. Half the patients experienced the HMD condition first, followed by the mobile device condition. The other half experienced the mobile device first, followed by the HMD. During these studies, patients' physiology was monitored noninvasively. Both HMD and mobile platform conditions were able to reduce the heart rate during exploration of virtual environments (see Fig. 5). The reduction in subjective pain scores correlated well with reduction in heart rate, confirming a less anxious or aroused state. In addition, patients often spontaneously reported feeling more relaxed and less stressed when using the VR.

Discussion

This study demonstrated that significant reductions in pain and anxiety can be achieved using the smaller screen of a mobile device. These results were not as effective as those achieved with the full HMD immersion. From a clinical protocol point of view, it may be useful to use the HMD setting in the clinic or hospital and provide mobile devices that patients can use outside the clinic or at home. To a certain extent, there is probably a learning component that will be necessary when using the mobile device. We are currently conducting studies where we are trying to determine if initial HMD exposure results in more effective pain reduction on mobile devices. Patients who use VR for therapy often demonstrate a positive learning effect over the course of repeated sessions. The advantage of the in-clinic training is that patients are taught to recognize their levels of physiological arousal and are then taught relaxation techniques such as paced breathing and progressive muscle relaxation. We believe that the use of mobile devices should be correlated with physiological intervention to achieve the best results. In addition, the positive correlation between reduction in subjective pain ratings and improvement in physiological measures provides strong evidence that these techniques can be adapted for wider clinical use.

We are exploring the use of other mobile devices such as iPads and iPhones where real-time physiological measures are incorporated into the design of the virtual environments. In this way, the patient's own physiology will influence the visual simulation so that a feedback loop reinforces the pain reduction strategy.

TABLE 1. PUBLISHED STUDIES USING HANDHELD DEVICES IN PAIN MANAGEMENT

Title/Author	*Description*	*Methods*	*Results*
Multi-Modal Distraction. Using Technology to Combat Pain in Young Children with Burn Injuries[26] Miller K, Rodger S, Bucolo S, Greer R, Kimble RM	This easy to use, handheld interactive device uses customized programs designed to inform the child about the procedure he/she is about to experience and to distract the child during dressing changes.	A prospective randomized control trial was completed in a pediatric tertiary hospital, Burns Outpatient Clinic. Eighty participants were recruited and studied over their first three dressing changes. Pain was assessed using validated child report, caregiver report, nursing observation, and physiological measures.	MMD distraction (MMD-D) and MMD procedural preparation (MMD-PP) were both shown to relieve reported pain significantly ($p \leq 0.05$) and reduce the time taken for dressings ($p \leq 0.05$) compared to SD and VG. The positive effects of both MMD-D and MMD-PP were sustained with subsequent dressing changes.
Development and Testing of a Multidimensional iPhone Pain Assessment Application for Adolescents with Cancer[27] Stinson JN, Jibb LA, Nguyen C, Nathan PC, Maloney AM, Dupuis LL, Gerstle JT, Alman B, Hopyan S, Strahlendorf C, Portwine C, Johnston DL, Orr M	Our research group has developed a native iPhone application (app) called Pain Squad to tackle the problem of poorly managed pain in the adolescent with cancer group. The app functions as an electronic pain diary and is unique in its ability to collect data on pain intensity, duration, location, and the impact pain has on an adolescent's life (i.e., relationships, school work, sleep, mood). It also evaluates medications and other physical and psychological pain management strategies used. Users are prompted twice daily at configurable times to complete 20 questions characterizing their pain, and the app transmits results to a database for aggregate reporting through a Web interface.	We used both low and high fidelity qualitative usability testing with qualitative semi-structured, audiotaped interviews and iterative cycles to design and refine the iPhone based Pain Squad app. Qualitative thematic analysis of interviews using constant comparative methodology captured emergent themes related to app usability. Content validity was assessed using question importance rating surveys completed by participants. Compliance and satisfaction data were collected following a 2 week feasibility trial where users were alarmed to record their pain twice daily on the app.	Thematic analysis of usability interviews showed the app to be appealing overall to adolescents. Analyses of both low and high fidelity testing resulted in minor revisions to the app to refine the theme and improve its usability. Adolescents resoundingly endorsed the game-based nature of the app and its virtual reward system. The importance of app pain diary questions was established by content validity analysis. Compliance with the app, assessed during feasibility testing, was high (mean 81%, *SD* 22%), and adolescents from this phase of the study found the app likeable, easy to use, and not bothersome to complete.
Evaluating the Usability of a Virtual Reality-Based Android Application in Managing the Pain Experience of Wheelchair Users[28] Spyridonis F, Gronli TM, Hansen J, Ghinea G	In this paper, we present an Android application (PainDroid) that has been enhanced virtual reality (VR) technology for the purpose of improving the management of pain.		Our evaluation with a group of wheelchair users revealed that PainDroid demonstrated high usability among this population, and is foreseen that it can make an important contribution in research on the assessment and management of pain.
Virtual Reality on Mobile Phones to Reduce Anxiety in Outpatient Surgery[29] Mosso JL, Gorini A, De La Cerda G, Obrador T, Almazan A, Mosso D, Nieto JJ, Riva G	When undergoing ambulatory surgical operations, the majority of patients experience high levels of anxiety. Different experimental studies have shown that distraction techniques are effective in reducing pain and related anxiety. Since VR has been demonstrated as a good distraction technique, it has been repeatedly used in hospital contexts for reducing pain in burn patients, but it has never been used during surgical operations.	With the present randomized controlled study, we intended to verify the effectiveness of VR in reducing anxiety in patients undergoing ambulatory operations under local or regional anesthesia. In particular, we measured the degree to which anxiety associated with surgical intervention was reduced by distracting patients with immersive VR provided through a cell phone connected to a HMD compared to a no-distraction control condition.	A significant reduction of anxiety was obtained after 45 minutes of operation in the VR group but not in the control group, and, after 90 minutes, the reduction was larger in the experimental group than in the control group.

In summary, we first validated the pain reduction techniques in controls and then tested them in patients with chronic pain. The mobile devices were easy to use and were not associated with any adverse effects. There was no cybersickness, and patients with chronic pain enjoyed using the systems and experienced pain relief. Larger-scale studies and longer-term follow-up are needed. These techniques, however, do appear to be both safe and effective when used in a chronic pain population.

Acknowledgments

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Author Disclosure Statement

No competing financial interests exist.

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PAIN CONTROL DURING WOUND CARE FOR COMBAT-RELATED BURN INJURIES USING CUSTOM ARTICULATED ARM MOUNTED VIRTUAL REALITY GOGGLES

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We describe the first two cases where virtual reality was added to usual pain medications to reduce excessive pain during wound care of combat-related burn injuries. Patient 1 was a 22 year old male who suffered 3rd degree burns on 32% of his body, including his right hand, during a roadside bomb terrorist attack in Iraq. The nurse administered wound care to half of the right hand during VR and the other half of the same hand during no VR (treatment order randomized). This patient was the first to use a unique custom articulated robotic-like arm mounted VR goggle system. Three 0-10 graphic rating scale pain scores for each of the two treatment conditions served as the primary dependent variables. The patient reported less pain when distracted with VR. "Time spent thinking about pain" dropped from 100% during no VR to 15% during VR, "pain unpleasantness" ratings dropped from "moderate" (6/10) to "mild" (4/10). Wound care was "no fun at all" (0/10) during no VR but was "pretty fun" (8/10) during VR. However, Patient 1 reported no reduction in worst pain during VR. Patient 2 suffered 2nd and 3rd degree burns when his humvee was hit by a terrorist's rocket propelled grenade in Iraq. During his wound care debridement, "time spent thinking about pain" was 100% (all of the time) with no VR and 0 (none of the time) during VR, "pain unpleasantness" ratings dropped from "severe" (7/10) to "none". Worst pain dropped from "severe" (8/10) to mild pain (2/10). And fun increased from zero with no VR to 10 (extremely fun) during VR. Although preliminary, using a within-subjects experimental design, the present study provided evidence that immersive VR can be an effective adjunctive nonpharmacologic analgesic for reducing cognitive pain, emotional pain and the sensory component of pain of soldiers experiencing severe procedural pain during wound care of a combat-related burn injury.

Introduction.

U.S. soldiers injured in Iraq with significant burns are treated at the U.S. Army Institute of Surgical Research (USAISR) at Brooke Army Medical Center in San Antonio, TX. The mean length of inpatient stay for burn patients at this medical center is approx 25 days. (Kauvar et al.) Recovery often involves extensive outpatient physical therapy rehabilitation. Soldiers often move to San Antonio to continue their outpatient physical therapy for six months, a year or longer. Currently, wounded warfighter inpatients with severe burn wounds may have their bandages removed each day, so the wound can be inspected, cleaned and kept free of infection. Wounded warriors with severe burns remain conscious during daily wound care. Typically, they receive strong short-acting opioid analgesics and anxiolytics about twenty minutes prior to debridement (cleaning of dead skin from their healing burn wound). Despite early, aggressive

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use of opioid analgesics, patients frequently experience severe to excruciating pain during daily burn wound care. (Carrougher et al.) Excessive pain can increase the amount of time it takes caregivers to complete the wound care, and can increase how long the patient remains in the hospital before discharge. Clinical and laboratory studies of civilians have shown large drops in subjective pain during virtual reality, (Hoffman et al., 2008 & Hoffman, 2004) and fMRI results with healthy volunteers show reductions in pain-related brain activity during VR analgesia. (Hoffman et al., 2004) If VR reduces procedural pain in patients with combat-related injuries, this would be a valuable advance in combat casualty care with potential widespread military applications in the future. The two patients in this case report are the first to quantify whether VR distraction can reduce high levels of subjective pain reports in soldiers with combat-related burn injuries undergoing wound care and dressing change. Both patients used a unique articulated robotic-like arm that allowed the VR goggles to be placed near the patient weightlessly, eliminating the need for the patient to put on a VR helmet and reducing the amount of surface contact needed with the patient (see Figure 1A and 1B).

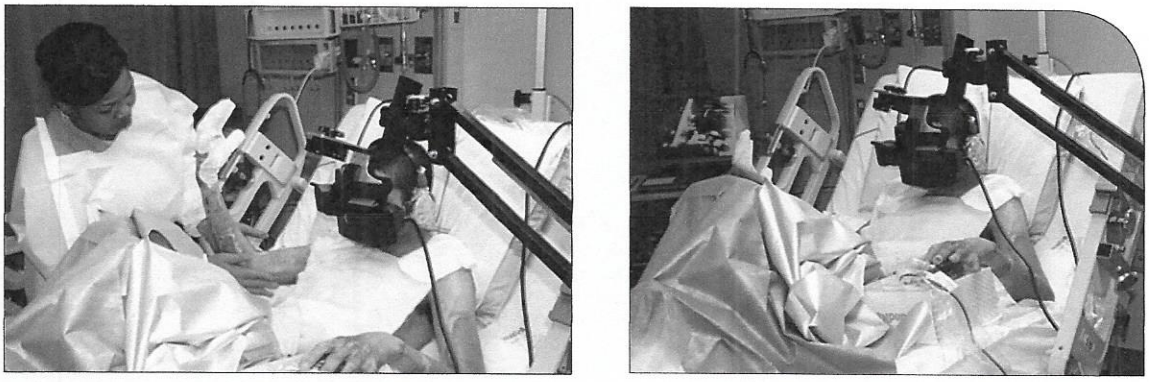


FIGURE 1A AND 1B. U.S. Army soldier receiving immersive Virtual Reality to reduce his pain during severe burn wound care, using our unique articulated arm mounted VR goggles designed by Hoffman and Magula, that hold the displays near the patient's eyes. Photos and copyrights Hunter Hoffman, U.W.

SUBJECT

Patient 1 was a U.S. Army soldier medically evacuated from Iraq to USAISR after suffering severe burns covering 32% of his body approximately 45 days prior to this intervention. While a passenger in a vehicle that was attacked by an improvised explosive device (roadside bomb), he experienced full thickness burns on his hands, arms, anterior and posterior chest and distal thighs. In the following weeks, donor skin was harvested from unburned portions of his body and transplanted as skin grafts to many of his severe burn wounds. In keeping with the standard practice, continuous wound care and frequent dressing changes were required to optimize the healing process.

A 10 minute segment of wound care to the patient's right hand, identified from previous days' procedures as being

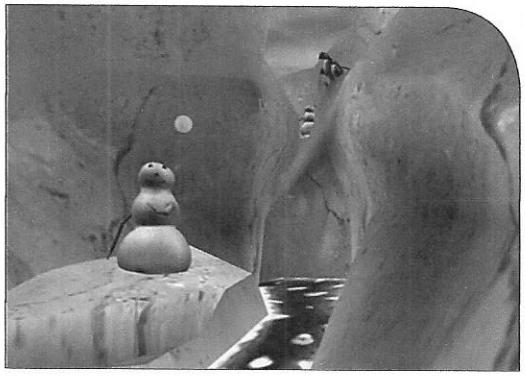
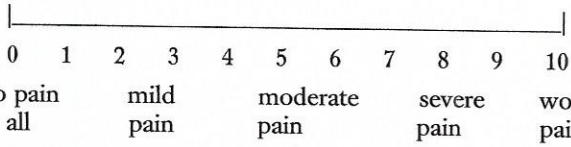


FIGURE 2. A snapshot of SnowWorld (the virtual world burn patients interact with during wound care). Image by worldbuilder Ari Hollander, www.imprintit.com, copyright Hunter Hoffman, UW., www.vrpain.com.

excessively painful, was divided into two equivalent five minute wound care segments. Pre-medication with two percocet tablets by mouth approximately 20 minutes prior to wound care served as the opioid analgesic for this session. During one of the five-minute sessions he received no VR distraction (i.e., standard pre-medication only). During the other five-minute treatment session, the participant looked into the articulated arm mounted VR goggles and underwent wound care while experiencing immersive, interactive VR (randomized to receive VR first or second).

During two brief pauses in the wound care procedure (once after each five minute wound care period), the patient completed three subjective pain ratings using Graphic Rating Scales (GRS) labeled 0 – 10 with respect to the preceding 5 minutes of wound care. "Please indicate how you felt during the past five minute session by rating your response on the following scales." Each question was accompanied by a pictorial example of the labeled graphic rating scale such as the "worst pain" rating shown below.

How much TIME did you spend thinking about your pain during the past five minutes? I thought about my pain during Virtual Reality 0 = none of the time, 1-4 = some of the time, 5 = half of the time, 6-9 = most of the time, and 10 = all of the time. How UNPLEASANT was you pain during the Virtual Reality (a similar 10-cm line with numeric and word descriptors beneath it: 0 = not unpleasant at all, 1-4 = mildly unpleasant, 5-6 = moderately unpleasant, 7-9 = severely unpleasant, and 10 = excruciatingly unpleasant)? Rate your WORST PAIN during the past 5 minutes.



How much FUN did you have during Virtual Reality (10-cm line with numeric and verbal descriptors: 0 = no fun at all, 1-4 = mildly fun, 5-6 = moderately fun, 7-9 = pretty fun, 10 = extremely fun)? To what extent (if at all) did you feel NAUSEA for any reason during Virtual Reality (10-cm line with numeric and verbal descriptors: 0 = no nausea at all, 1-4 = mild nausea, 5-6 = moderate nausea, 7-9 = severe nausea, and 10 = vomit)? While experiencing the virtual world, to what extent did you feel like you WENT INSIDE the computer-generated world (10-cm line with numeric and verbal descriptors: 0 = I did not feel like I went inside at all, 1-4 = mild sense of going inside, 5-6 = moderate sense of going inside, 7-9 = strong sense of going inside, 10 = I went completely inside the virtual world)? After wound care with no VR, each patient was asked the same questions but "during Virtual Reality" was replaced by "without Virtual Reality". After-wound care with no VR, patients were not asked the question about presence.

Such pain rating scales have been shown to be valid through their strong associations with other measures of pain intensity, as well as through their ability to detect treatment effects. (Jensen, 2003 & Jensen et al., 2001) The specific measures used in the current study were designed to assess the cognitive component of pain (amount of time spent thinking about pain), the affective component of pain (unpleasantness), and the sensory component of pain (worst pain). Affective and sensory pain are two separately measurable and sometimes differentially influenced components of the pain experience. (Gracely et al., 1978) Gracely et al., have shown ratio scale measures such as the labeled Graphic Rating Scales used in this study to be highly reliable. In addition, a GRS rating of 'fun' during wound care was measured. (Hoffmann et al., 2008)

Patient 2, a 21-year-old male, was injured when his humvee was hit by a terrorist's rocket propelled grenade in Iraq. The explosion caused 2nd and 3rd degree burns on 15% of his body: lower back, flank, buttox, bilateral hands, bilateral upper arms. A 12-minute segment of wound care to the patient's left and right arms identified from previous days'

procedures as being excessively painful was divided into two equivalent six-minute wound care segments. Pre-medication with one fentanyl lollypop (400 mic) and two percocet tablets by mouth approximately 20 minutes prior to wound care served as the opioid analgesic for this session. During one of the six-minute wound care sessions he received no VR distraction (i.e., standard pre-medication pharmacologies only). During the other six minute wound care session the participant looked into the articulated arm mounted VR goggles and underwent wound care while experiencing immersive, interactive VR (randomized to receive VR first or second). During two brief pauses in the wound care procedure (once after each six minute wound care period), the patient completed three subjective pain ratings using Graphic Rating Scales (GRS) labeled 0 – 10 with respect to the preceding 6 minutes of wound care, using the same measures described above for patient 1.

For both patients, the VR system consisted of a Voodoo Envy laptop with NVIDIA GForce Go 7900 GTX (512 MB) video card; Intel Core 2 Duo (T7400) CPU @ 2.16 GHz, 2 GB RAM @ 994 MHz. While in High Tech VR, each subject followed a pre-determined path, "gliding" through an icy 3-D virtual canyon (Figure 2). He 'looked' around the virtual environment and aimed via a mouse. He pushed a mouse trigger button to shoot virtual snowballs at virtual snowmen, igloos, and penguins (see www.vrpain.com). Each subject saw the sky when he looked up, a canyon wall when he looked to the left or right, a flowing river when he looked down, and heard sound effects (e.g., a splash when a snowball hit the river) mixed with background music by recording artist Paul Simon. Participants looked into a pair of Rockwell Collins SR-80 VR goggles (see www.imprintit.com) with a custom made neoprene blinder on top and sides, which largely blocked his view of the real world. These VR goggles afforded approximately 80° diagonal field of view for each of the rectangular eyepieces with 100% overlap between the right and left eye images. The goggles were held in place near the patient's eyes by a custom made articulated arm mounting system.

Results

As shown in Figure 3 below, Patient 1 reported less pain when distracted with VR (e.g., "time spent thinking about pain" dropped from "all the time" during no VR to "some of the time" 1.5 (15%) during VR, "pain unpleasantness"

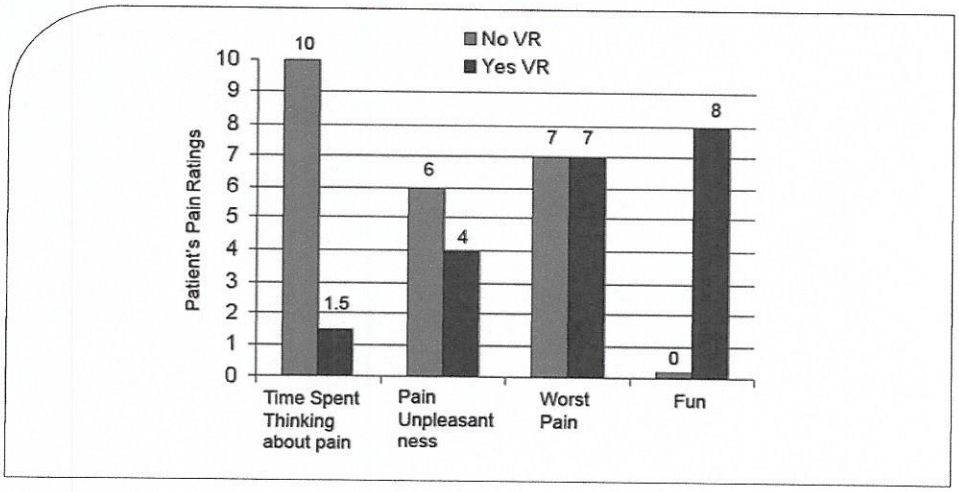


Figure 3. Patient 1 reported large reductions in amount of time thinking about pain during VR (shown in blue) compared to no VR (shown in red) during severe burn wound care of burn injury resulting from an Improvised Explosive Device (roadside bomb) attack/explosion.

ratings dropped from "moderate" (6/10) to "mild" (4/10). VR did not reduce Worst pain (0% drop) in Patient 1. Wound care during VR was "pretty fun" (8/10) vs. "no fun at all" (0/10) during no VR and the patient reported having a "moderate sense of going inside the computer-generated world" (6/10).

As shown in Figure 4 below, Patient 2 reported that during his wound care debridement, Time spent thinking about pain was 100% with no VR and 0 with VR, "pain unpleasantness" ratings dropped from "severe" (7/10) with no VR to "none" during VR. Worst pain dropped from "severe" (8/10) with no VR to mild pain (2/10) during VR. And fun increased from zero with no VR to 10 during VR. Patient 2 reported having "a strong sense of going inside the computer-generated world" (8/10). Both patients and their wound care nurses noted that they would prefer VR be available for subsequent dressing changes as they found it to be helpful as an adjunctive modality for pain control. Patient 2 was very determined to continue playing SnowWorld as long as possible. And the wound care nurse of patient 1 spontaneously remarked she was pleasantly surprised to see that when in VR, the patient was not pulling his hand away from her as she worked on his hand, a "protective" behavior he consistently exhibited during daily wound care of his hand with No VR.

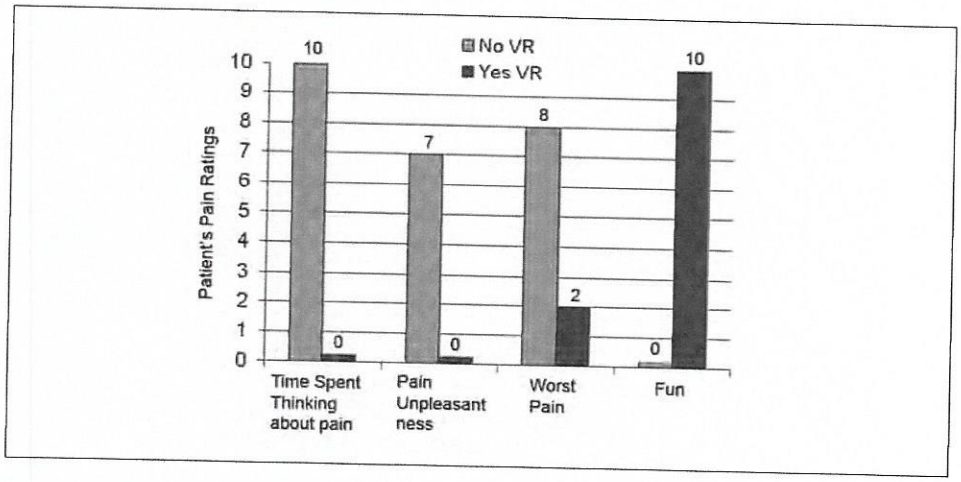


FIGURE 4. Patient 2 reported large reductions in pain during VR (shown in blue) compared to no VR (shown in red) during burn wound care of a severe burn injury resulting from a rocket-propelled grenade attack/explosion.

DISCUSSION

The results of these two case studies demonstrate that immersive VR reduced the reported amount of time patients with a combat-related burn injury spent thinking about their pain and VR reduced pain unpleasantness. VR did not reduce patient one's worst pain rating during his burn wound care. But VR did reduce patient two's worst pain from severe (a rating of 8) down to mild (a rating of 2). Although case studies are scientifically inconclusive and controlled studies are needed, these results provide the first available evidence that VR can reduce severe acute pain during medical procedures (wound care and dressing changes) in patients with combat-related burn injuries. Because excessive acute pain during medical procedures for combat-related injuries remains a widespread medical problem, and our preliminary results support the notion that VR might prove valuable for pain control in combat trauma patients, additional research on this modality with this patient population is warranted.

Acknowledgments:

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Clinical Use of Virtual Reality Distraction System to Reduce Anxiety and Pain in Dental Procedures

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Abstract

Virtual reality (VR) has been used by clinicians to manage pain in clinical populations. This study examines the use of VR as a form of distraction for dental patients using both subjective and objective measures to determine how a VR system affects patients' reported anxiety level, pain level, and physiological factors. As predicted, results of self-evaluation questionnaires showed that patients experienced less anxiety and pain after undergoing VR treatment. Physiological data reported similar trends in decreased anxiety. Overall, the favorable subjective and objective responses suggest that VR distraction systems can reduce discomfort and pain for patients with mild to moderate fear and anxiety.

Introduction

ONE OF THE MOST CHALLENGING ASPECTS of dental care that medical practitioners face today is the treatment of patient pain.[1] Despite advances in dental technologies and treatment, many people still avoid or delay dental care because of the fear and anxiety of pain.[2] Analgesics have been the mainstream solution for alleviating pain in the past. However, medications are often not effective. More recently, advanced technologies have integrated both the knowledge of the mechanisms of pain medications and techniques in behavioral medicine. These advances have moved toward using distraction and hypnosis techniques to treat pain.[3]

Pain perception has a strong psychological component. In order to experience pain, conscious attention is required.[2] Distraction has been found to take a patient's attention away from pain. Attention given to pain often determines not only the level of pain being reported, but also the distress levels. By encouraging a patient to focus his/her attention on other thoughts, less attention is available for the pain.[4,5] Virtual reality (VR) utilizes advanced technologies to create virtual environments (VE) that allow patients to be immersed in an interactive, simulated world.[6] These advanced systems interact at many levels with the VE, stimulating sights, sounds, and motion to encourage immersion in the virtual world to enhance distraction from pain.[7]

Other studies have also shown that involving the patient in a VE reduced their reported levels of pain during medical procedures such as chemotherapy, physical therapy, burn wound changes, and surgery (see Table 1).[8–11] In one study where children either played video games or navigated through a VE while receiving wound care for their burns, exposure to VR lessened their reported pain ratings as compared with playing video games.[12] In another controlled study, adult burn patients undergoing physical therapy reported less pain while involved in VR than those that only participated in standard physical therapy.[13] Evidence shows that VR is effective in reducing pain in children with cancer, as chemotherapy-related symptom distress was reduced significantly immediately after using VR during treatment.[14] Specifically for dental work, another clinical study observed that dental patients undergoing plaque removal below their gum line experienced considerable reduction in pain when using VR compared to participants that watched a movie and to participants that did not have any type of distraction.[15]

Research involving the concept of distraction has shown that techniques used in the past such as concentrating on deep breathing or watching a movie are less effective than using VR. This study examines the efficacy of using VR to control dental pain using both patient reported surveys and physiological measurements to evaluate fear and pain before and after dental treatment. Dental fear has been measured with questionnaires such as the Dental Anxiety Scale and Dental Fear Survey, as well as the Dental Fear Interview. While there are numerous self-report instruments that measure various aspects of the sensory, affective, and evaluative components of pain, only a few tools have been developed that directly assess fear and anxiety associated with pain. This study will integrate both subjective and objective variables to determine a more effective way of measuring and reducing both pain and distress.

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FIG. 1. Patient in treatment room.

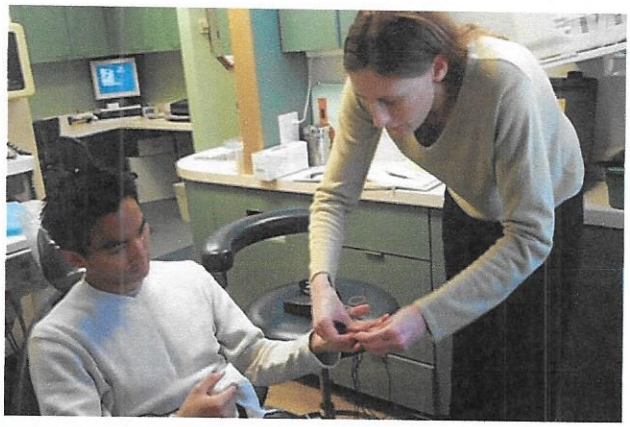

FIG. 3. Measurement without the virtual reality (VR) distraction system.

Methods

Setting and patients

We recruited five adult patients for the study on a voluntary basis as they came for their dental treatments at the Scripps Center for Dental Care in La Jolla, CA (Dr. John F. Weston, D.D.S.) (see Fig. 1).

Outcome measures

Patients first completed the Dental Anxiety Scale and Amount of Fear Scale. The Dental Anxiety Scale is a 4-item questionnaire that asks about fear of dental treatment. The Amount of Fear Scale is a 45-item, Likert-type (1–5 scale) verbal report instrument used to assess dental fear. The survey provides a total dental fear score.

A post-experience questionnaire was created by the investigators to assess patient treatment preference and effects of the VR distraction system. This questionnaire includes the presence questionnaire (from Usoh et al. "Using Presence Questionnaires in Reality," Witmer & Singer, Vs. 3.0), and STAIP-AD Test form Y (from Consulting Psychologists Press).

The Procomp+ biofeedback device by Thought Technology was used to assess physiological measures. This device is an advanced biofeedback and psychophysiological data acquisition system. It measures electromyogram (EMG), temperature, galvanic skin response (GSH), electroencephalogram (EEG), heart rate variability, heart rate, and respiration rate (see Fig. 2).

Procedures

Before we began treatment, the patients completed the questionnaires. We also recorded demographic information, the date of last treatment, and the details about the dental procedure. We attached seven sensors to the patients' fingers, abdomens, and arms to gather physiological information. The clinician performed the dental treatment without the use of the VR distraction system for 5 minutes (see Figs. 3 and 4) and then performed it with use of the VR distraction system for 5 minutes (see Fig. 5).

The VEs included relaxing nature worlds where the patients could navigate through beaches, forest, mountains, and other pleasant areas. The patients self-navigated to provide a further sense of control.

Results

Standardized questionnaires

Scores for the pre/post questionnaires, including their subscales, are shown in Table 2.

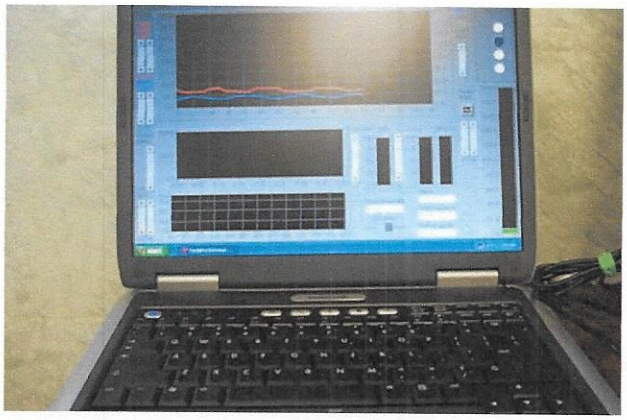

FIG. 2. Psychophysiological monitoring and biofeedback equipment.

FIG. 4. Biofeedback sensors and wireless trackball.

TABLE 1. PREVIOUS RESEARCH OF VIRTUAL REALITY (VR) DISTRACTION FOR DENTAL PROCEDURES

Title	*Method*	*Results*
Improving Dental Experiences Using Virtual Reality Distractions: A Simulations Study[16]	Participants ($n=69$) were randomly assigned to one of three VR conditions: active, passive, or control. Each participant was labeled as high or low dentally anxious prior to dental treatment with the VR application.	VR distraction affected on concurrent experiences, such as perceived control, as well as memories after the dental experience had ended. Participants with higher anxiety experienced greater reduction in memory vividness.
The Impact of Virtual Reality Distraction on Pain and Anxiety during Dental Treatment in 4–6 Year Old Children: A Randomized Controlled Clinical Trial[17]	120 healthy children aged 4–6 years with no previous anxiety disorder were randomly divided into two even groups. The study consisted of three consecutive treatment sessions. The first visit consisted of fluoride therapy. In the next sessions, the groups received restorative treatment with and without VR eyeglasses in a randomized single blind controlled crossover fashion. Then at the end of each session, the subjects' pain severity was assessed using Wong Baker FACES Pain Rating Scale, and state anxiety was measured by Faces version of the Modified Child Dental Anxiety Scale [MCDAS (f)].	There was a significant decrease in pain perception ($p<0.001$) and state anxiety scores ($p<0.001$) with the use of VR eyeglasses during dental treatment.
Virtual Reality Distraction for Pain Control During Periodontal Scaling and Root Planing Procedures[18]	The authors recruited 38 patients. They used a within-patient/split-mouth design. Patients received scaling and root planing procedures (SRP) under three treatment conditions in three quadrants. The three conditions were control, watching a movie, and VR. After each SRP procedure, patients responded to questions about their discomfort and/or pain by using a visual analog scale (VAS) (range = 0 to 10 in which lower numbers indicate less pain or discomfort). The authors also recorded patients' blood pressure (BP) and pulse rate (PR). Patients were asked which of the three treatment modalities they preferred.	The mean ($\pm$ standard deviation) VAS scores for five questions pertaining to control, movie, and VR were 3.95 ± 2.1, 2.57 ± 1.8, and 1.76 ± 1.4 respectively. Paired t tests revealed that VAS scores were significantly lower during VR compared with the movie ($p<0.001$) and control ($p<0.001$) conditions. Similarly, BP and PR were lowest during VR, followed by the movie and control conditions. Patients reported that they preferred the VR condition.
The Effect of Virtual Reality During Dental Treatment on Child Anxiety and Behavior[19]	The behavior, anxiety, and heart rate of 26 children aged 5–7 years were evaluated for the first 5 minutes of two restorative treatment visits. Thirteen children viewed VR at their first restorative visit and not the second, and 13 children viewed VR at the second restorative visit and not the first. Before and immediately following the restorative visits, each child was instructed to draw a human figure. The restorative appointments were video recorded and heart rate monitored. The Koppitz method of evaluating drawings was used to measure anxiety. The Frankl behavior rating scale was used to evaluate behavior.	Differences (ANOVA) in behavior ($p \leq 0.50$) and anxiety ($p \leq 0.65$) were not significant. The overall pulse rate was significantly lower (ANOVA; $p \leq 0.001$) when the child was wearing glasses and viewing VR.
The Effectiveness of Virtual Reality for Dental Pain Control: A Case Study[15]	Two patients (aged 51 and 56 years old) with adult periodontitis—a chronic, progressive inflammatory disease that affects gums, ligaments, and bones around the teeth—were studied in the treatment room of a periodontist. Each patient received periodontal scaling and root planing (scraping off/removing plaque deposits below the gum line, hereafter referred to as scaling) under three treatment conditions: (1) VR distraction, (2) movie distraction, and (3) a no-distraction control condition. Condition order was randomized and counterbalanced. For each of the three treatment conditions, five visual analog pain scores for each treatment condition served as the dependent variables. On 0–10 labeled scales, both patients provided sensory and affective pain ratings, and subjective estimates of time spent thinking about his pain during the procedure.	For patient 1, mean pain ratings were in the severe range while watching a movie (7.2) or no distraction (7.2), but in the mild pain range (1.2) during the VR condition. Patient 2 reported mild to moderate pain with no distraction ($M=4.4$), mild pain while watching the movie ($M=3.3$), and essentially no pain while in VR ($M=0.6$) during his periodontal scaling.

TABLE 2. PATIENT SCORES BETWEEN PRE- AND POST- QUESTIONNAIRE

Pre questionnaire				
Patient	*Amount of fear*	*Self-Eval1*	*Self-Eval2*	*Absorption*
P1	83	39	10	16
P2	113	22	27	16
P3	136	25	16	18
P4	144	30	19	12
P5	111	21	17	16
Mean	117.4	27.4	17.8	15.6
Post questionnaire				
Patient	*Post_Exp*	*Self-Eval1*	*Self-Eval2*	*Presence*
P1	37.5	40	9	166
P2	55	23	29	127
P3	40	31	11	179
P4	56	31	17	136
P5	45	17	25	138
Mean	46.7	28.4	18.2	149.2
Difference in scores between pre and post questionnaires				
Patient		*Part I*	*Part II*	
P1		1	−1	
P2		1	2	
P3		6	−5	
P4		1	−2	
P5		−4	8	
Mean		1	0.4 (−1.5)*	

*0.4 for all patients; −1.5 for patients 1–4.

We evaluated the differences between pre/post self-evaluation scores (post−pre score=changes) with the *t* test (see Table 3).

For part I of the self-evaluation questionnaire (Ho:u=0, Ha:u<0), the *p* value is 0.56. This is strong evidence to support that the true mean of the change is >0, that is, treatment increased the scores for patients. Data from part II has a *p* value of 0.1875 (except patient 5 data; it is obvious that the value 8 is an outlier), supporting that using the VR distraction system decreased the anxiety for patients.

Physiology

We analyzed physiological measures (such as the heart rate and respiration rate) along with order and condition (after use of the VR distraction system and after nonuse of the system). In these analyses, several significant effects were shown (see Figs. 6 and 7; Tables 4–6).

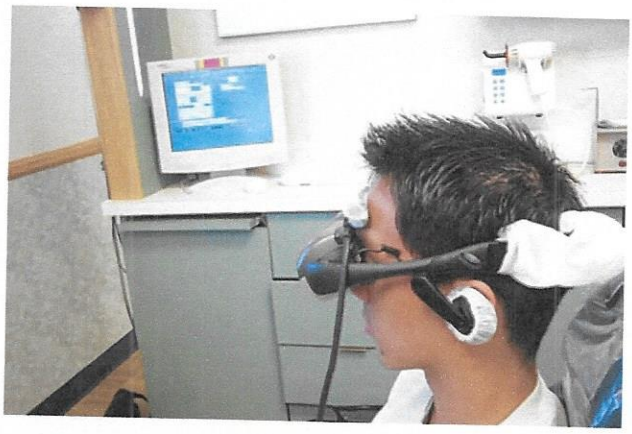

FIG. 5. Measurement with VR distraction system.

Within the EKG data, LFN increased an average of 14.968 for four of the five patients after VR distraction. The average increase of the LF frequency band most likely indicates effectiveness of the VR distraction in reducing anxiety.

HRV is characterized by three main components: the high frequency (HF) component (0.15–0.40 Hz) measures the influence of the vagus nerve in modulating the sinoatrial node. The low frequency (LF) component (0.04–0.15 Hz) provides an index of sympathetic effects on the heart, particularly when measured in normalized units. The very low frequency (VLF) component (0.003–0.04 HZ) reflects the influence of several factors on the heart, including chemoreceptors, thermoreceptors, the renin-angiotensin system, and other nonregular factors. Almost all of the variability from a short-term spectral analysis of HRV is captured in these three components. An example of one of the patient's EKG data is shown in Figure 8 to visualize the comparative features.

Discussion

An inexpensive, commercially available VE could have a significant impact in reducing perceived pain involved in a variety of medical procedures.

The physiological results of this research suggest that the use of the VR distraction system may be a beneficial option for patients with mild to moderate fear and anxiety associated with dental treatments. This system may be a useful adjunct in dental offices to help reduce anxiety, discomfort, boredom, and the time required to perform routine dental procedures. It allows them to relax by allowing them to navigate to another location while still physically remaining in the dental office.

TABLE 3. STATISTICAL ANALYSIS OF PRE AND POST QUESTIONNAIRES

	Mean	*Standard deviation*	n	*Standard error*	*Reference*	t *Value*	df	p
Pre questionnaire	1.000000	3.535534	5	1.581139	0.00	0.632456	4	0.280719
Post questionnaire	0.400000	4.929503	5	2.204541	0.00	0.181444	4	0.864843
Post questionnaire (without patient 5)	−1.500000	2.886751	4	1.443376	0.00	−1.03923	3	0.187548

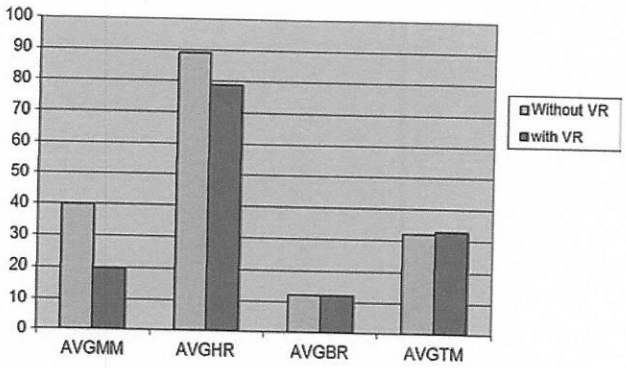

FIG. 6. Results show a trend of factors related to fear and anxiety reduction with VR distraction.

TABLE 4. STATISTICAL VARIABLE DEFINITIONS AND ABBREVIATIONS

SDNN	Standard deviation on the NN intervals (NN = normalized R to R = normalized IBI)
VLF	Power in the VLF bandwidth (0.0033–0.04 Hz)
LFN	Power in the LF bandwidth (0.04–0.15 Hz), in normalized unit
HFN	Power in the HF bandwidth (0.15–0.4 Hz), in normalized unit
LF/HF	Ratio LF/HF
Total Power	Total power in the 0.0033–0.4 Hz bandwidth
AvgMM	Average HR Max–HR Min value
AvgHR	Average heart rate
AvgBR	Average respiration (breathing) rate
AvgTM	Average temperature

Additional research exploring the mechanism by which VR distraction is achieved will be needed. There is much room for improving "presence and realism" in future VR applications specifically designed for treating pain. New virtual worlds, custom built to be more immersive, could produce even larger reductions in pain. Such new worlds can take advantage of the versatility of VR software. On a clinical level, several observations were noted by the clinical staff and from the survey results to improve on existing problems with the design of the study (see Table 7).

The cost of an immersive VR system has dropped dramatically since the mid-1990s, and additional price reductions are inevitable. At the same time, the quality and portability of VR has increased dramatically, benefiting from the enormous improvements in more conventional computer technology (e.g., cheaper memory, cheap and fast graphics accelerators, higher information processing capabilities of the hardware, and a dramatic maturation in the quality of VR world building software commercially available).

To summarize, the present study provides encouraging initial support for the use of VR as a technique for controlling fear and anxiety during dental procedures. Additional empirical research will be needed to determine whether VR can become a viable form of fear and anxiety control during dental treatments. Techniques that prove effective for treating dental pain will likely prove effective for other painful procedures.

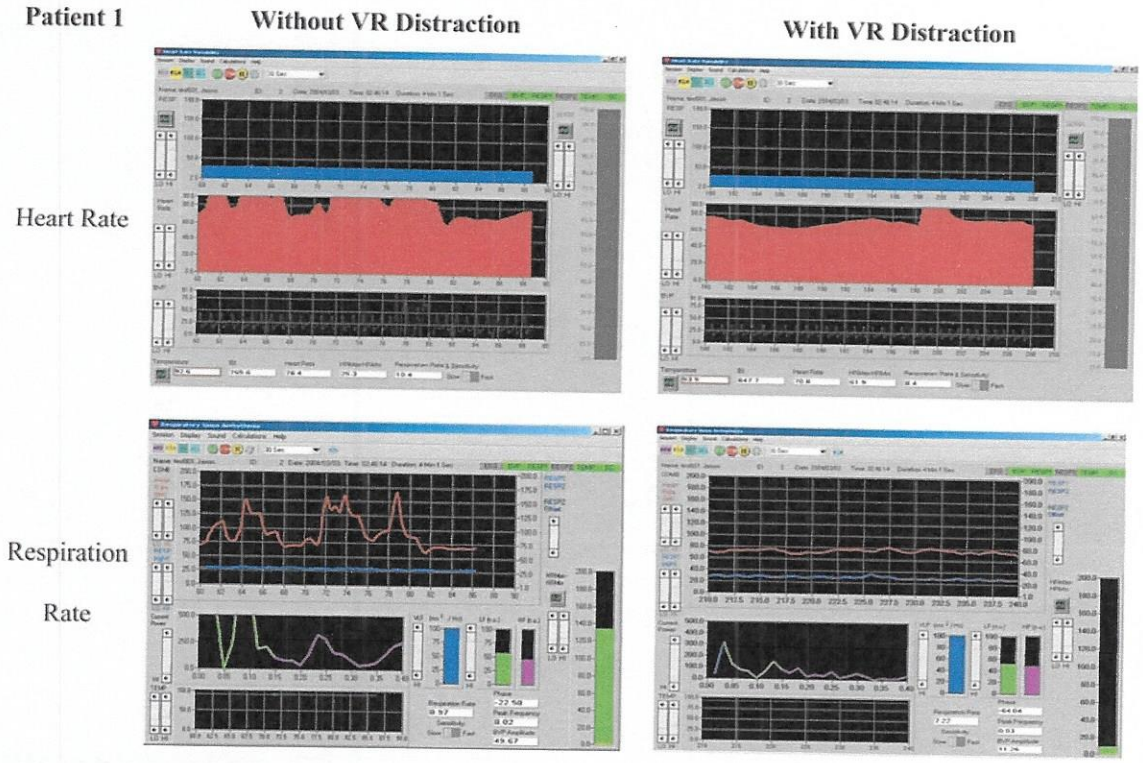

FIG. 7. Evaluation outcome chart (heart rate, respiration rate) example.

TABLE 5. EKG STATISTICAL DATA WITHOUT VR DISTRACTION

	SDNN	*VLF*	*LFN*	*HFN*	*LF/HF*	*POWER*
Patient 1	322.91	12,726.91	56.46	43.54	1.3	32,431.2
Patient 2	119.85	905.51	36.18	63.82	0.57	3,069.24
Patient 3	194.59	1,514.26	49.41	50.59	0.98	6,206.21
Patient 4	149	508.68	33.17	66.83	0.5	1,885.13
Patient 5	116.04	1,613.61	44.59	55.41	0.8	5,730.46
Mean	180.478	3,453.794	43.962	56.038	0.83	9,864.448

TABLE 6. EKG STATISTICAL DATA WITH VR DISTRACTION

	SDNN	*VLF*	*LFN*	*HFN*	*LF/HF*	*POWER*
Patient 1	350.46	7,080.83	54.97	45.03	1.22	34,153.53
Patient 2	54.07	385.69	73.41	26.59	2.76	947.02
Patient 3	71.6	394.2	59.78	40.22	1.49	1,518.05
Patient 4	116.61	2,095.33	60.1	39.9	1.51	2,525.88
Patient 5	81.59	739.1	46.39	53.61	0.87	1,166.04
Mean	134.866	2,139.03	58.93	41.07	1.57	8,062.104

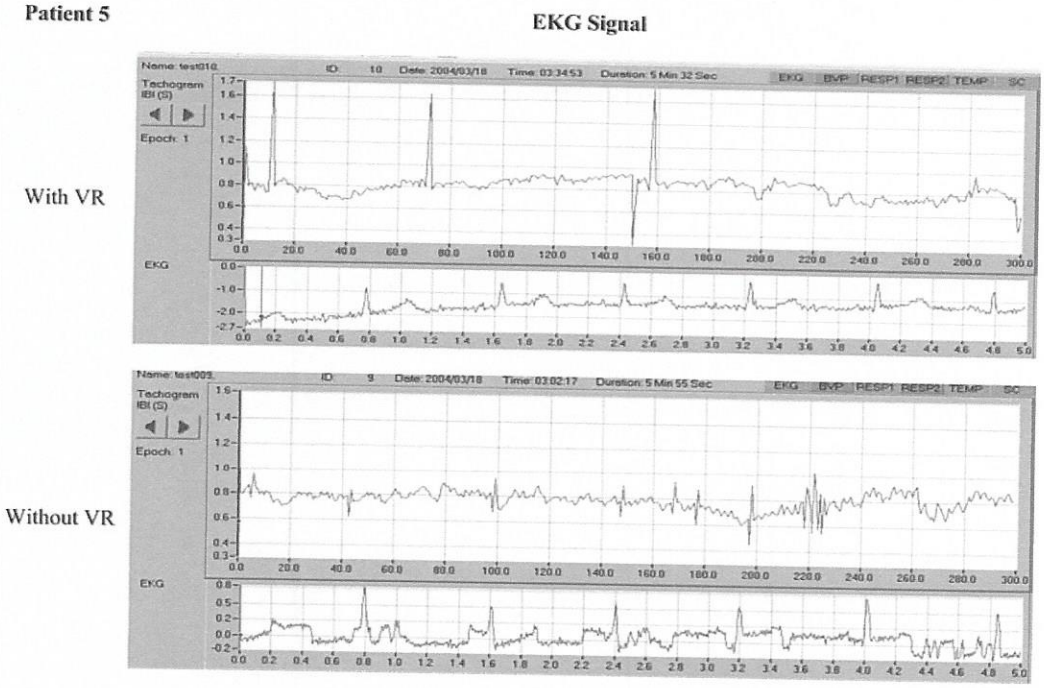

FIG. 8. EKG of patient 5 with and without VR distraction.

TABLE 7. OBSERVED AND REPORTED CLINICAL IMPROVEMENTS

1	Set up virtual equipment in a spacious area to allow room to operate freely
2	Ensure the patient is familiarized with the virtual environment (VE) before beginning operations
3	Head-mounted display size and compatibility are essential for a smooth operation, as it may be difficult to adjust mid-operation
4	Offer a wide range of VE to accommodate the varying tastes of patients
5	Use disposable covers between patients to maintain aseptic technique while saving time

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Author Disclosure Statement

No competing financial interests exist.

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Virtual Reality as a Distraction Technique in Chronic Pain Patients

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Camelia Sulea, MD,[1] and Mark D. Wiederhold, MD, PhD, FACP[2]

Abstract

We explored the use of virtual reality distraction techniques for use as adjunctive therapy to treat chronic pain. Virtual environments were specifically created to provide pleasant and engaging experiences where patients navigated on their own through rich and varied simulated worlds. Real-time physiological monitoring was used as a guide to determine the effectiveness and sustainability of this intervention. Human factors studies showed that virtual navigation is a safe and effective method for use with chronic pain patients. Chronic pain patients demonstrated significant relief in subjective ratings of pain that corresponded to objective measurements in peripheral, noninvasive physiological measures.

Introduction

PAIN MEDICATIONS ARE THE THIRD MOST WRITTEN prescription today, and few prescription pain drugs achieve acceptable pain relief in more than 50% of treated patients. Many people deal with physical pain in their daily lives, and the pain can range from mild to excruciating. The most common causes of pain include chronic illness, accidents, surgery, advanced cancer, lower back problems, arthritis, shingles, headaches, and fibromyalgia. Additionally, many of these patients have problems obtaining adequate medication to control their pain.[1] One way to help is by using virtual reality (VR) to draw attention away from the patients' mental processing, thereby decreasing the amount of pain consciously experienced by the patient.

VR has also been found to be effective in reducing reported pain and distress in patients undergoing burn wound care, chemotherapy, dental procedures, venipuncture, and prolonged hospital visits.[2–16] It appears that VR may change how the brain physically registers pain, not just the perception of pain stimuli.[2] An interesting study showed that 86% of patients undergoing wound care from a burn injury reported severe to excruciating pain even with therapeutic levels of opioids.[3] The challenges of treating severe pain confront clinicians daily. The search for adjunctive techniques has led to a number of studies where pharmacological agents are combined with behavioral modification approaches. More recently, distraction techniques have been used as an adjunct during unpleasant medical procedures. Examples of these techniques include deep breathing, viewing videotapes, listening to music, and playing video games.[4–6] The success of these psychologically based techniques has led to the innovative use of VR as a distraction technique (see Table 1).

A study conducted by Sarig et al. explored the use of VR in managing chronic neck disability and pain. Twenty-five symptomatic and 42 asymptomatic individuals reported pain using conventional pain ratings as their cervical range of motion was measured. The goal of the study was to determine if range of motion correlates with pain management. Results indicated significant limitations in range of motion measurements, as they showed sensitivity but lacked specificity.[22] In 2013, Sarig et al. conducted a similar study to explore the issue further. Out of 25 patients, a comparison of self-reported outcomes and cervical range of motion showed correlations of 0.4–0.6 between the two measurements. This objective quotient indicates that subjective pain ratings can be supplemented with range of motion measurements and fear of motion reports to measure pain for physical rehabilitation studies. Moreover, VR was seen to not only reduce pain but objectively increase function.[16]

A pilot study of VR to treat fibromyalgia in 2013 studied the long-term effects of VR therapy. The six women in the study who had undergone 10 sessions of therapy supported by adaptive virtual environments (VEs) were assessed at pretreatment, post-treatment, and at 6 months follow-up. Results show that both depression rates were significantly reduced and coping strategies reflected positive growth.[19]

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Another fibromyalgia study considered the use of noninvasive mirror visual feedback using VR to treat chronic pain of one fibromyalgia patient using ketamine as a pain reliever. On a 15 trial experiment, patient pain was shown to have decreased significantly, indicating the supplementary nature of VR with other medications.[20]

In 2010, Patterson et al. combined VR with hypnosis. The randomized, controlled study of 21 trauma patients compared subjective pain ratings of patients that were induced under VRH (virtual reality hypnosis) and standard VR. Positive results of VRH therapy indicate a synergistic and additive effect of the analgesic efficacy of hypnosis and VR distraction techniques.[23]

Other chronic conditions have been studied using VR as an adjunctive treatment. The first dermatological study of pruritus was conducted in 2009. Exposure to a computer-simulated game seemed to reduce the subjective pruritus intensity significantly among the 24 patients. Although pain and itching are activated under different internal brain mechanisms, a comparison of the commonalities of pain receptors, activations, and neural pathways can lead to insights on how to use these tools for the treatment of a variety of conditions such as chronic itching and chronic pain.[24]

Methods

Participating in this study to investigate the efficacy of an interactive VE were 40 patients aged 22–68 years with average daily pain for at least 3 months and a daily average pain intensity score of ≥ 4 (0 = no pain, 10 = worst possible pain).

Results

Before we tested the pain distraction system on patients, we wanted to validate usability and safety in controls. To determine the human factors related to the use of our pain distraction system, we conducted an initial study with 15 controls. The subjects were enrolled as per the approved IRB protocol and signed the consent form. All participants went through a 15 minute VR exposure session while wearing a HMD. The VEs consisted of pleasant and relaxing scenes, including natural areas such as forests, beaches, and mountains. Relaxing music and soothing effects such as the branches swaying and tall grass moving were added. Tree branches for example moved six to eight times per minute to guide breathing regulation.

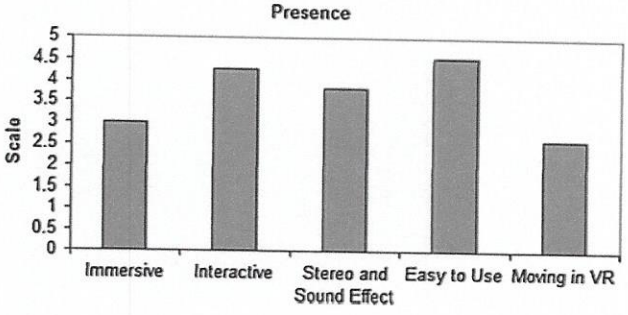

FIG. 1. The scales of sense of being in the virtual reality (VR) simulated environment—Ease of use, Immersive, and Interactive effects on a scale from 1 to 7, where 7 represents the normal experience of being in a place. 1 = "not at all," 7 = "very much." VR environment was easy to use, interactive, immersive, and real.

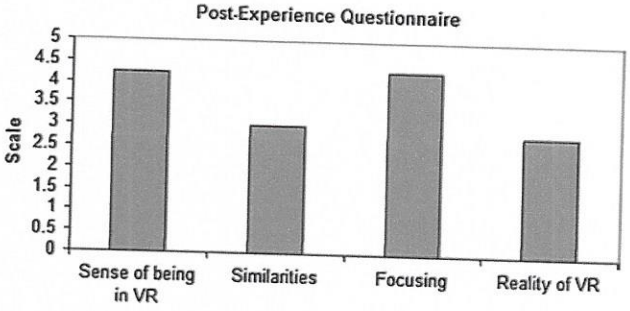

FIG. 2. The scales of sense of being in the VR—how real was VR versus the simulated environment, similarities between the simulated environment and the actual places patients visited, how focused on the tasks patients were during the simulated environment, on a scale from 1 to 7, where 7 represents the normal experience of being in a place. 1 = "not at all," 7 = "very much." VR was immersive and real.

Self-report questionnaires were completed by participants and scored on a scale of 1 to 7, where 1 = "no effect" and 7 = "highly effective." Overall the pain distraction VE was found easy to use, had good stereo sound effects, and was immersive and interactive (see Figs. 1–3).

Controls reported good levels of presence and immersion when using the environments. The system was easy to use and understand. Evaluation of post-experience questionnaires showed that the sense of being in the VEs was high. This sense of being in VR correlated well with levels of immersion and interactivity on the presence questionnaires. Because we were concerned with potential adverse effects in patients using the VR system, we administered the Simulator Sickness Questionnaire. This questionnaire showed very low levels of fatigue, headache, eyestrain, and nausea when using the VR system. These low numbers indicate the VR system is both safe and effective.

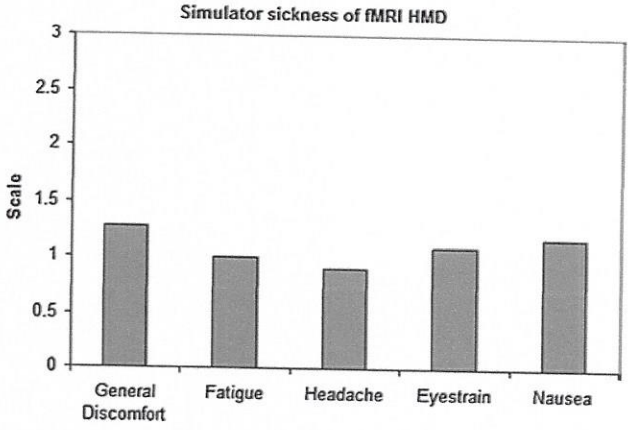

FIG. 3. Sickness exploration questionnaire scores in terms of general discomfort, fatigue, headache, eyestrain, and nausea, their mean scales are all <1.5, where the scales range from 0 to 3. 0 = "Absent," 3 = "Severe." No serious side effects were observed. It was determined that VR was indeed safe to use with this population.

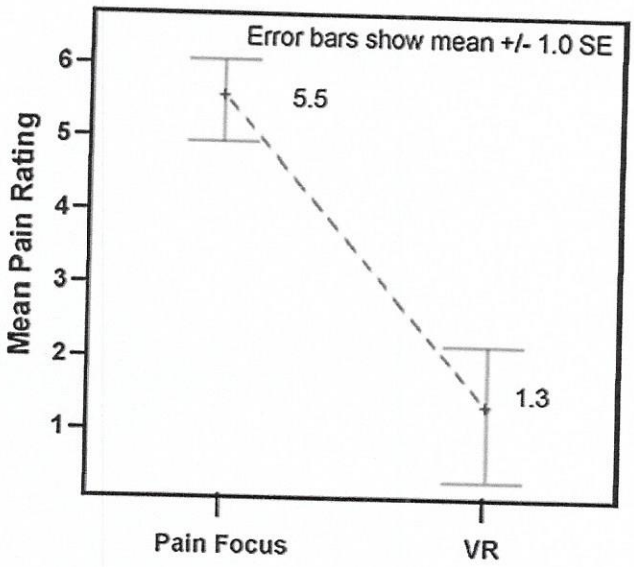

FIG. 4. Comparison of subjective pain ratings.

In our first pilot study, six chronic pain patients, ranging in age from 22 to 68 years, tested the VE with a head-mounted display and physiological sensors. All six participants reported a drop in pain while in the VE, and the magnitude of pain reduction from the VR compared to the pain focus condition was large (75.8%) and significant. A nonparametric Wilcoxon signed rank test indicated that the mean pain rating during the VR condition was significantly lower than the session with no distraction ($n=6$; $p=0.028$). Each of the six participants exhibited higher mean skin temperature when engaged in the VE than when in the pain focus condition. A paired t test also indicated that the overall mean temperature was significantly higher when participants were using VR ($df=5$; $p=0.004$). A higher average temperature in VR suggests a reduced level of discomfort and anxiety, substantiates the self-reported pain ratings, and suggests that

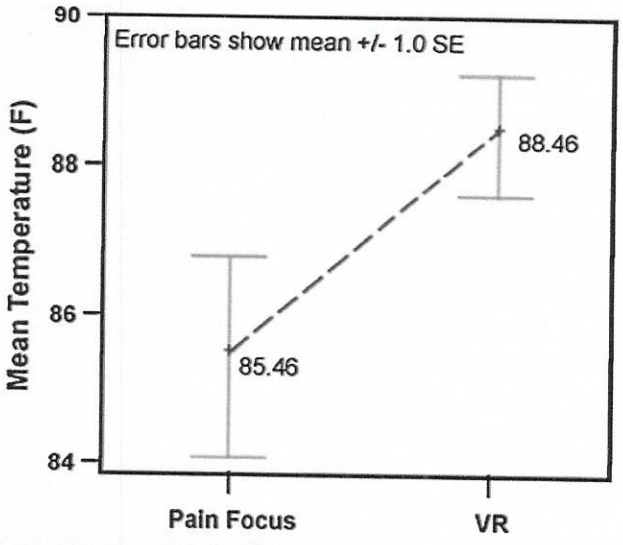

FIG. 5. Comparison of objective pain ratings.

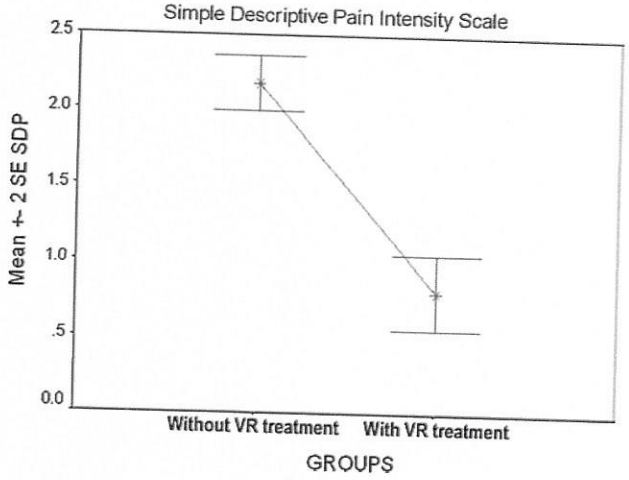

FIG. 6. Comparison of reported pain intensity.

VR is an effective method of reducing pain and anxiety (see Figs. 4 and 5).

As in the previous study, we compared a pain focus condition to a VE exploration condition in 34 additional chronic pain patients. Data on heart rate and skin temperature were collected, as well as pain intensity ratings obtained from self-report questionnaires. All patients reported a decrease in pain while in the VE, with significance ranging from $p<0.05$ to $p<0.001$, depending upon which of the three pain rating scales were used (see Fig. 6). The significant decrease in heart rate ($p<0.05$) while the patients were in the VE indicates a reduced level of pain and anxiety, and suggests that VR is an effective method of reducing this distress (see Fig. 7).

Discussion

Overall, the results of this study show VR is effective at reducing pain. Within the subjective outcomes, patients reported significantly lower pain ratings while exploring the VE than during the pain focus session. Several patients reported encouraging feedback as well, such as "this is the first pain relief I have had in 3 years," "I was so busy playing the

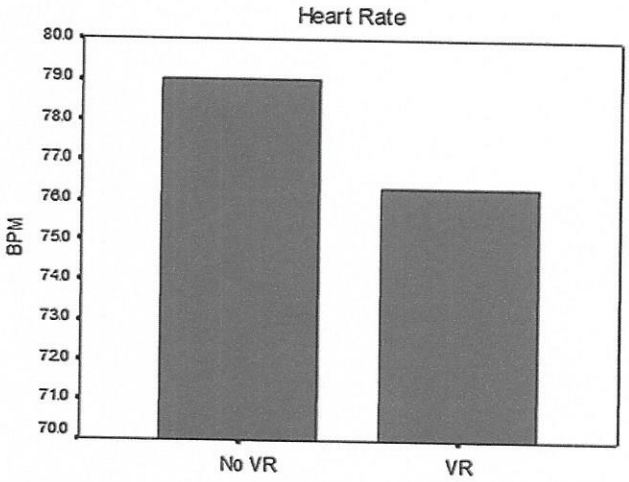

FIG. 7. Comparison of heart rate.

TABLE 1. CURRENT RESEARCH OF VIRTUAL REALITY (VR) TREATMENT OF CHRONIC PAIN

Title	*Method*	*Result*
Do Neck Kinematics Correlate with Pain Intensity, Neck Disability or with Fear of Motion?[16]	Twenty-five patients (19 females, 6 males; mean age 39 ± 12.7 years) with chronic neck pain participated in this cross-sectional study. A customized VR system was employed to evaluate cervical range of motion (ROM) and kinematics, using an interactive game controlled by cervical motion via electromagnetic tracking. Self-reported outcome measures included pain intensity (visual analog scale), disability (Neck Disability Index), and fear of motion (TAMPA scale of kinesiophobia). Kinematic measures included cervical ROM, mean and peak velocity, and number of velocity peaks (NVP) reflecting smoothness of motion.	Results showed significant correlations of approximately 0.4–0.6 between ROM and fear of motion, pain intensity, and disability. All 12 kinematic measures were correlated with fear of motion, but only a few were correlated with pain intensity, and with disability. The results emphasize fear of motion as a subjective measure primarily correlated with neck kinematics, including range, velocity, and smoothness of cervical motion. The level of neck disability was found to be partly related to ROM or to other kinematic impairments. However, ROM by itself remains a valid measure related to pain intensity and to fear of motion in patients with chronic neck pain. All correlations demonstrated were moderate, indicating that these measures involve other factors in need of further research.
A Virtual Reality System Combined with Biofeedback for Treating Pediatric Chronic Headache—A Pilot Study[17]	Ten children attending an outpatient pediatric neurology clinic were treated by the proposed system. Participants practiced relaxation with biofeedback and learned to associate successful relaxation with positive pain-free virtual images of themselves.	Nine patients completed the 10-session intervention. Ratings of pain, daily functioning, and quality of life improved significantly at 1 and at 3 months post-treatment. Most patients reported applying their newly acquired relaxation and imagery skills to relieve headache outside the lab.
Virtual Visual Effect of Hospital Waiting Room on Pain Modulation in Healthy Subjects and Patients with Chronic Migraine[18]	Sixteen CM and 16 controls underwent 62 channels LEPs from the right hand, during a fully immersive VR experience, where two types of waiting rooms were simulated. The RH simulated a classical hospital waiting room while the IH represented a room with sea viewing.	CM patients showed a reduction of laser pain rating and vertex LEPs during the IH vision. The sLORETA analysis confirmed that in CM patients the two VR simulations induced a different modulation of bilateral parietal cortical areas (precuneus and superior parietal lobe), and superior frontal and cingulate girus, in respect to controls.
Virtual Reality in the Treatment of Fibromyalgia: A Pilot Study[19]	The sample comprised six women diagnosed with fibromyalgia (FM) according to the American College of Rheumatology guidelines (1990). The treatment program consisted of 10 sessions of group CBT with the support of an adaptive virtual environment (VE) containing a specific content for developing relaxation and mindfulness skills. Patients were assessed at pretreatment, post-treatment, and at a 6 months follow-up for the following outcome variables: functional status related to pain, depression, a negative and positive affect, and coping skills.	The results showed the long-term benefits of significantly reduced pain and depression and an increased positive affect and use of healthy coping strategies.
Using Mirror Visual Feedback and Virtual Reality to Treat Fibromyalgia[20]	We have previously used noninvasive mirror visual feedback to treat subjects with chronic pain from phantom limbs and suggested its use for complex regional pain syndrome: once considered intractable pain. We wondered whether such methods would work to alleviate the chronic pain of FM. We tested mirror visual feedback on one FM patient.	On 15 trials, the patient's lower limb pain rating (on a scale from 1 to 10) decreased significantly. These preliminary results suggest that noninvasive dissociative anesthetics such as VR goggles, ketamine, and mirror visual feedback could be used to alleviate chronic pain from FM.

(*continued*)

TABLE 1. (CONTINUED)

Title	*Method*	*Result*
Nonimmersive Virtual Reality Mirror Visual Feedback Therapy and Its Application for the Treatment of Complex Regional Pain Syndrome: An Open-Label Pilot Study[21]	A small open-label case series. Five patients with complex regional pain syndrome received VR mirror visual feedback therapy once a week for five to eight sessions on an outpatient basis. Patients were monitored for continued medication use and pain intensity.	Four of the five patients showed >50% reduction in pain intensity. Two of these patients ended their visits to our pain clinic after five sessions.
Neck Pain Assessment in a Virtual Environment[22]	Cervical range of motion (CROM) measures were collected from 25 symptomatic and 42 asymptomatic individuals using VR and conventional assessments. Analysis of variance was used to determine differences between groups and assessment methods. Logistic regression analysis, using a single predictor, compared the diagnostic ability of both methods.	Results obtained by both methods demonstrated significant CROM limitations in the symptomatic group. The VR measures showed greater CROM and sensitivity while conventional measures showed greater specificity. A single session exposure to VR resulted in a significant increase in CROM.
Virtual Reality Hypnosis for Pain Associated with Recovery from Physical Trauma[23]	The authors report a randomized, controlled study of 21 hospitalized trauma patients to assess the analgesic efficacy of virtual reality hypnosis (VRH)-hypnotic induction and analgesic suggestion delivered by customized VR hardware/software. Subjective pain ratings were obtained immediately and 8 hours after VRH (used as an adjunct to standard analgesic care) and compared to both adjunctive VR without hypnosis and standard care alone.	VRH patients reported less pain intensity and less pain unpleasantness compared to control groups.
Effects of Virtual Reality Immersion and Audiovisual Distraction Techniques for Patients with Pruritus[24]	Twenty-four patients suffering from chronic pruritus—16 due to atopic dermatitis and eight due to psoriasis vulgaris—were randomly assigned to play an interactive computer game using a special visor or a computer screen. Pruritus intensity was self-rated before, during, and 10 minutes after exposure using a visual analog scale ranging from 0 to 10. The interviewer rated observed scratching on a three-point scale during each distraction program.	Student's t tests were significant for reduction of pruritus intensity before and during VRI and AVD ($p=0.0002$ and $p=0.01$ respectively), and were significant only between ratings before and after VRI ($p=0.017$). Scratching was mostly absent or mild during both programs.
Exploratory Findings with Virtual Reality for Phantom Limb Pain: From Stump Motion to Agency and Analgesia[25]	A sample of subjects with "arm" ($n=7$) and "leg" ($n=7$) amputations underwent trials of a VR system, controlled by motion captured from their stump, which was translated into movements of a virtual limb within the VR environment. Measures of pain in the phantom limb were elicited from patients before and during this exercise as they attempted to gain agency for the movement they saw, and feel embodied within the limb. After this, each subject was interviewed about their experiences.	Five subjects in each group felt the virtual limb to be moved by them and felt sensations of movement within it. With this, they also reported reductions in their phantom limb pain greater than expected from distraction alone. No carry over effect was seen.

game, I forgot about my pain," and "even though the procedure was finished, I wanted to keep playing." This shows that this technology is significant not only in reducing pain but also in eliminating the interruptive nature of chronic pain.

Moreover, objective measures further supported the reduction of pain with use of the VR system. Skin temperature was significantly higher and heart rate was lower during the VR session, which indicates greater relaxation.

In virtual technologies, a necessary factor to consider is the presence felt by the user. In a study conducted by Hoffman et al., the distractive properties of a virtual program were greatly enhanced with higher immersion and presence of the VE used to reduce pain and anxiety of burn patients.[26] Similarly, a comprehensive review of immersiveness on physiology reported that greater immersion has relaxing effects on physiological factors such as heart rate, respiration rate, skin temperature, and skin resistance.[27] Due to the high presence and realism scores of the self-report surveys, the virtual program used in this study can be considered as effective in engaging patients, and thus distracting from pain.

Additional studies can further determine the correlation between presence and pain management, as well as the association of pain distracting qualities of VR and various types of pain.

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Author Disclosure Statement

No competing financial interests exist.

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multidisciplinary team of clinical experts. Successful distraction by using these interactive tools may provide an additional augmentative option that is acceptable and often preferred by many patients. Further elucidation of the mechanisms underlying pain relief should be explored so that improvements and the specific creation of environments linked to specific types of pain and specific disease conditions can be developed.

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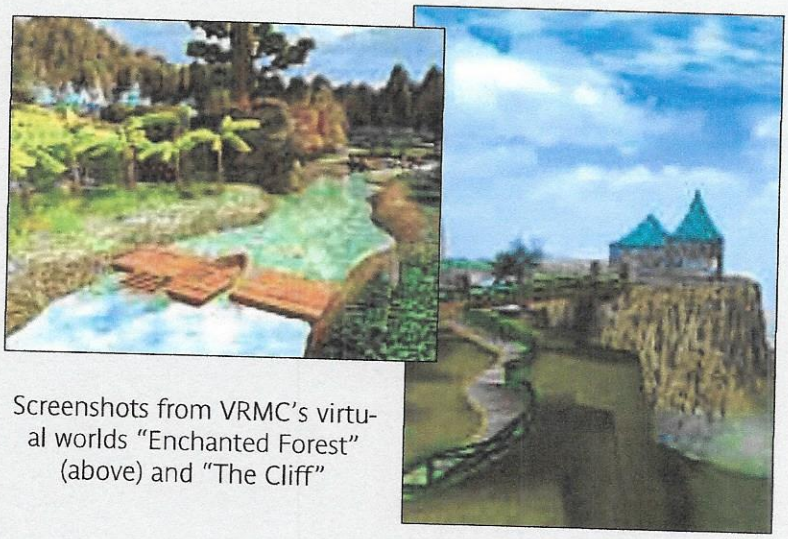

Screenshots from VRMC's virtual worlds "Enchanted Forest" (above) and "The Cliff"

Virtual Reality Analgesia in SnowWorld

▸ By Hunter Hoffman

In the following article the author discusses the Virtual Reality world SnowWorld, a VR system designed specifically for burn patients, and describes how distraction and immersion play an important role in pain management.

Why does a child getting wound care while in the virtual world, SnowWorld, behave as if they are not even in the hospital, when the child knows for sure that

Continued on page 20

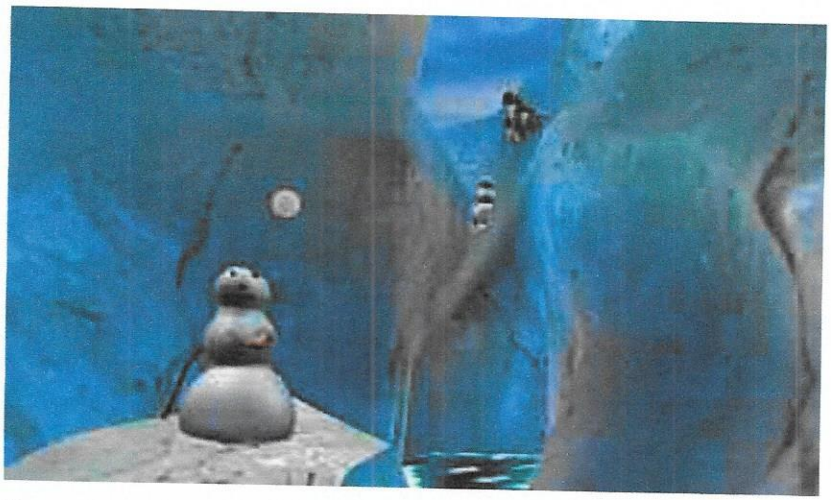

Figure 1: A screenshot of what patients see in the goggles during immersive virtual reality pain distraction.

Product Comparison Chart:
Pain Management Systems

Here, we provide an overview of popular products on the market to treat pain. Ranging from TENS machines, which treat pain through electrical stimulation of the nerves, that can fit in your pocket, to 3-D pain distraction and relief software which can be used on a mobile platform, such as a cell phone, improved technologies are making pain more manageable on a smaller, more portable level, making these products even more appealing to the user. Virtual Reality pain treatment systems will see more widespread use as mobile platform popularity continues to grow.

PRODUCT	DESCRIPTION OF PRODUCT	MANUFACTURER
Acticare TSE	an improvement on TENS machines, offers transcutaneous spinal electroanalgesia (TSE) therapy, can fit in your pocket and focuses on the central nervous system	Acticare
Pro Sport device	device combines microcurrent transcutaneous stimulation with somatic bio-feedback, adjunctive treatment in the management of post-surgical and post-traumatic pain.	Avazzia BEST
Virtual Reality Pain Management System	3-D interactive VR pain distraction and relief software product, can either be used in clinical, PC-based setting or on a mobile platform such as a cell phone	Virtual Reality Medical Center
The DonJoy® Pain Control Device (PCD)	portable, disposable pump that continuously delivers physician prescribed local anesthetic directly into a surgical site over an extended period of time to manage postoperative pain	DJ Orthopedics Inc.
Virtual Reality Pain Distraction System	system designed to distract patients during painful procedures using head-mounted display (HMD) and game pad or joystick	Fifth Dimension Technologies
Re-Mission	pain distraction PC video game for cancer patients, in the game a heroine battles tumors and chemotherapy side effects inside a human body	HopeLab
SnowWorld	a virtual reality world for burn patients to help reduce their pain, designed to be used when the patient's bandages are changed	Human Interface Technology Lab (HIT Lab)
SCENAR Sport D	hand-held pain relief device intended for delivering general therapeutic non-invasive treatment to the body's physiological systems via skin areas	Scenar Health
TENS Pain Control Units	TENS pain control units, which treat pain through electrical stimulation of the nerve, disrupts the pain signal so the pain is no longer felt	Vitalityweb.com, Inc.
Calmare(R) Therapy Treatment	device, with a biophysical rather than a biochemical approach, uses a multi-processor able to simultaneously treat multiple pain areas by applying surface electrodes to the skin	Competitive Technologies, Inc.
Ben's Game	video games designed to provide a high level of pain distraction, allows the player to battle monsters while keeping the body safe from hair loss and other chemotherapy side effects	Make a Wish Foundation
TENS Units	company sells a variety of TENS pain units that help control pain by sending small electric impulses through electrodes to nerve fibers	Healiohealth

they are not in SnowWorld? Burn patients put on a virtual reality (VR) helmet and have the feeling of being transported to the place depicted by the virtual environment – SnowWorld. These burn patients act as if they are really there. More importantly, when in VR, burn patients often act as if they are not in the real world undergoing painful medical procedures.

While in VR, burn patients report large reductions in pain unpleasantness and pain intensity, they spend much less time thinking about their pain during wound care, and even report having fun during wound care while in VR. Burn patients immersed in SnowWorld during wound care experience potent non-pharmacologic "VR analgesia."

My colleague, Dave Patterson, and I originated the technique of using immersive VR for pain control in the mid '90s. Since then, our interdisciplinary research team at the University of Washington in Seattle, including Hoffman, Patterson, Carrougher, Richards, Seibel, Jensen and Sharar, has been studying how severe burn patients act when immersed in SnowWorld. We have been informally observing patients' pain behavior, such as whether or not they pull their hand away from the nurse. We have also been empirically quantifying how burn patients respond to being in VR – how being in VR affects their pain, as measured with patient pain ratings and fMRI brain scans. We have also begun to explore why burn patients feel less pain while in VR, i.e., the mechanisms of VR analgesia.

Allowing patients to "go into" VR during painful procedures can help reduce excessive pain non-pharmacologically. Compared to standard of care (pain medications with no VR), researchers consistently find 30-50% reductions in pain ratings when VR is used adjunctively, that is, in addition to usual pain meds, during civilian severe burn wound care and during physical therapy to stretch the burn patients newly healing skin. Military patient populations with combat-related burn injuries are showing similar benefits of VR analgesia. In addition, fMRI brain scans testing healthy volunteers receiving brief thermal pain stimuli have shown large reductions in pain-related brain activity associated with VR analgesia (Figure 1). We have also used VR to treat burn patients sitting in a tub of water. Using a custom-made static fiberoptic VR helmet with 800,000 tiny fibers per eye, we showed that VR analgesia can reduce some of the most severe pain in medicine – severe burn wound care/debridement in the hydroscrub tanks. Surprisingly, contrary to prevailing wisdom that distraction is less effective at higher pain levels, our results showed that VR was most effective in patients who needed it the most, those with worst pain scores of seven or higher on a scale from zero to 10.

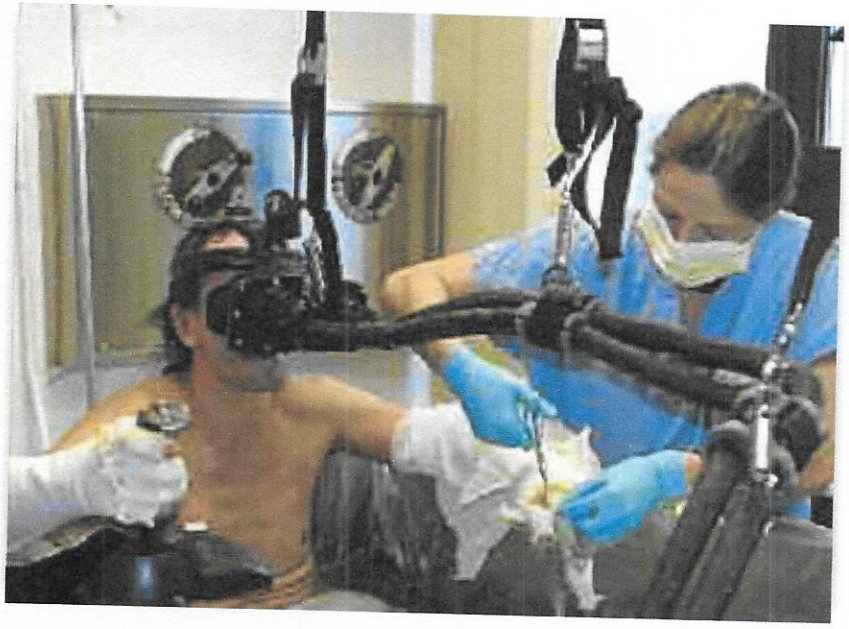

Figure 1: A patient wears waterfriendly VR goggles while undergoing severe burn wound care at Harborview Burn Center in Seattle, Washington.

Immersive VR is hypothesized to reduce pain via a non-pharmacologic attentional mechanism. Patients look into VR goggles and the goggles block patients' view of the hospital room so they cannot see the wound care. Instead, the goggles substitute synthetic computer-generated images from an illusory 3-D virtual world. Noise-canceling earphones block sounds from the hospital room, and substitute more calming music and sound effects. The patient interacts with the virtual world, throwing snowballs at objects, which makes it even more attention grabbing. According to our logic, pain requires attention and patients have a limited amount of attention available. VR draws upon these limited attentional resources, leaving less attention available to process incoming pain signals. Consistent with involvement of an attentional mechanism, burn patients report spending much less time thinking about their pain during wound care while in SnowWorld. In addition, laboratory pain studies have shown that on a divided attention task, where the participant's primary task is to monitor a string of numbers, performance on the primary task drops significantly when participants go into VR.

Computer Science and Engineering

To maximize VR analgesia for burn patients in SnowWorld, my colleagues and I have designed our VR systems (hardware and software) to maximize immersion of the VR system in an attempt to maximize VR analgesia. In laboratory studies at the University of Washington, Seattle, based on the earlier framework of immersion laid out by Slater and Wilbur, we have manipulated helmet quality and interactivity to see if these manipulations affected the chances that participants would see if these manipulations would affect the amount of VR analgesia reported by participants in our VR systems. Immersive VR appears to show a non-pharmacologic dose-response relationship where more immersive VR systems (presumed to be more attention grabbing) reduce pain more effectively than less immersive VR systems. For example, in a between-groups, double blind analog pain study manipulating only hel-

met quality, more immersive medium field of view VR goggles (via a commercially available NVIS SX LCD helmet) led to clinically meaningful reductions in pain in two out of three participants, whereas less immersive narrower field of view VR goggles (Cy-Visor) led to clinically meaningful reductions in pain in only one out of three participants. In another study, one group interacted with the virtual world via a trackball and the other group was not given a trackball and thus viewed SnowWorld passively. Interactivity increased the objective immersion of the VR system, and as predicted, increased the analgesic effectiveness of immersive VR.

In summary, so far, high tech VR helmet quality, such as wide field of view goggles, and interactivity, such as playing SnowWorld with a mouse-like trackball or other input device, have been isolated as important factors contributing to VR analgesia. Improvements in the field will become pertinent in future research, such as a pair of scanning fiber VR goggles that Hoffman's team are currently working on building.

This article is a synopsis of the keynote presentation Dr. Hoffman gave at RAVE-2010 in Barcelona on March 3, 2010.

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"Surreal" Pain Research

"Surreal World," one of the virtual worlds discussed in the following article, features interactive environments based on paintings done by Dalí and Miró and aims to captivate users' attention as they interact with various objects, including a representation of the sensation of pain.

By José Gutierrez-Maldonado

In past years, research on the use of virtual reality (VR) in pain has received considerable support in Spain due to financial aid calls for research on chronic pain supported by "Fundació La Marató de TV3" in 2007. The consortium formed by the research groups led by Jose Gutierrez-Maldonado (University of Barcelona), Mel Slater (University of Barcelona) and Cristina Botella (University Jaume I) obtained this type of financial aid and coordinate their work in the frame of the project "Development and application of technologically-advanced methods based on VR for attention-diversion, visualization and body image modification, as adjunct analgesic techniques against chronic pain." One of the main aims of the subprojects of the coordinated project mentioned above is the development of virtual environments for attention-diversion, beliefs modification, body schema modification, mood induction and behavioral activation.

The virtual environments, aiming to provide attention-diversion, were developed by the group led by Jose Gutierrez-Maldonado along with Vicky Rangel, Ivan Alsina, Desiree Loreto, Katia Cabas, Olga Gutierrez-Martinez and Ruben Nieto. Called "Surreal World," the first prototype was released in 2007. The current version (Surreal World 3.0) allows the user to navigate through virtual environments that recreate Dalí and Miró paintings and focus on obtaining the patient's attention through interaction with objects that generate surprise due to their surreal features. This research group has also developed an environment that al-

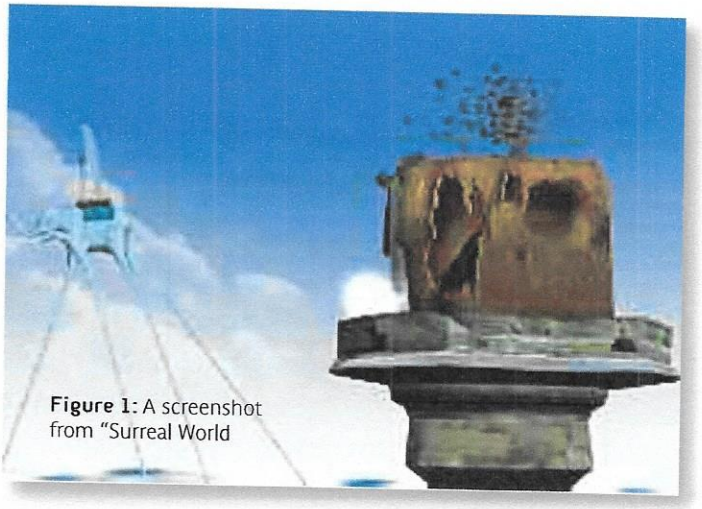


Figure 1: A screenshot from "Surreal World

Virtual Reality and Interactive Simulation for Pain Distraction

By effectively distracting the brain during painful medical procedures, Virtual Reality (VR) environments assure less attention is available for patients to acknowledge, and continue to pay attention to, pain. In the following article, the authors provide an overview of VR treaments to minimize pain and provide a history of related studies.

By Mark D. Wiederhold & Brenda K. Wiederhold

Recent studies show that pain affects 13% to 53% of the population throughout the world, making pain management one of the highest priorities in medicine today. Approximately 10,000 physicians specialize in pain management, yet only 5% of patients with the most severe pain ever get to see a specialist. Although chronic pain is the most common reason for seeking medical care, more than 20% of people with chronic pain do not seek a doctor's care. Chronic pain rises with age and affects a higher proportion of women than men. Although three to six months is the definition for chronic pain, long-term surveys show that 20% to 46% of chronic pain patients have had it for 10 years or more. Pain is of moderate to severe intensity for most patients, and other than the opioid analgesics, few prescription pain drugs achieve acceptable pain relief in more than 50% of treated patients. Evidence shows that there is a clear need for adjunctive pain relief.

Two-thirds of chronic pain patients say that pain interferes with daily activities, especially participating in physical activity—and the less physical activity there is the more acutely pain affects and complicates quality of life. Chronic pain is associated with poor general health and interferes with mental health as well. As a result, more than one-third of pain sufferers feel isolated by their pain, and almost one-third say they feel their families do not understand their pain.

Background

Virtual reality (VR) utilizes innovative technology and software to display virtual environments to users with the aid of a head-mounted display. Head tracking allows the user to interact with and actively view the environment in 360 degrees. Therefore, the images that the user sees reacts to the position they move their head. Another way VR is reactive is through the manipulation of the environment, usually through a mouse or keyboard. These advanced systems allow users to interact on many levels with the virtual environment, exploiting many of their senses, and encouraging them to become immersed in the world they are experiencing.

Immersion is one of the concepts that allow VR environments to distract patients undergoing various medical procedures in ways that go above and beyond other techniques. Immersion relates to how present the user feels in the world and how real the environment seems. When immersion is high, much of the user's attention is focused on the virtual environment, leaving little left to focus on other things such as pain.

Review of Clinical Studies

Clinical applications of VR and other technologies, and experimental research on why it has such a powerful impact on behavioral healthcare, medicine, and neuroscience, have demonstrated an array of success in significantly altering the way we view current methods of treatment for pain and anxiety and opens up exciting new possibilities and areas of improvement and innovation in nonpharmacological adjunctive pain relief. VR has been found to be effective in reducing reported pain and distress in patients undergoing burn wound care, chemotherapy, dental procedures, venipuncture, and many other painful procedures by drawing attention away from the patients' mental processing, thereby decreasing the amount of pain consciously experienced by the patient. Additional-

ly, VR for neurorehabilitation and physical rehabilitation has demonstrated success, as has VR for other such diverse areas such as prosthetics and orthotics training. Promising outcomes have been achieved by research conducted since the 1980's.

Firstly, studies have shown that distraction can take place by performing as simple an action as looking at pictures. A study was conducted in which elderly persons were shown affective images and pictures while performing their physiotherapy exercise and results implied that affective images and pictures appear to be a useful nonpharmacological intervention for pain management of elderly persons.

Preliminary distraction studies, conducted in 1984, investigated three types of distraction with patients undergoing dental procedures to obtain amalgam restorations. The distraction conditions included an audio-comedy program, a video-comedy program, and a video game. Distraction was successfully induced in patients who viewed the video comedy and played the video game during the dental procedure. This finding suggests that an increase in physiologic arousal is connected to effective distraction. This data diverges with earlier reports of the utilization of relaxation which produces a decrease in physiologic arousal during such dental procedures.

More than a decade later, similar studies involving VR distraction were conducted using cancer patients. This work, which consisted of immersing users in the virtual forest walk system, a virtual environment, to investigate the efficacy of VR technology in the psycho-oncological care of patients' mental health, demonstrated that that the exposure had a considerable positive effect in the mental support of cancer patients. In

Figure 1: A patient is immersed in a virtual environment (shown on lap top, foreground) to lessen pain during a medical procedure

another study, VR distraction intervention for women suffering from cancer was used to control chemotherapy-related symptom distress, boosting patients' ability to remain on schedule for treatment regimens and cope with the disease, and improve patients' quality of life and increasing the chances for survival by decreasing treatment-related symptom distress.

Several studies have identified distraction as a coping mechanism effective for children with cancer. In one study, VR as a distraction intervention for minimizing chemotherapy-related symptom distress in children with cancer was explored where patients wore a Virtual IO headset during an intravenous chemotherapy treatment while playing one of the following three CD Rom-based scenarios – Magic Carpet, Sherlock Holmes Mystery, and Seventh Guest. According to the data analysis of the SDS, VR intervention was effective at decreasing the level of symptom distress immediately after the chemotherapy treatment, however, it did not have a lasting effect. It is interesting to note, though, that the high levels of anxiety during the initial chemotherapy treatment showed a decrease during successive treatments.

Further studies support the idea that in comparison with the no distraction condition, diminutions in pain and anxiety, including lowered pulse rates, were witnessed for children with cancer who used the VR distraction during treatment. Further examinations into the analgesic potential of VR as a distraction intervention for patients with cancer was further examined in a study which showed VR glasses are a practical, age-appropriate, nonpharmacological addition to standard care in handling the pain associated with lumbar punctures in adolescents. In another study, the efficacy of VR as a behavioral intervention designed to reduce distress during a port access for 7-14 year old oncology patients. Distress experienced by the children was evaluated through both subjective self-ratings as well as objective physiological and behavioral ratings. On all measures, VR was effective in decreasing children's distress.

As well as providing distraction from pain during chemotherapy treatment using VR, patients conveyed that they experienced an altered perception of time. These findings support the idea that VR can help make chemotherapy treatments more tolerable; however, using VR doesn't improve chemotherapy-related symptoms. VR can also be used to educate patients and has been shown to lead to significant increases in cancer-related self-efficacy and knowledge through the use of an appealing interactive videogame platform. HopeLab has created a PC-based game, titled Re-Mission, which consisted of 20 missions within fictional cancer patients' lives, undergoing radiation, chemotherapy, and immunotherapy.

Several studies focusing on burn pain, such as work done by Hunter Hoffman (see article on page 14), have led mental healthcare to new frontiers as well. Studies found that immersive VR decreased the amount of pain reported in addition to the amount of time burn patients spent thinking about the pain during physical therapy. The data provides preliminary support that VR can act as a strong nonpharmacologic pain reduction method for adult burn patients. Another study investigated children with acute burn injuries and found strong support for the use of VR-based games in providing analgesia for children's acute pain with minimal side effects, reusability and versatility, as well as little impact on the physical hospital environment.

The effectiveness of VR as a pain distracter has also been examined for patients undergoing venipunctures and wound dressings. One investigation looked at whether VR was more effective at decreasing pain and distress in children undergoing minor procedures versus watching animated movies. These findings indicate that VR is at least as effective as and significantly more pleasant than watching an animated movie. Other research findings suggested that visual stimuli generated by an eyeglass display were a helpful nonpharmacological adjunct for pain relief in elderly patients receiving wound dressings for leg ulcers. Similar findings further supported VR as a pain distracter for children undergoing venipunctures.

In order to understand how VR can effectively reduce pain, work has been done to investigate the neural correlates of VR analgesia. In a particular study, participants' pain-related brain activity was measured using fMRI during conditions of VR and no VR. VR considerably decreased pain-related brain activity in all five regions of interest including the anterior cingulate cortex, primary and secondary somatosensory cortex, insula, and thala-

Figure 2: Shell City, a Virtual World used by VRMC for pain treatment, encourages users to interact with the environment by collecting shells along the beach and creating calming music and images with the shells they have collected.

Table 1: Virtual Reality (VR) and Pain Distraction Studies

Year	First Author	No. of Participants	Procedure	Treatment	Results
1999	Oyama	22	Oncology care	One VR session, virtual forest walk	Better mood, less fatigue post VR, forest had significant effect on mental support
1999	Schneider	22	Chemotherapy	VR during three treatments	Less symptom distress after treatment
2000	Hoffman	12	Physical Therapy	Three minutes with VR and three minutes without	Significant pain reduction during VR
2000	Sullivan	26	Dental procedures	VR exposure	VR reduced pulse but had no significant effect on behavior or anxiety
2002	Sander	30	Lumbar puncture	VR glasses/video and standard care vs only standard care	VR helped distract 77% of experimental group
2003	Reger	57	Venipuncture	HMD VR vs flat-screen VR vs cartoon viewing vs no distractions	Significantly lower affective pain with HMD Reduction in pain for eyeglass display
2003	Tse	33	Wound dressing	Eyeglass display with soundless video broadcast vs static blank screen	Significantly lower pain scores with video images
2004	Gershon	59	Port access (venipuncture)	VR vs non-VR distraction vs no distraction	Reduced pain, anxiety, pulse rate
2004	Hoffman	8	Painful thermal stimuli	Within-subjects design, SnowWorld vs no VR	Significantly reduced pain-related brain activity
2004	Hoffman	39	Painful thermal stimuli	VR helmet/headphones/headtracking vs.see-through VR glasses	VR presence significantly, positively correlated with pain reduction
2004	Schneider	20	Chemotherapy	VR distraction during sessions	Distraction decreased symptom distress
2004	Wiederhold	6	Chronic pain	Icy Cool Fantasy VR HMD	Significant pain reduction, higher skin temperature
2005	Das	7	Dressing changes	VR and pharmaceutical analgesics vs analgesics only	Pain score without VR: 4.1; with VR 1.3
2005	Schneider	92	Chemotherapy	VR vs no VR	Altered perception of time indicating immersion
2005	Tse	15	Physiotherapy	Affective pictures during sessions	Significantly decreased pain score, NS increase in quality of life
2005	Wolitzky	20	Port access procedure	Gorilla habitat VR HMD vs no VR	Children using VR experienced significantly less pain and anxiety
2006	Cole	375	Cancer treatment	RCT, standard video game vs standard and Re-Mission video game	Significantly increased self-efficacy, as well as ability to manage side effects
2006	Lange	44	Venipuncture or wound care	Block randomization, VR vs movie	VR decreased distress, perceived by parents/staff as more effective
2006	Wiederhold	8	Dental procedures	VR vs no VR	Effective distraction and pain management mechanism; as perceived by patients/staff
2007	Mosso	27	Ambulatory surgery	Enchanted Forest VR	Avoidance of general anesthesia
2009	Nilsson	21	Needle-related procedures	VR game	Best results when game type corresponded to procedure
2009	Leibovici	24	Chronic pruritus	Immersive VR	Reduced itching and scratching

mus, as anticipated. Direct modulation of brain pain responses by VR distraction was demonstrated by the data.

These studies support the use of VR to distract patients from pain and anxiety during painful or unpleasant medical procedures. Continuing education and research ensures that the field continues to grow and further direction will be used to begin to dissect and analyze the specific brain mechanisms underlying pain distraction with VR.

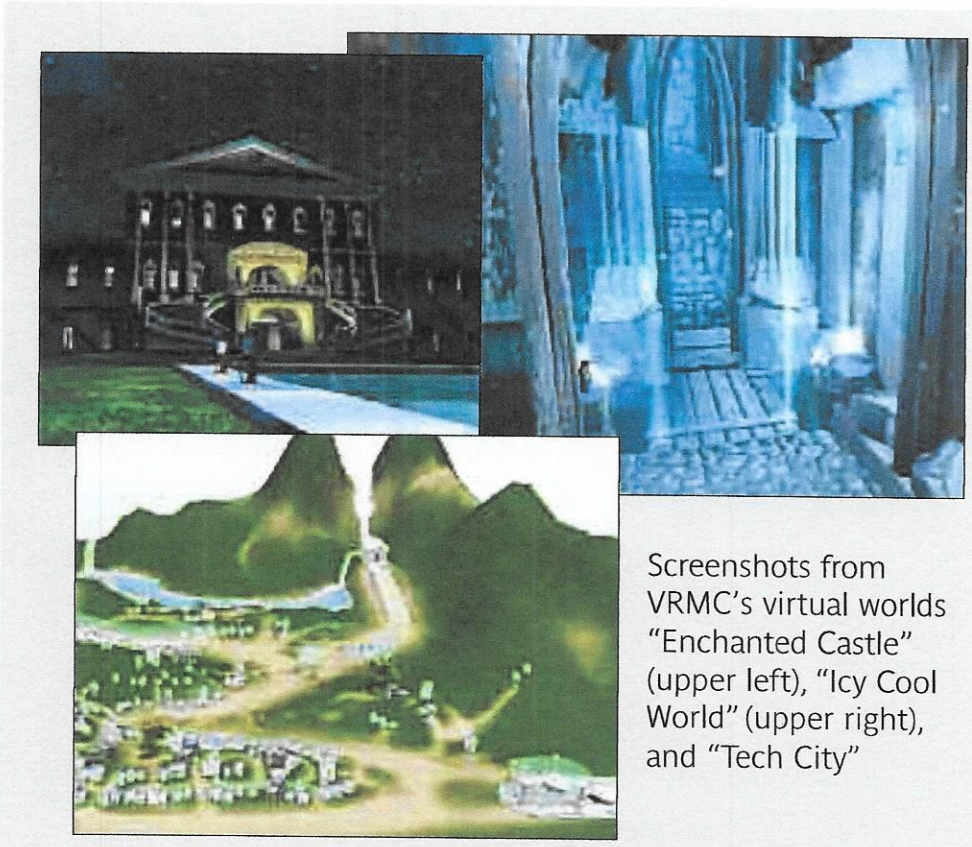
Treatment Outside the Clinic

Although it is widely recognized that VR treatment is applicable to treating anxiety and pain in a clinical setting, a certain number of factors has hindered its use outside the office, such as the large amount of space needed for equipment and high cost of utilizing such systems.

A low-cost alternative to the traditional delivery method for VR is the cell phone. Virtual Reality Medical Center (VRMC) has produced a number of PC-based portable medical devices, including programs to treat pain and pain-related anxiety. To test the efficacy of a prototype virtual environment for the cell phone, VRMC compared a pain focus condition to a virtual environment condition in participants with chronic lower back pain. Data on heart rate and skin temperature were collected, as well as pain-intensity ratings obtained from self-report questionnaires. As with VRMC's PC-based product, all participants reported a drop in pain while in the cell phone virtual environment. As in the PC product study, the significant decrease in heart rate and the significant increase in skin temperature while the participant was in the virtual environment substantiates the three self-reported pain ratings, indicates a reduced level of pain and anxiety, and suggests that VR via small-screen display is an effective method of reducing this distress. These findings will support the use of VR distraction outside the doctor's office and encourage patients to address anxiety and pain through nonpharmacological methods.

Work at The Virtual Reality Medical Center (VRMC)

The VRMC specializes in the creation of augmented reality environments that are used to increase levels of immersion and presence, both effective for increasing distraction which can lead to diminished pain, for participants undergoing therapy. Funded by the National Institutes of Health and the National Institute on Drug Abuse, the VRMC developed a VR pain distraction system to be used in the dental office. Patients had a variety of dental procedures including replacement of crowns, fillings, root canals, and cosmetic dental work and during the dental procedures the patients wore a VR head mount and observed a variety of software environments. While the patients were in the virtual environments, non-invasive sensors were used to measure physiological signals including electrocardiogram, skin temperature, skin conductance, and respiratory rate. Overall, dental patients reported a reduction in the level of discomfort and pain while exploring the interactive virtual worlds.



Screenshots from VRMC's virtual worlds "Enchanted Castle" (upper left), "Icy Cool World" (upper right), and "Tech City"

Conclusions and Future Directions

After looking at an overview of research involving the use of VR and other types of interactive simulation tools that demonstrate a capability for reduction in painful or other unpleasant symptoms during medical procedures, it is evident that there seems to be a correlation between level of interactivity and immersion in the virtual environments and success in relieving distressing symptomatology. In particular, preliminary evidence suggests changes in brain fMRI patterns that seem to correlate with effectiveness of pain relief during VR interactions. Clearly, management and successful intervention for serious pain requires a

multidisciplinary team of clinical experts. Successful distraction by using these interactive tools may provide an additional augmentative option that is acceptable and often preferred by many patients. Further elucidation of the mechanisms underlying pain relief should be explored so that improvements and the specific creation of environments linked to specific types of pain and specific disease conditions can be developed.

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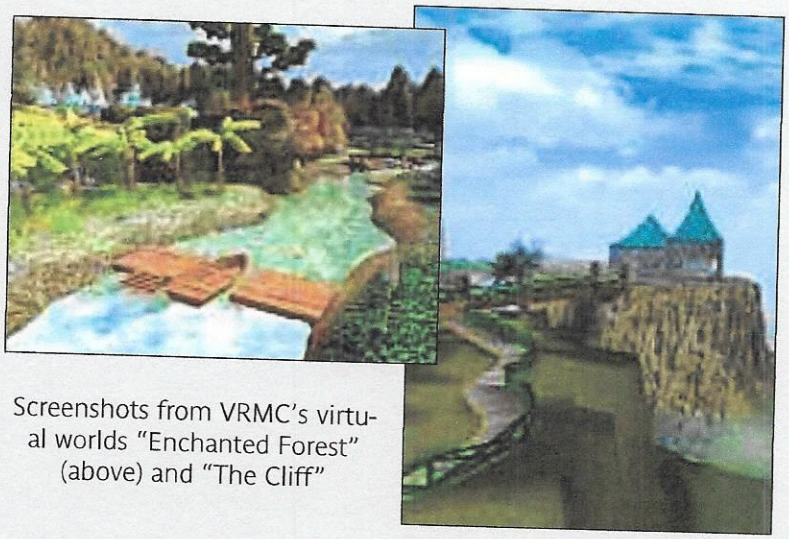

Screenshots from VRMC's virtual worlds "Enchanted Forest" (above) and "The Cliff"

Virtual Reality Analgesia in SnowWorld

▸ By Hunter Hoffman

In the following article the author discusses the Virtual Reality world SnowWorld, a VR system designed specifically for burn patients, and describes how distraction and immersion play an important role in pain management.

Why does a child getting wound care while in the virtual world, SnowWorld, behave as if they are not even in the hospital, when the child knows for sure that

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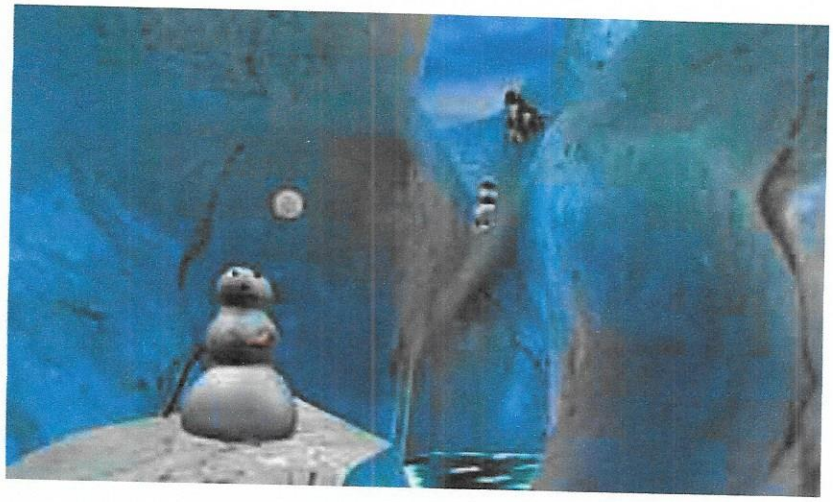

Figure 1: A screenshot of what patients see in the goggles during immersive virtual reality pain distraction.