Virtual Reality as a Distraction Technique in Chronic Pain Patients

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Editorial

How Can Virtual Reality Interventions Help Reduce Prescription Opioid Drug Misuse?

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and Mark D. Wiederhold, MD, PhD, FACP[5]

The recent death from a heroin overdose of actor Philip Seymour Hoffman at the age of 46 highlights the danger of opioid addiction. However, according to the U.S. Centers for Disease Control, prescription opioids such as OxyContin, Percocet, and Vicodin may be gateway drugs for heroin addiction and are responsible for five times as many deaths. ''The main driver of overdoses right now in our country is from opioid medications, more than from heroin,'' said Nora Volkow, director of the National Institute on Drug Abuse (NIDA).[1] Prescription drug overdose rates have more than tripled since 1990, paralleling a 300% increase in sales of strong prescription opioids.[2]

What is being done about this growing problem, and how can virtual reality (VR)-assisted behavioral interventions help? In addition to NIDA, other U.S. agencies involved in the fight against prescription opioid abuse and misuse include the Drug Enforcement Administration and the Food and Drug Administration. In February, the DEA launched a new texting initiative, TIP411, which helps the public report suspicious activity such as seeing a pharmacy tech drive off in an expensive car. Tipsters can use the keyword PILLTIP to report anomalies that may indicate illegal prescription drug activity, and the message will be forwarded to a DEA agent for investigation. The FDA is proposing to reclassify hydrocodone combination pills such as Vicodin from Schedule III to Schedule II. Adoption of the proposal would mean that prescriptions for this type of drug couldn't be called in over the phone and would require reauthorization from the physician before being refilled.[3]

Studies have concluded that only a small percentage of people who are prescribed opioids for medical reasons will go on to develop addictions to these drugs, and that one of the ways to prevent addiction is to preselect for no previous history of or current problems with drug or alcohol abuse or addiction.[4] Consistent with other studies on the subject, one study using Medicaid data found that about 3% of individuals will graduate to abuse or dependence, with the population most vulnerable to addiction being those younger than 40.[5] Studies suggest similar rates of prescription opioid misuse in the EU, although direct United States–Europe comparisons are difficult because of different physician prescribing patterns.[6] Another study found that ''Native Americans had significantly greater rates of nonmedical prescription drug use and drug use disorders, highlighting the need for culturally-sensitive prevention and intervention programs.''[7]

In addition to humanitarian reasons, there are significant financial incentives to find ways to reduce the incidence of prescription opioid misuse. One study found that ''mean annual direct health care costs for opioid abusers were more than eight times higher than for nonabusers.''[8] Another study noted, ''The total cost of prescription opioid abuse in 2001 was estimated at $8.6 billion, including workplace, health care, and criminal justice expenditures.''[9]

Of course, this amount is a drop in the bucket compared to the total cost to the U.S. economy of chronic pain, recently estimated by the Institute of Medicine at between $560 and $630 billion annually.[10] The European Federation of International Association for the Study of Pain (IASP) Chapters notes that to date, ''there is no comprehensive pan-European epidemiological survey laying out the scope of the pain problem.''[11] However, a 2010 report noted that ''chronic pain costs Europe billions of euros every year, with national costs ranging from 1.1 billion to nearly 50 billion Euros.''[12] Combinations of prescription opioids with other drugs have a modest additive effect on pain relief, while combinations of prescription opioids with behavioral interventions have been shown to be effective, for example, in reducing headache pain. As we researchers in the field of VR-assisted therapy have been saying for many years, it would be most helpful if we could identify predictors of who will be likely treatment responders.[12]

The editor and others involved in VR research have made strides in showing the effectiveness of ''various psychological techniques, including distraction by virtual reality environments and the playing of video games, [which] are being employed to treat pain.''[13] Perhaps if additional dollars were directed to support evidence-based research on both the psychological and neurophysiological mechanisms related to pain, and the effectiveness of these nondrug modalities, we would be able to make a significant contribution to reducing

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the need for opioid prescriptions and the deadly consequences of their abuse. As recently suggested by Herta Flor, ''The analysis of neurophysiological mechanisms may also lead to the development of new psychological interventions that can target these changes in a much more specific manner than pharmacological interventions.''[14]

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Personalizing Therapy

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Health and well-being are prime beneficiaries of the convergence of the sciences, as cognitive, computational, bio-, and nanotechnologies intermingle. But our societies and health systems are struggling to bring to market the deep innovations that result. We struggle to do this in large part because we are prisoners of systems built for a different model, governed by responsible professional prescription of blockbuster, one-shot solutions, based on the evidence of randomized trials for safety and efficacy.

After a decade spent observing, as a non-specialist, the fields of medical innovation and e-health in its broadest sense, including virtual reality (VR), I see with increasing clarity the opportunity cost imposed by the prevailing paradigm on what could otherwise be an explosion of health innovation.

I do not feel alone. On the disproportionate dominance of the gold standard, Sir Michael Rawlings, the then UK Clinical Excellence czar, laid out in his 2008 Harveian Oration the need to respect all evidence as evidence, from randomized double-blinded control trials down to individual experience of ''what worked'': evidence was always ''valid,'' and the weight to be given to it in each case was the crucial judgment call.

The need to embrace less general evidence is nowhere clearer than in a field such as pain, where complementary treatments are available, and individual responses will vary.

In what we might call the polypractice of pain therapy, we see increasing recourse to combinations of drugs, at varying daily rhythm and dosage, alone and in combination with other therapies, for example VR over the Internet, full immersion clinical VR, or talking support. Polytherapy is used because it works. But it will necessarily work differently for different conditions in different individuals at different stages.

This complexity is increasingly well understood and accommodated in end-of-life scenarios, at least in specialized palliative settings. But non-specialized professionals lack good decision support mechanisms that would allow them to be incorporated into polypractice. Liability regimes, made strict by the penumbra of Thalidomide, discourage physicians and may in practice completely rule out any personal choice to follow their physician in less established therapies.

Despite the obstacles, best-in-class, innovative practitioners, for example Dr. Peter Hutton, Consultant Anaesthetist in Birmingham, United Kingdom, have at least achieved a liability regime allowing real-time telemedicine deployment of variable dosages for pain relief medication. The fact that even this is not yet mainstream hints at the obstacles to be overcome in broader polytherapy. But the facts emerging from such experiences will reinforce the case, one hopes, for more forward-leaning attitudes from health managers and regulators.

At the EU level, too, innovators are nibbling at the obstacles. The highly successful European Innovation Partnership on Active and Healthy Aging covers pain management. So does the Horizon 2020 Research and Innovation Strategy: in its 2014–2015 Health Work Programme, calls will cover ''underdiagnosed or untreated pain … new therapies for chronic non-communicable diseases, self-management of health … mobile health … patient empowerment supported by ICT.''

Within this word cloud of opportunity, I hope we will receive from around the world good proposals addressing the question of chronic pain management using ICT tools. Our first deadlines are in April 2014, but most of the elements quoted above stretch into next year, and the program as a whole lasts until 2020.

To conclude, any successful approach to pain-related innovation needs to be broad enough to cover the full range of conceivable polypractice. We need to open the field for innovation. We cannot in future await blockbuster breakthroughs. We must rather open multiple paths for personalized pain relief.

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Virtual Reality Research Continues to Progress at the National Institutes of Health

David A. Thomas, PhD

The National Institute on Drug Abuse (NIDA), part of the National Institutes of Health (NIH), is among the leading funders of pain research at the NIH. By law, the NIH must issue announcements of areas of research interest. One major series of pain research funding announcements, issued by 11 Institutes and developed in cooperation with the NIH Pain Consortium, is titled *Mechanisms, Models, Measurement, and Management in Pain Research* (see http://grants.nih.gov/grants/guide/pa-files/PA-13-118.html).

In these announcements, the NIH states that they are interested in research on ''…non-pharmacological and novel (e.g. virtual reality) therapies for pain treatment in diverse populations such as ethnic minority groups and persons with disabilities.'' The specific mention of virtual reality (VR) is not by chance. There is a genuine understanding at the NIH of VR's potential to treat pain, and this has translated to the NIH funding a substantial amount of VR pain research. Using the NIH RePORT system (www.report.nih.gov/) to search NIH funded projects VR and pain projects, dozens of funded projects can be found, representing tens of millions of dollars in funding over the past decade.

Why such an interest at NIDA, and across the NIH, in VR to treat pain? First, there is a huge need for new pain treatments. Approximately 100 million people in the United States suffer from chronic pain,[1] and each case is somewhat different. No single pain treatment exists that is good for everyone, or even the majority of people. VR is proving itself as one viable option for reducing pain in suffering, and thus its development must be a priority.

Second, while opioids can be effective in the treatment of pain, they have a significant side effect profile, and the rates of misuse and addiction are staggering. In the United States alone, according to the Centers for Disease Control and Prevention, approximately 16,000 people die each year from a prescription opioid overdose. That exceeds deaths from cocaine and heroin overdoses combined. The last decade of research has established that VR, in a variety of situations, offers a safe and effective treatment of pain, without the possibility of drug addiction or many side effects common to opioids.

And progress has accelerated in the development of using VR for the treatment of pain. This special issue of *Cyberpsychology, Behavior, & Social Networking* is just another demonstration of how this field has developed and grown, and what a positive impact VR can have in alleviating pain. I expect advancements in this field to continue for many years to come.

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Psychological Factors Influencing the Effectiveness of Virtual Reality–Based Analgesia: A Systematic Review

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Abstract

The experience of pain is affected by remarkable psychological factors. The concept of neuromatrix suggests that pain is an amalgam of affect, cognition, and sensation mediated through diverse brain regions. Moreover, the experience of pain appears to be reduced by environmental stimuli that drive attention away from the noxious events. Accordingly, immersion in a computer-generated, three-dimensional virtual environment has been used as an efficient distraction tool in a number of studies on pain management. However, no systematic approaches have explored the psychological factors that influence the effectiveness of virtual reality (VR) as a distraction technology. This review aims to outline the fundamental psychological factors involved in the use of VR to provide pain management. An analysis of the literature revealed some important elements associated with the patients' subjective experience. Eleven studies met the inclusion criteria and were included in the review. The results suggest the importance of different psychological factors in the effectiveness of the analgesic distraction. While sense of presence influence the effectiveness of VR as a distraction tool, anxiety as well as positive emotions directly affect the experience of pain. Future challenges for pain management via VR include adopting properly validated measures to assess psychological factors and using different experimental conditions to better understand their complex effects.

Introduction

Classic research characterizes pain as an automatic access to consciousness[1] and a powerful demand for attentional resource.[2] While pain is a reaction to painful stimuli, it is still a controlled process. Therefore, any task that demands a similar or greater amount of cognitive resources could possibly interfere with the perception of pain. The phenomenon of pain relief via distraction emerged after the rise of the gate control theory.[3] According to this theory, nociceptive signals do not travel directly from the area of injury to the brain but have to pass through a ''gate'' mechanism located in the spinal cord. Depending on how open the gate is, a signal is perceived as more or less painful. Many factors could open or close the gate. Some are sensory; for example, if one gets a cut on his or her skin but puts the injured area under fresh water, that action stimulates large-diameter fibers in the spinal cord, which inhibits the activity of small-diameter fibers and closes the gate, thus relieving the pain. Other factors that could influence whether the gate opens or closes are behavioral and psychological,[4] such as the level of attention paid to the pain, the emotion associated with it, and related experiences.[5]

The role of psychological factors in the experience of pain has become even more critical in light of recent work related to the neuromatrix.[6–8] The neuromatrix is an extensive neural network representing the cerebral signature for pain perception. This network is deemed to mediate the pain experience itself,[9] and the authors use a biopsychosocial model[7] to describe pain as an amalgam of affect, cognition, and sensation mediated through diverse brain regions.[10] In the original model, parallel networks contribute to the sensory-discriminative (S), affective-motivational (A), and evaluative-cognitive (E) dimensions of the pain experience.[8] In this view, pain is not only an unpleasant sensory experience, but also a multisystem output that is aimed to action[11] with the primary goal of restoring the brain's homeostatic regulation system.[8,12,13]

Recent research[10,14,15] has partially challenged the concept of neuromatrix; pain intensity can be dissociated from the magnitude of response in the matrix, and the neural configuration of the matrix also appears responsive to

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non-nociceptive stimuli. However, the idea of a complex pain network is still fundamental to understand how the final experience of pain is mediated by different factors, including cognitive and emotional factors.[16,17] According to the review by Linton and Shaw,[18] psychological factors involved in pain experience deserve to be recognized and treated independently of physiological factors. Attention is particularly important because pain perception requires that cognitive resources be directed toward the painful stimulus. A patient's interpretation of the events surrounding the painful stimulus, expectations about pain, cognitive sets, and preexisting beliefs and attitudes all play a role in the way a patient experiences and copes with pain. Furthermore, emotional activations have a strong effect on pain experience. Not only does pain generate negative emotions such as fear and anxiety,[19] but also emotions actively mediate the experience of pain (e.g., they are associated with higher self-reported pain[19,20]). Moreover, recent research suggests that anticipatory anxiety related to difficult incoming situations could directly *generate* pain experiences, even in the absence of actual painful stimuli in the environment.[21]

Given that distraction and other psychological factors influence the experience of pain, numerous interventions aimed to reduce pain in medical procedures are based on distraction techniques.[22,23] Patients are engaged in tasks at the same time of their pain experience. Patients report significant pain reduction when they allocate cognitive and attentional resources to the distractor stimulus. To date, distraction techniques have used many types of materials and activities to engage patients' attentional system and help them to manage their pain. Past research has found that relaxation, hypnosis,[24] cognitive tasks,[25–27] movies, and nurse coaching[28] all reduce patients' experience of pain. More recently, virtual reality (VR) has emerged as an innovative and very efficient distraction tool. In VR, a patient is fully immersed into a simulated environment by using a head-mounted display, headphones with environmental sound and/or noise reduction, and a head-tracking system that allows the patient to naturally move in the virtual environment. Moreover, VR can be interactive, so that the user is able to act within the virtual environment to achieve a goal.

Several reviews about the efficacy of VR-based analgesia have already been published,[5,29,30] and some of these reviews recognize the importance of properly understanding the role of patients' individual characteristics[31] and subjective experience[32] when considering the effectiveness of VR as a pain reliever. If pain distraction is a psychological process, then psychological factors need to be considered to improve its efficacy. For this reason practitioners and researchers have experimented with distraction in different forms by manipulating its intensity and adapting their methods to different types of pain through different contexts. Additionally, VR methods vary in the technology that they employ, and experience in a VR simulator can vary based on the active contribution of the user's cognitive and emotional characteristics.[33] VR functioning and effectiveness are sensitive to the user's expectations, emotions, and engagement in the activity. To our knowledge, no reviews of VR-based analgesia have directly assessed the effects of psychological factors. Thus, we decided to focus our review on these factors to outline the psychological validation of VR-based analgesia in order to provide insights and guidelines for future implementation. In general, psychological factors influence both the experience of pain and the treatment outcome,[18] so they must be properly assessed in pain management interventions. Focusing on the particular intervention of VR-based analgesia, we then propose a theoretical discussion about the different effects of the psychological factors upon the process.

Methods

We followed guidelines from the preferred strategies to report items in systematic reviews (PRISMA[34]).

Search strategy

A preliminary search performed independently by two of the authors identified several psychological factors analyzed in past research on VR-based pain management. Some factors are related to the subjective experience of the virtual environment, such as sense of presence or immersion; others are emotional and concern patients' individual reactions to the pain management situation, such as anxiety or fun. We then performed an extensive review of the scientific literature to identify articles investigating psychological factors, specifically immersion, presence, fun, and anxiety. A computer-based search was carried out (updated January 2014) on scientific databases (Scopus and PubMed) using the following search string: (pain control OR pain management OR analgesia AND virtual reality) AND (presence OR immersion OR fun OR anxiety).

Systematic review flow

Figure 1 illustrates the flow diagram of the review process. In total, 156 publications emerged from an initial search. All publications were individually abstract-screened by the authors on the basis of the following inclusion criteria:

a. Research article
b. Experimental design (either between or within subjects) with at least one group of participants (single-case studies excluded)
c. Measured at least one of the psychological factors of interest

After this screening, 19 nonduplicated citations emerged. A deeper investigation of these 19 articles was performed by two authors in order to select articles that met the full criteria, resolving disagreements by consensus. This analysis excluded eight articles because VR was used for purposes other than distraction or the virtual system used was a video game without immersion devices. Ultimately, 11 articles met the full criteria and were included in this review (see Table 1 for the summary of the features of each article included).

Results

The selected articles will be analyzed considering each psychological factor separately. Thus, each of the following sections will take into account one psychological factor and will describe the relevant results. If one article has considered more than one factor, then it will be discussed in different sections.

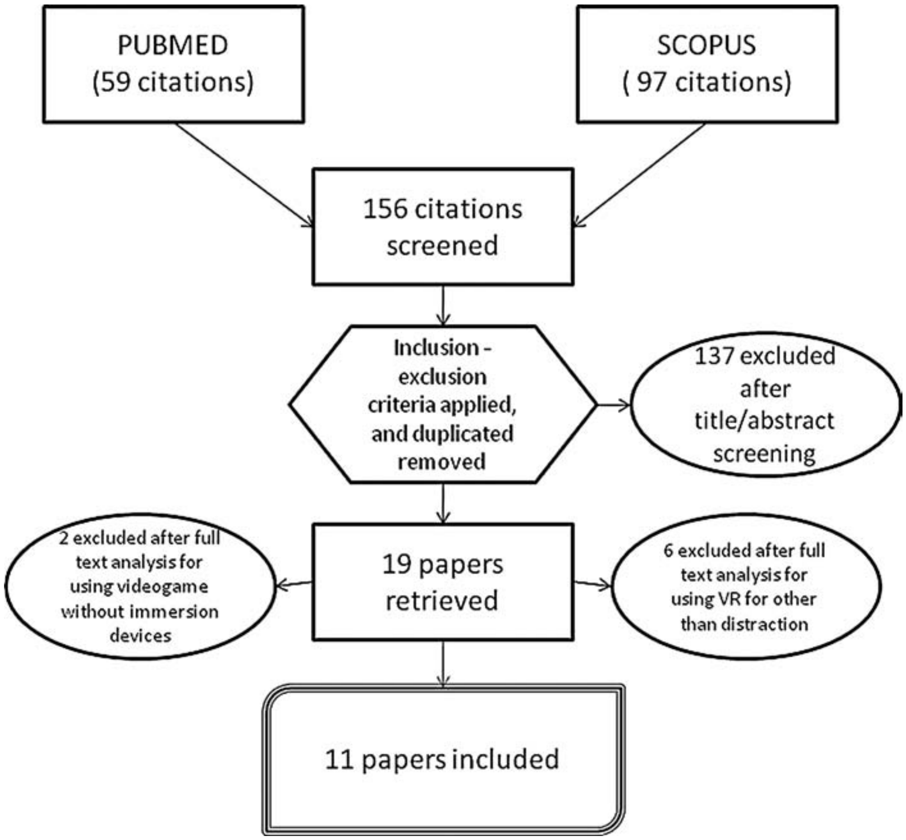

FIG. 1. The flow diagram of the review process.

Immersion/presence

There is sometimes confusion between the concepts of immersion and presence.[35] Immersion is defined as the physical/sensorial stimulation provided by the virtual environment[35,36] and the degree of perceptual realism that the virtual system is able to achieve.[37,38] A sense of presence is defined as the illusion of actually being in the virtual environment. From an experiential viewpoint, a VR user could feel more or less *present* in the environment he or she is interacting with.[39–41] The sense of presence could be considered as the psychological equivalent of immersion,[42] though presence may not be described only in technical terms. If technological advancements in the VR machinery influence the sensation of ''being there,'' the state of mind of the user, the user's personality traits, and the arrangement of a narrative context within the virtual experience also play a fundamental role.[33,43–45] For this reason, the sense of presence measured in users has been often considered as sort of ''ecological validity'' for VR implementations.[45,46]

There is surely debate about how to measure the sense of presence. Past studies have considered behavioral responses,[47] physiological correlates,[48,49] and qualitative interviews,[50] but self-report instruments are the most frequently used method to assess presence. Users are asked to report their presence level on a scale when answering questions about how much they felt immersed into the virtual environment. Moreover, a number of validated questionnaires to evaluate presence are available.[51,52] Ten out of the 11 studies included in this review evaluated presence. However, presence is sometimes analyzed only as a one-condition control variable. This happens when the design of a study uses an experimental group of participants who are exposed to VR distraction and a control group that either is or is not exposed to another type of distraction. Some studies only measured presence in the VR condition, given that presence is an important control for the efficacy of VR.[53–57]

Gutierrez-Martinez and colleagues[54] investigated the effects of VR-based analgesia in a group of 37 volunteers who were exposed to experimentally induced pain by placing their hand in a cold pressor. All volunteers participated in two consecutive sessions, one session using VR (Surreal World, a presentation of 3D environments with strange and evocative images) and the other session using only a blank screen. The session with VR produced significant reductions in pain compared with the control condition. The authors found a significant negative correlation between subjective pain ratings and presence ratings: The greater the sense of presence in the VR condition, the more attention drawn to the VR environment, and consequently the perceived pain is reduced. Similar results were found by Hoffman et al. (11 participants with burn wounds)[58] and by Tse and colleagues (72 participants with experimentally induced pain).[59] Presence ratings (or, in the case of Tse et al.,[59] ''the degree of immersion'') were positively correlated with an increase of the pain threshold. Furthermore, in three different studies with 88 total participants of different ages, Sharar et al.[57] measured presence in the VR conditions. Interestingly, children reported higher levels of presence (and also of perceived ''realness'' of the environment) than adults.

A few studies tested participants who were already experiencing pain, rather than inducing pain experimentally.

Table 1. Features of the Included Studies

Reference	*Pain type*	*Sample*	*Design*	*VR content*	*Results for psychological factors: presence/immersion*	*Results for psychological factors: fun*	*Results for psychological factors: anxiety*
1. Hoffman et al.[61]	Experimentally induced	39 students, age range 18–20	Between-subjects design (high-tech VR vs. low-tech VR)	SnowWorld	High-tech VR mitigated pain confronted with low-tech VR; sense of presence was higher in subjects in high-tech VR condition.	Patients rated how much fun they had during the most recent pain stimulus. FUN ratings were higher in high-tech condition and correlated with high presence.	X
2. Gutierrez-Martinez et al.[54]	Experimentally induced	37 subjects	Within-subjects design; VR vs. non-VR	Surreal World (auditory and visual inputs based on art images)	High presence correlated with low pain intensity.	X	X
3. Hoffman et al.[58]	Real pain (burn wound debridement in the hydrotherapy tank)	11 subjects	Within-subjects design; VR vs. non-VR	SnowWorld	Patients with the highest presence ratings showed significant reductions in worst pain ratings.	Patients with the highest presence ratings also reported the highest levels of perceived fun.	X
4. Maani et al.[55]	Real pain (combat-related burn injuries)	12 soldiers	Mixed design (high pain ratings vs. low pain ratings × VR vs. non-VR)	SnowWorld	Presence was considered only as a control variable for VR condition's efficacy; participants reported moderate levels of it.	Participants were asked how much fun they had during VR. Those with highest ratings of pain reported a 100% increase of fun; those with lower pain ratings also reported significant fun level.	X
5. Van Twillert et al.[75]	Real pain (burn injuries)	19 subjects	Within-subjects design (VR vs. non-VR and other distraction methods)	SnowWorld	X	X	For 13 of 19 patients, VR produced significant reductions in pain. Trait anxiety and state anxiety were measured. Reductions of it were found in VR and television conditions, but not significant.
6. Tse et al.[59]	Experimentally induced	72 subjects	Within-subjects design (pain is measured every 20 seconds of the intervention)	A VR system to watch videos of natural environments such as mountains and falls	''Degree of immersion'' results correlated with the improvement in pain threshold.	X	The participants having a lower level of anxiety prior to experiment had better improvement in pain management.

(*continued*)

Table 1. (Continued)

Reference	*Pain type*	*Sample*	*Design*	*VR content*	*Results for psychological factors: presence/immersion*	*Results for psychological factors: fun*	*Results for psychological factors: anxiety*
7. Gold et al.[53]	Real pain (during IV placement)	20 children	Between-subjects design: VR vs. non-VR	"Street Luge," a fast-moving virtual world in which the player races downhill on a skateboard	Presence was considered only as a control variable for VR condition efficacy; participants reported "sufficient" levels of it.	X	Anticipatory anxiety regarding IV placement positively correlated with general anxiety of children and anxiety during past procedures.
8. Chan et al.[62]	Real pain (burn injuries)	8 children	Between-subjects design; VR vs. non-VR × before, during, and after the treatment	An interactive game taking place in an ice cream factory	Presence did not show significant correlations with pain ratings; also pain ratings did not significantly differ between VR and non-VR conditions.	X	Qualitative interviews to nurses: children in VR condition showed reduced anxiety in their observable behavior.
9. Sharar et al.[57]	Real pain (burn injuries)	88 subjects (different ages through three different studies)	Within-subjects design; VR vs. non-VR	SnowWorld	Sense of presence was measured only in VR condition as a control variable; it resulted higher in children.	Fun related to VR was analyzed only in studies 2 and 3. VR condition obtained significantly higher fun scores than non-VR.	X
10. Wender et al.[60]	Experimentally induced	21 subjects	Between-subjects design; interactive VR vs. passive VR	SnowWorld	Interactive VR resulted more effective in reducing pain ratings, but sense of presence showed no significant differences between conditions.	Fun during the most recent pain stimulus. Interactive VR condition obtained significantly higher fun scores than noninteractive VR.	X
11. Schmitt et al.[56]	Real pain (burn injuries)	54 subjects	Within-subjects design; standard pharmacologic therapy + VR vs. standard pharmacologic therapy + non-VR	SnowWorld	Sense of presence was measured as a control variable in VR condition; it remained constant through the 5 days of the study.	Fun ratings were significantly higher in VR condition than in non-VR condition. They remained constant through the 5 days of the study.	X

VR, virtual reality.

Maani et al.[55] compared VR and a control condition without VR in 12 soldiers with combat related burn injuries; Gold et al.[53] used a similar protocol with 20 children who were experiencing pain from intravenous placement. Both experiments were successful in reducing pain using VR and showed that participants reported sufficient levels of presence in the VR condition. In particular, Gold and colleagues[53] consider a good presence level as an important indicator to validate their virtual environment (*Street Luge*) for future applications.

Schmitt et al.[56] considered the integration of VR with standard pharmacological pain therapy in a 5-day study with repeated sessions. Participants were 54 pediatric patients with burn injuries. Researchers found a meaningful reduction in pain ratings in the VR condition starting on the first day, and the reduction was maintained over the subsequent therapy sessions. Presence ratings were also affected on the first day of treatment and maintained over the course of the experiment.

Wender et al.[60] tried to understand the importance of interactivity in the analgesia effect of VR, so they compared the use of an interactive VR and a noninteractive VR with 21 subjects (pain was experimentally induced). Interactive VR showed an increase of 75% in the perceived analgesia effect compared with noninteractive VR. Presence ratings did not significantly differ between interactive and noninteractive VR. However, the opposite was found by Hoffman and colleagues.[61] Noninteractive high-technology VR showed stronger pain reduction and higher presence ratings confronted with low-technology VR in 39 students with experimentally induced pain.

The only other negative result was reported by Chan et al.[62]: Eight children with burn injuries were divided between a VR condition and a non-VR control. Children in the VR condition played an interactive game featuring an ice cream factory. Although a general reduction in perceived pain emerged, it did not discriminate between VR and non-VR and so sense of presence showed no significant correlations with pain ratings.

Fun

Users' emotional responses are fundamental for the effective functioning of a virtual environment,[63] and surely an emotional involvement appears to be strongly connected to a sense of presence and perceived realism in VR.[41,43,64] For this reason, many researchers consider the concept of ''fun'' and evaluate positive emotions and delight in virtual applications. To date, fun has been considered in many user experience studies[65,66] to the point that some usability experts describe their work as ''funology.''[67] Six out of the 11 studies in the present review evaluated participants' experience of fun, all obtaining strong positive results. Hoffman and colleagues[58,61] found that fun ratings positively correlated with presence ratings and pain reduction. Similarly, soldiers with high pain ratings also experienced more fun when exposed to VR.[55] In the experiments by Sharar et al.[57] and Schmitt et al.,[56] participants in the VR condition obtained significantly higher fun ratings compared with participants who participated in a non-VR condition. Wender et al.[60] compared interactive VR and noninteractive VR in 21 healthy participants with experimentally induced pain and asked them to rate their fun during the most recent painful sensation. Participants in the interactive VR condition showed significantly higher ratings of fun compared with participants in the noninteractive VR condition. Taken together, these studies suggest that participants' experience of fun is a critical component of the effectiveness of VR as a pain reliever.

Anxiety

In the context of pain management, negative emotions of patients are also an important factor. Anticipatory anxiety is a well-known problem for patients who are involved in bothersome or painful medical procedures.[68,69] In the field of VR-based pain reduction, a number of studies have considered the particular moment of wound care treatments in patients with burn injuries, events that are often characterized by anticipatory anxiety regarding the upcoming pain (see[70] for a review). Despite the great amount of studies measuring anxiety during VR-based interventions for pain reduction, none of them considered anxiety as a mediator of VR efficacy. For this reason we selected studies that either provided a measure of anxiety changes between pretreatment and treatment, investigated the difference between state and trait anxiety, or analyzed the correlations between anxiety and other variables affecting the virtual experience.

Chan et al.[62] considered anticipatory anxiety in their experiment, which involved eight children with burn injuries. The children played an interactive VR game while nurses changed their dressing. The researchers used qualitative interviews with the nurses, a common method to understand the relationship between pain and anxiety in medical procedures.[71,72] The authors report important reductions in anxiety: During VR exposure, patients stopped crying and kicking and, with little encouragement by the nurses, started concentrating on the game without showing negative reactions to the procedure. Gold et al.[53] used validated measures to analyze affective pain (i.e., worry about the pain) and the Childhood Anxiety Sensitivity index[73] to assess trait anxiety in their sample of children undergoing intravenous placement. Anticipatory anxiety related to the procedure was also assessed. The analysis showed multiple significant correlations between measures. Affective pain increased in the control condition with no VR, but remained identical in VR condition, and was also significantly correlated with pain intensity. Anticipatory anxiety regarding the procedure positively correlated with child's general anxiety, and also with the anxiety they experienced during past intravenous placements.

State and trait anxiety may influence the effectiveness of VR differently. Tse et al.[59] induced a controlled pain in 72 participants using a tourniquet technique. They assessed anxiety with a single Likert scale (1–10 level of anxiety) before the experiment and found that participants' ratings were negatively correlated with their improvement in pain threshold during the VR stimulation. Participants with a lower level of anxiety had better improvement in pain reduction; therefore, it may be important to use proper instruments to evaluate dispositional anxiety in patients before VR interventions, such as STAI.[74] In fact, Van Twillert et al.[75] were the only researchers to measure trait and state anxiety using the STAI questionnaire. Patients with burn injuries ($N = 19$) were either not distracted or were exposed to different distraction methods, including VR (SnowWorld), during their dressing change. A state anxiety reduction (2%) was present in conditions with VR and television, but this reduction was not significant.

Discussion

The findings of the reviewed literature indicate that psychological factors influenced the effectiveness of VR-based analgesia. These studies suggest that elements related to the subjective experience of VR influence or are related to the outcomes of interventions. In the few studies that did not find significant differences for what regard the psychological factors, such as Chan et al.[62] with presence, the analgesic effect is not significant too. The reviewed studies suggest that a high sense of presence is associated with desirable analgesia effects. It is also important that participants have fun in the virtual experience, as pleasant virtual environments tend to generate better distraction outcomes. Subjects who experience less pain also report having more fun. The role of anxiety must also be considered, as anxiety related to the intervention could be reduced by VR, and participants with low anxiety are more responsive to VR-based analgesia.

Psychological factors, considered broadly, might interact with VR-based analgesia in two ways. On the one hand, they could directly modify the experienced pain, regardless of the VR system (e.g., high anticipatory anxiety increases the amount of perceived pain). On the other hand, they could influence the efficacy of the VR technology involved in the process of pain management via distraction (e.g., high attention devoted to the VR increases its distractive properties). Figure 2 shows a schema of how the psychological factors considered here impact the VR-based analgesia process. However, we think that the study of psychological factors in VR-based analgesia is in its infancy and, to date, it has not been performed with validated and solid instruments. In the following sections, analyzing the psychological factors one by one, we provide some guidelines to develop and improve the study of VR-based analgesia in the future.

Presence

Presence may be the most important psychological factor that is *directly linked* to the experience of VR. The results of the reviewed studies showed that a high level of presence appears to be associated with desirable analgesia effects. The sense of presence may not have a direct impact on pain experience *per se*; however, presence could allow VR to be distractive from a perceptual point of view. Some recent accounts strongly link presence to attention,[76] and measuring presence informs experimenters whether their virtual representation is perceived as an environment by users. It is a place where they could have experiences, watching, hearing, and interacting with things. They could experience imaginary adventures in the VR environment and enact their intentions through the mediation of connected peripherals.[41] In conclusion, VR is a very rich stimulus that is also able to distract people from their pain, but for VR to be effective, users must have the feel of being in it. For this reason, it is important to measure presence to monitor VR-based interventions.

Ten of the 11 articles considered in this review measured the sense of presence. Unfortunately, all but two studies[53,62] used a single question, such as, ''To what extent did you feel like you 'went into' the virtual world?'' Chan et al.[62] used the Presence Questionnaire, while Gold and colleagues[53] used a Child Presence Questionnaire whose reference is not provided. Research and debate on the sense of presence suggests that a number of factors generate or influence presence (see[39] for a review), so some complex questionnaires are now available to properly assess this construct. A single question may not be a complete way to measure the sense of presence, since the sensation of ''being there'' normally emerges from several different elements of the experience. Reducing presence to a unique question risks preventing the participant from evaluating the complexity of his or her sensations. For example, the Presence Questionnaire by Witmer and Singer[52] measures different dimensions such as involvement, perceived control, naturalness/realness of the virtual representation, and interface quality. In contrast, the ITC-SOPI by Lessiter and colleagues[51] considers additional elements, such as characteristics of the user (previous experience with technology and virtual devices) and possible negative effects that interfere with the sense of presence (symptoms related to simulator sickness).

Another issue is that researchers often measured the sense of presence as only a one-condition control variable. This is understandable because, in these cases, they compared VR with non-VR or with other distraction tools that do not promote immersion. However, to really advance knowledge about the effectiveness of VR-based analgesia, different

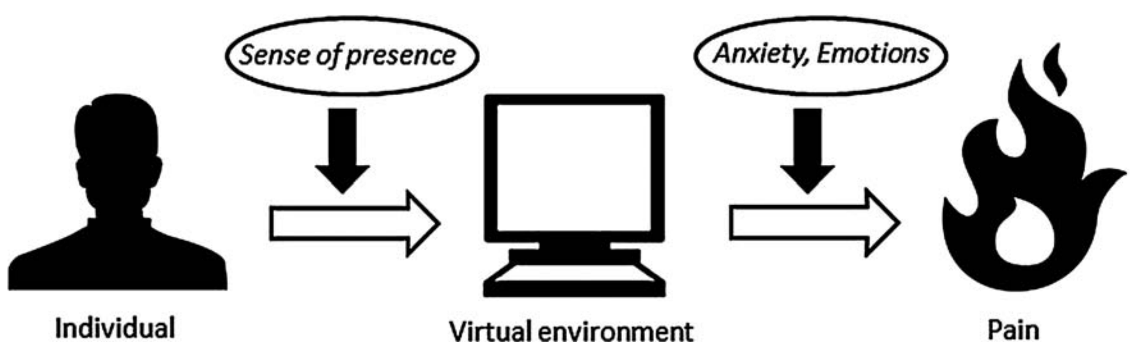

FIG. 2. The virtual reality–based analgesia process. The experience of pain by the individual is mediated by the virtual environment. Sense of presence affects the effectiveness of the virtual environment as a distraction tool, while anxiety and emotional responses affect directly the perceived pain.

virtual environments have to be compared. Certainly, numerous experiments and reviews today offer support to the efficacy of VR-based analgesia. However, guidelines about how exactly a virtual environment has to be conceived and designed are generally missing from past research. Hoffman et al.[61] compared high-tech VR with low-tech VR (i.e., differently advanced machineries for VR), while Wender and colleagues[60] compared interactive VR with noninteractive VR. Other comparisons are necessary in order to identify the best-performing type of technology to be used in pain management. Is one type of device better than others? Does narrative/cinematic VR provide more distraction than a simple exploratory design? Are there differences in gender or age regarding the response to different types of contents in VR? In the context of similar research objectives focused on the different types of VR, measuring the sense of presence with proper instruments could be a fundamental variable, given its strong links with efficacy.

Fun and anxiety

We combine fun and anxiety here into a single section as *emotional responses*. Both fun and anxiety were related to VR-based analgesia's efficacy and the two responses were always analyzed independently. The association between anxiety and pain is a well-known phenomenon in clinical settings. Scientific findings supported this common experience: Some studies demonstrated that anxiety levels can predict pain intensity.[77,78] Furthermore, anxiety enhances the different components related to the experience of pain, including pain threshold, pain discrimination, and pain intensity. A possible explanation for the effect of anxiety on pain has been proposed by Ploghaus and colleagues.[79] The authors conducted a functional magnetic resonance imaging experiment in which they compared activation responses to noxious thermal stimulation while perceived pain intensity was manipulated by changes in either physical intensity or induced anxiety. Imaging data pinpointed differential activity in the hippocampus in response to identical noxious stimuli depending on the anxiety modulation. In other words, anticipatory anxiety acts as a prime, recruiting the hippocampus to amplify the aversive event and preparing the individual to behave adaptively in case of the worst possible outcome. While sense of presence intervenes on the efficacy of VR as a distraction tool, anxiety (and emotional responses in general) can also directly operate on the experience of pain.

Research on the influence of emotions on the experience of virtual environments (and vice versa) is broad[80–82] (provide some diverse examples), but recent approaches that analyze the entire emotional response, and not just *a priori* emotional categories, have theoretical and methodological benefits.[83] Specifically, dimensional conceptions of emotions provide better recognition of ambiguous and complex affects.[84] Moreover, these models have been particularly useful for the research in applied cyberpsychology.[85] According to Russel's model,[86] an emotion is a modification of the ''core affect,'' a neurophysiological category corresponding to the combination of valence (positive/negative) and arousal (low/high intensity). Adaptive self-report methods such as the Self-Assessment Manikin,[87] which provides participants with pictorial Likert scales to evaluate their own experience on a variety of dimensions, are suitable to measure the emotional response in its entirety, without forcing participants into in predesigned categories. Also, psychophysiological measures could provide researchers with a more objective monitoring of emotions during the experimental tasks. The use of similar instruments and the reference to dimensional models of emotions in future research on VR-based analgesia could answer interesting research questions. How intense are emotions during treatment, and how could a high or low emotional intensity influence patient outcomes? Are emotions with positive valence (fun) or emotions with negative valence (anxiety) predominant during pain management? Can these emotions coexist, and with what effects?

Conclusions

The present review analyzed the impact of psychological factors on the effectiveness of VR-based interventions designed to distract from pain. The necessity to consider the phenomenon of pain as multifaceted is supported by the neuromatrix hypothesis.[12] According to this theoretical framework, pain is an amalgam of affect, cognition, and sensation mediated through widespread brain regions, and is likely to be influenced by several factors. A review of the psychological factors involved in VR-based pain distraction reveals that psychological factors (specifically, presence, fun, and anxiety) influence VR efficacy. However, this review also reveals some gaps and limitation in the literature, namely, that few studies in the extensive literature on the use of VR for pain management specifically considered these psychological factors, and sometimes these factors were not analyzed as influencing the effectiveness of VR. Given the present findings, we made only the first steps to predict which psychological state should be promoted during virtual experience in order to achieve a greater reduction in pain. Upon recognizing the importance of these psychological factors, it is now necessary to measure them with validated tools.

Author Disclosure Statement

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Virtual Reality as a Distraction Technique in Chronic Pain Patients

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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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[2]Virtual Reality Medical Center, San Diego, California.

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.

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.

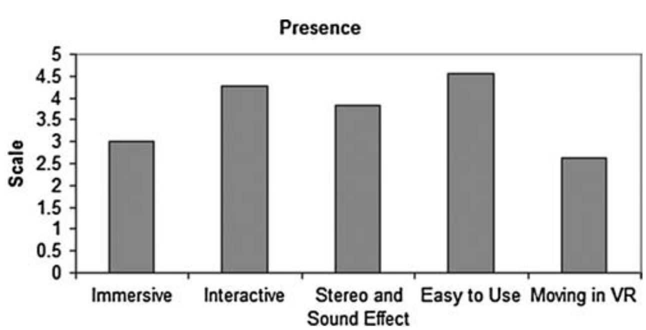

FIG. 1. The scales of sense of being in the virtual reality (VR) simulated environment—Ease of use, Immersive, and Interactive effects on a scale from 1 to 7, where 7 represents the normal experience of being in a place. 1 = ''not at all,'' 7 = ''very much.'' VR environment was easy to use, interactive,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

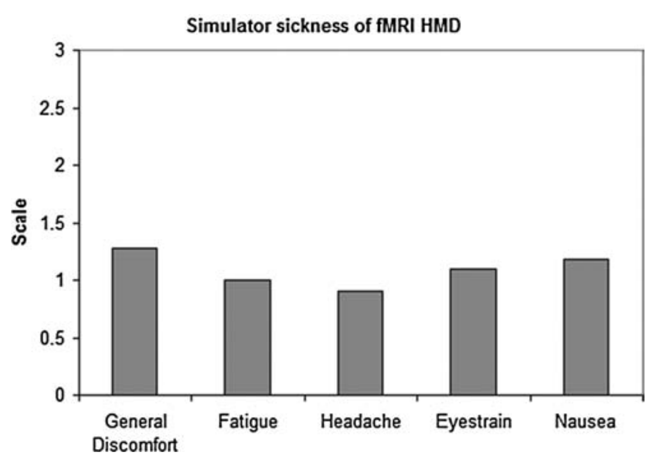

FIG. 3. Sickness exploration questionnaire scores in terms of general discomfort, fatigue, headache, eyestrain, and nausea, their mean scales are all <1.5, where the scales range from 0 to 3. 0 = ''Absent,'' 3 = ''Severe.'' No serious side effects were observed. It was determined that VR was indeed safe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

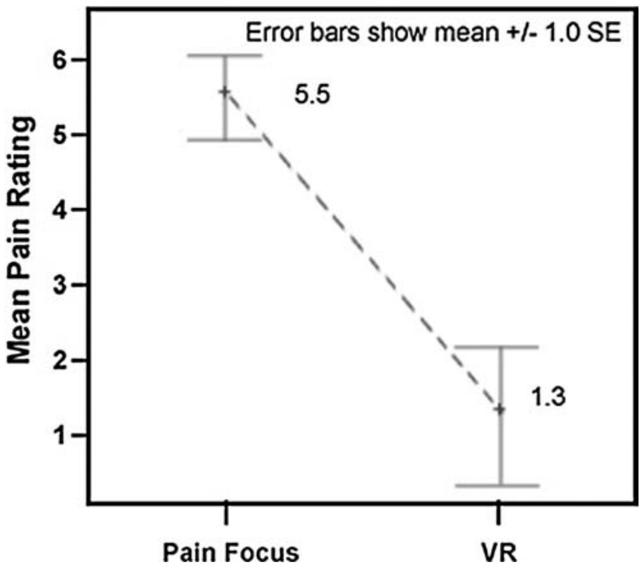

FIG. 4. Comparison of subjective pain ratings.

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

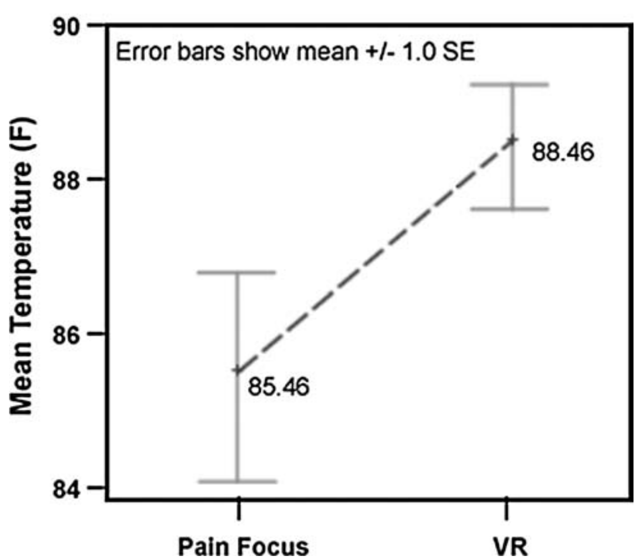

FIG. 5. Comparison of objective pain ratings.

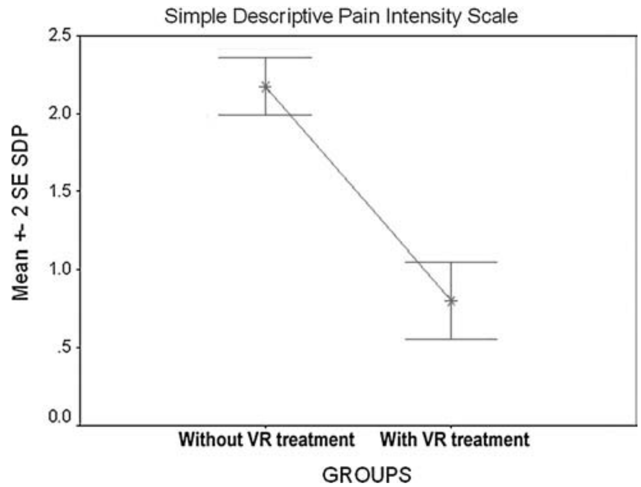

FIG. 6. Comparison of reported pain intensity.

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

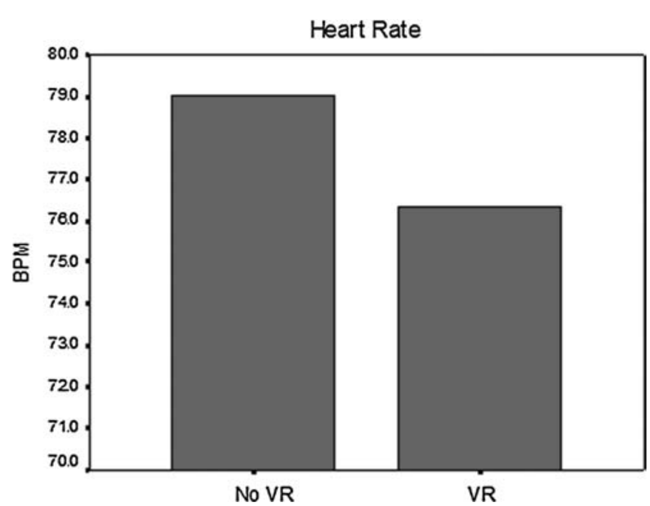

FIG. 7. Comparison of heart rate.

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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Differential Effects of Two Virtual Reality Interventions: Distraction Versus Pain Control

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Abstract

There is evidence that virtual reality (VR) pain distraction is effective at improving pain-related outcomes. However, more research is needed to investigate VR environments with other pain-related goals. The main aim of this study was to compare the differential effects of two VR environments on a set of pain-related and cognitive variables during a cold pressor experiment. One of these environments aimed to distract attention away from pain (VRD), whereas the other was designed to enhance pain control (VRC). Participants were 77 psychology students, who were randomly assigned to one of the following three conditions during the cold pressor experiment: (a) VRD, (b) VRC, or (c) Non-VR (control condition). Data were collected regarding both pain-related variables (intensity, tolerance, threshold, time perception, and pain sensitivity range) and cognitive variables (self-efficacy and catastrophizing). Results showed that in comparison with the control condition, the VRC intervention significantly increased pain tolerance, the pain sensitivity range, and the degree of time underestimation. It also increased self-efficacy in tolerating pain and led to a reduction in reported helplessness. The VRD intervention significantly increased the pain threshold and pain tolerance in comparison with the control condition, but it did not affect any of the cognitive variables. Overall, the intervention designed to enhance control seems to have a greater effect on the cognitive variables assessed. Although these results need to be replicated in further studies, the findings suggest that the VRC intervention has considerable potential in terms of increasing self-efficacy and modifying the negative thoughts that commonly accompany pain problems.

Introduction

Research over the last decade has shown that virtual reality (VR) is a useful tool for pain management. In general terms, VR reduces pain levels, anxiety, unpleasantness, and the need for analgesia, at the same time as increasing the pain threshold, pain tolerance, and procedural cooperation. Moreover, people enjoy using VR and are keen to use it again during other painful medical procedures.[1–3]

The effects of VR have been mainly explained in terms of pain distraction. Since attentional resources are limited, diverting attention away from pain by means of VR leaves fewer resources available for pain processing.[1] This mechanism is not new, as distraction is a traditional psychological intervention for pain that has been shown to possess considerable efficacy.[4] However, VR distraction is thought to be more effective because it is immersive and engaging, integrating many sensory experiences and, therefore, demanding a greater amount of attention.[5]

What is not completely clear is whether VR works solely by drawing attention away from pain. For example, it has been hypothesized that VR may also work by changing the way in which people think and perceive reality.[6] Being able to identify mechanisms of action other than pain distraction, or designing interventions to act specifically on other mechanisms, could have enormous potential in terms of extending the application of VR beyond the clinical setting of acute procedural pain (where most applications have so far been applied[7–9]). Applying the strategy of pain distraction in a situation of nonacute pain outside the clinic is difficult due to the amount of equipment that is needed. However, if VR has other mechanisms of action (such as changing the way in which people think), the resulting effects could more easily be extrapolated outside the healthcare setting, thereby raising the possibility of developing useful strategies for persistent pain or long-term pain problems.

Some recent studies have used VR applications for purposes other than pain distraction. For example, Shiri et al.[10]

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designed a VR system that aimed to reinforce patients with pain-free virtual images once they achieved an adequate state of relaxation (as measured by a biofeedback procedure). Results showed that the VR system improved daily functioning and quality of life and decreased pain ratings in a sample of children with chronic headache. In another recent example, Botella et al.[11] combined cognitive behavioral therapy with a VR environment that sought to develop relaxation and mindfulness skills in fibromyalgia patients. Results showed a significant reduction in pain and depression, as well as an increase in positive affect and the use of healthy coping strategies.

In order to explore whether VR might have a mechanism of action other than pain distraction, we developed and tested a VR intervention whose aim was to increase pain control. The intervention involved presenting subjects with a figure that represented pain and which could be converted into a figure representing no pain. It was hypothesized that controlling the virtual figure could help people to increase their sense of pain control. The specific aim of the present study was to test the effects of this intervention on a set of pain-related and cognitive variables, comparing the results with those obtained when using an environment designed for pain distraction.

Method

Participants

Participants were 77 psychology students at the University of Barcelona (70 female). They were aged between 20 and 56 years ($M = 24.06$; $SD = 5.22$), and received course credits for taking part. They were all instructed to refrain from consuming alcohol or using other drugs on the day prior to the study. The exclusion criteria were cardiovascular disease, hypertension, metabolic dysfunctions, pregnancy, Raynaud's disease, epilepsy, mental disorder, chronic pain conditions, diseases producing neuropathic pain, or having taken pain/anti-inflammatory medication during the 4 hours prior to the study.

Apparatus and equipment

Cold pressor apparatus. A plastic tank (34 cm × 34 cm × 16 cm) filled with iced water maintained at 6°C (± 1°C) was used for the cold pressor procedure. To ensure that the water temperature remained constant before each trial, a waterproof thermometer was attached to the inside of the tank. However, the temperature could not be seen by the participant. The range of tolerance achieved with this water temperature was between 1 3 minutes,[12,13] thereby giving participants assigned to the VR conditions enough time to interact with the VR environments.

Before each cold water immersion, an additional tank with warm water (32°C) was used for stabilization of hand temperature. A digital thermometer to measure hand temperature and an atmospheric thermometer to measure room temperature were used. The room temperature was maintained at 22°C.

Hardware. The VR environments were displayed with two BARCO ID R600 projectors controlled by a computer. They were projected onto a 2.43 meter × 1.82 meter screen with a resolution of 1024 × 768 pixels. The distance between the screen and the participant, who was provided with StereoGraphics Corp. polarized 3D glasses, was 2 meters.

Software. The VR environments were modeled and animated with 3D Studio Max 8. Adobe Photoshop 7 was used to create the different textures. Virtools 3.5 (Educational Version) was used to program physical and visual effects, such that the participant could interact with the VR environment.

Measures

There were five pain-related measures:

Pain threshold. Pain threshold was defined as the number of seconds of immersion in the cold pressor tank until the participant reported that the cold sensation first began to feel painful.

Pain tolerance. Pain tolerance was defined as the total number of seconds that each participant kept his/her hand immersed in the cold water.

Pain sensitivity range. Pain sensitivity range (PSR) was defined as the total number of seconds that passed between the participant first reporting that the cold sensation had begun to feel painful (pain threshold) and the point at which his/her hand was withdrawn from the cold water (pain tolerance).

Strongest pain intensity. The strongest pain intensity was assessed with a visual analog scale (VAS) that consisted of a line with two anchors: ''no pain'' and ''the most intense pain.'' Immediately after withdrawal, participants were asked to rate the strength of the most intense pain they had felt during the procedure by making a vertical mark on the point of the line that they considered representative of their pain. The distance from the left anchor to the vertical mark served as the pain rating for the strongest pain intensity.

Estimation of time. Participants were asked to estimate how long they thought they had had their hand in the water by the time of withdrawal. The difference between the estimated and real time was calculated.

Two cognitive measures were used:

In vivo pain catastrophizing. This was assessed using the 13-item Pain Catastrophizing Scale (PCS[14]). Subjects are asked to reflect on past episodes of pain and to rate using a 5-point scale the frequency of the catastrophic cognitions described in each item. Scores can be computed for three subscales: helplessness, rumination, and magnification. Standard PCS instructions and items were modified slightly in order to assess catastrophizing cognitions in relation to the cold water immersion (e.g., by asking subjects to consider statements such as ''There was nothing I could do to reduce the intensity of the pain'' or ''I worried all the time about whether the pain would end''). This was done because laboratory-based studies have highlighted the importance of specifying the context in which catastrophizing is assessed.[15–17] Results in our sample showed that the internal consistency was high for the in vivo PCS total score ($\alpha = 0.90$).

Pain self-efficacy. Based on the work of Bandura et al.,[18] pain self-efficacy was assessed through two scales: (a) perceived self-efficacy for tolerating pain, and (b) perceived self-efficacy for reducing pain intensity. The first of these aspects was assessed by asking participants to estimate how much time they thought they would be able to keep their hand submerged in the cold water if they had to repeat the immersion. They have to give their answer according to a series of time categories corresponding to increasing durations of immersion; the categories covered a total range from 0 seconds to 8 minutes, at 30 second intervals. The second aspect—self-efficacy for reducing pain intensity—was measured using a scale that described four severities of pain (ranging from dull to excruciating). For each severity, participants were required to rate their perceived ability to reduce pain using a 3-point scale, ranging from 0 = ''limited ability'' to 2 = ''good ability.'' A total score (ranging from 0 to 8) was then computed, with higher scores indicating greater perceived self-efficacy in reducing pain. The internal consistency for this scale was adequate in the present sample ($\alpha = 0.78$).

Procedure

The study was approved by the ethics committee of the University of Barcelona. A between-subjects experimental design was used. Subjects participated individually and were randomly assigned to one of the following experimental conditions: (a) Non-VR intervention (control condition), (b) VR distraction intervention, or (c) VR control enhancement intervention.

Common instructions were initially given to all participants regarding the cold pressor experiment. The experimenter explained to participants that they had to immerse their nondominant hand in the cold water up to the wrist, palm-side down, and to leave their hand open (nonfisted). Participants were instructed to say ''It hurts now'' when their hand began to feel uncomfortable or hurt, and ''End'' when they decided to withdraw their hand from the water. All participants were asked to repeat the instructions to confirm that they had understood them.

Following these common instructions, participants assigned to the VR conditions (VR distraction and VR control enhancement intervention) were provided with stereoscopic glasses and spent 2–3 minutes learning the possible interactions with the virtual environment. This was done using their dominant hand to operate the mouse. Subsequently, and for all participants regardless of their experimental group, the lights in the room were turned off, with the experimenters remaining out of sight behind the participant in order to minimize any influence their presence might have on performance. The cold pressor trial was then immediately started. For safety reasons, the maximum permitted duration of immersion was 5 minutes, although participants were unaware of this. At the end of the trial, participants were asked to rest their hand on a towel placed on the table. They were then immediately asked to complete the VAS, the in vivo PCS, and the pain self-efficacy scales based solely on their experience during the cold pressor task. The specific features of each condition were as follows.

Non-VR condition (Non-VR). Participants assigned to the Non-VR condition were told that during the immersion, they had to look at a static blank screen in front of them.

VR distraction condition (VRD). To divert the attention of participants in this condition, a virtual environment called ''Surreal World'' was used. This was developed on the basis of surreal art images that were intended to surprise users with unreal objects that challenge the laws of physics. To improve the sense of presence in the surreal world, participants were able to generate simple interactions with the objects (e.g., clicking on certain objects will cause them to change or behave in another way). Participants were asked to navigate through the environment with one hand while immersing their other hand in the cold pressor.

VR control enhancement condition (VRC). For this condition, we designed a stereoscopic VR figure as a representation of pain. The figure, which appeared in the center of the screen against a black background, was an irregular sharp-edged polygon that was modelled according to certain sensory descriptors (e.g., burning, cutting, sharp, stabbing, and stinging) from the McGill Pain Questionnaire.[19] The figure was presented together with an unpleasant sound (a tone of 600 Hz at 80 dB). As was explained to participants, the initial figure and the sound represented an unpleasant pain sensation, but they could be gradually manipulated to achieve a pleasant and calm state (analogous to a situation of no pain). This pleasant state was represented by a spherical figure, with a certain resemblance to natural scenery, combined with an audio track produced by a generative music engine, creating a complex series of quiet environmental sounds.

Participants were asked to try to ameliorate their pain sensation (caused by the cold pressor) by modifying the virtual figure. To modify the initial stereoscopic figure, subjects simply had to click on the right button of the mouse. Three slider controls then appeared on the screen, and these enabled participants to change the shape and color of the figure, as well as the sound. They could also rotate the figure and move it nearer or farther away by clicking and dragging the mouse.

Data analysis

All the analyses were conducted using SPSS v20. Descriptive statistics were computed for the different pain-related measures and the cognitive measures. Between-subjects univariate analyses of variance (ANOVA) were conducted to test the effects of the three different conditions (i.e., Non-VR, VRD, and VRC) on each of the pain-related and cognitive measures. Post hoc comparisons were carried out to determine the specific differences between conditions.

Results

Pain-related measures

One-way between-subjects ANOVAs revealed significant differences between the three conditions for the following variables: pain threshold, $F(2, 74) = 3.56$, $p < 0.05$; pain tolerance, $F(2, 74) = 9.59$, $p < 0.0001$; pain sensitivity range, $F(2, 74) = 4.11$, $p < 0.05$, and estimation of time, $F(2, 74) = 3.17$, $p < 0.05$. There were no statistically significant differences in relation to pain intensity, $F(2, 74) = 0.88$, $p = 0.41$.

Post hoc comparisons (see Table 1) for pain threshold showed that it was significantly higher in the VRD condition compared with the Non-VR condition. None of the other comparisons showed significant differences in terms of pain threshold. As regards pain tolerance, this was significantly lower in the Non-VR condition as compared with both the

Table 1. Effects of Interventions on Pain-Related Measures

	Non-VR	*VRD*	*VRC*	*Pairs comparisons [95% CI]*
Pain threshold	19.97 (8.94)	70.10 (83.05)	62.12 (84.23)	No-VR < VRD* [−97.83, −2.43] VRD > VRC [−37.77, 53.73] VRC > No-VR (−5.54 ÷ 89.85)
Pain tolerance	47.44 (20.76)	145.38 (101.81)	148.74 (114.13)	No-VR < VRD** [−159.95, −35.93] VRD < VRC (−62.83 ÷ 56.12) VRC > No-VR **(39.29 ÷ 163.30)
Pain sensitivity	27.46 (19.50)	75.28 (78.64)	86.61 (100.31)	No-VR < VRD [−99.59, 3.97] VRD < VRC [−61.00, 38.33] VRC > No-VR* (7.36 ÷ 110.93)
Pain intensity	99.08 (24.36)	95.57 (35.02)	113.25 (75.23)	No-VR > VRD [−31.31, 38.34] VRD < VRC [−38.34, 31.31] VRC > No-VR (−20.65 ÷ 49.00)
Time estimation	−4.80 (24.01)	−21.92 (110.53)	−61.66 (72.70)	No-VR > VRD [−39.42, 72.40] VRD > VRC [−14.91, 95.66] VRC < No-VR * (−112.78 ÷ −0.95)

Data are mean (*SD*).
*$p<0.05$; **$p<0.001$.

VRD and VRC conditions, although there was no significant difference between the latter two conditions. The pain sensitivity range was significantly broader in the VRC condition in comparison with the Non-VR condition, but no significant differences were found for the other comparisons. Similarly, the underestimation of time was significantly greater in the VRC condition as compared with the Non-VR condition, but there were no significant differences for the other comparisons.

Cognitive measures

Statistically significant differences were observed in relation to self-efficacy for tolerating pain, $F(2, 74)=3.15$, $p<0.05$, and on the Helplessness subscale of the PCS, $F(2, 74)=4.62$, $p<0.05$. No differences were found for self-efficacy in reducing pain, $F(2, 74)=0.63$, $p=0.53$; PCS total scores, $F(2, 74)=1.25$, $p=0.29$; the Rumination subscale, $F(2, 74)=0.353$, $p=0.70$; or the Magnification subscale, $F(2, 74)=0.20$, $p=0.81$.

Post hoc comparisons revealed that self-efficacy for tolerating pain was significantly higher and helplessness ratings significantly lower during the VRC condition, as compared with the Non-VR condition. No significant differences emerged in any of the other comparisons (see Table 2).

Discussion

The aim of the present study was to test whether two different VR interventions, designed for pain distraction (VRD) and pain control (VRC), had differential effects on

Table 2. Effects of Interventions on Cognitive Measures Related to Pain

	Non-VR	*VRD*	*VRC*	*Pairs comparisons [95% CI]*
Self-efficacy tolerance	58.91 (48.63)	127.69 (175.25)	159.07 (160.07)	No-VR < VRD [−166.49, 28.93] VRD < VRC [−125.17, 62.41] VRC > No-VR* (3.30 ÷ 197.02)
Self-efficacy reduction	3.47 (1.44)	3.59 (1.30)	3.88 (1.31)	No-VR < VRD [−1.03, 0.80] VRD < VRC [−1.17, 0.58] VRC > No-VR (−0.50 ÷ 1.32)
Total catastrophism	18.90 (8.09)	15.68 (11.25)	14.52 (9.43)	No-VR > VRD [−3.59, 10.05] VRD < VRC [−5.44, 7.76] VRC > No-VR (−11.21 ÷ 2.43)
Helplessness	10.22 (4.53)	7.78 (5.96)	5.75 (4.30)	No-VR > VRD [−1.12, 6.01] VRD > VRC [−1.45, 5.52] VRC > No-VR** (−8.00 ÷ −0.94)
Rumination	7.45 (2.50)	6.86 (1.89)	7.04 (2.71)	No-VR > VRD [−1.12, 2.29] VRD < VRC [−2.29, 1.12] VRC < No-VR (−2.10 ÷ 1.28)
Magnification	2.77 (2.10)	2.43 (2.21)	2.83 (2.44)	No-VR > VRD [−1.28, 1.96] VRD < VRC [−1.98, 1.19] VRC > No-VR (−1.61 ÷ 1.73)

Data are mean (*SD*).
*$p<0.05$; **$p<0.001$.

pain-related and cognitive variables. With respect to pain-related variables, both interventions increased pain tolerance. Additionally, the VRC intervention increased the pain sensitivity range and the degree of time underestimation, as compared with the control condition. The VRD condition significantly increased the pain threshold in comparison with the control condition. Overall, therefore, both interventions have some effects on pain-related variables, a finding that is consistent with previous studies[1,4] and with our own results in earlier experiments involving the same interventions.[20–22] Notably, however, neither of the two interventions had any effect on pain intensity. This result might be expected for the VRC intervention, since its objective is to increase control over pain, and similar results were obtained when using this environment in previous experiments.[21,22] However, such a result is surprising in the case of the VRD intervention, since the available literature suggests that VR environments designed for pain distraction reduce pain intensity, this being the effect that we observed in a previous study that used this environment.[20] These results are likely due, at least in part, to the sample size used in the present study. However, the fact that participants were asked to indicate the strongest pain intensity rather than give an overall rating of pain intensity during the procedure may also have a bearing on these findings.[22]

As regards the cognitive variables, an effect on some of them was only observed for the VRC condition. This supports our hypotheses as well as the design of the intervention that aimed to enhance pain control. However, although these results are quite innovative and interesting, they now need to be replicated in larger samples, and especially in clinical contexts.

Assuming that our findings are replicated, an intervention such as the one presented here would have considerable potential in terms of extending the benefits of VR beyond the clinic. Patients would be able to use this VR intervention at the clinic to gain control over pain and change their cognitions, and this would then help them in their daily life outside the clinic. A number of reports along these lines have already been published, one example being experiments involving VR hypnosis.[23,24] In the introduction to this paper, we mentioned other examples[10,11] in which VR has been used for purposes other than pain distraction, and these could be particularly useful in the clinical context. What makes the intervention described here especially interesting and innovative is that it is designed to change cognitive variables (i.e., self-efficacy and catastrophizing) that have been shown to be very important in the context of chronic pain problems.[25,26]

The main weakness of this study is the use of an unbalanced sample regarding gender, since males and females have different responses to pain,[27] and this may influence the final results. Replications of this study with a more balanced distribution of males and females are needed. Also, in contrast to previous studies on VRD, this study used non-immersive VR. The link between immersion and presence and between pain distraction and presence is well established, so this difference may explain the limited efficacy of VRD in our study. The results obtained in this study showing that the intervention designed to enhance control (VRC) has a greater effect on the cognitive variables assessed than the intervention designed to increase distraction (VRD) can be applied, at this moment, only to nonimmersive VR systems. Replications of this study with immersive VR are needed.

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Author Disclosure Statement

No competing financial interests exist.

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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.

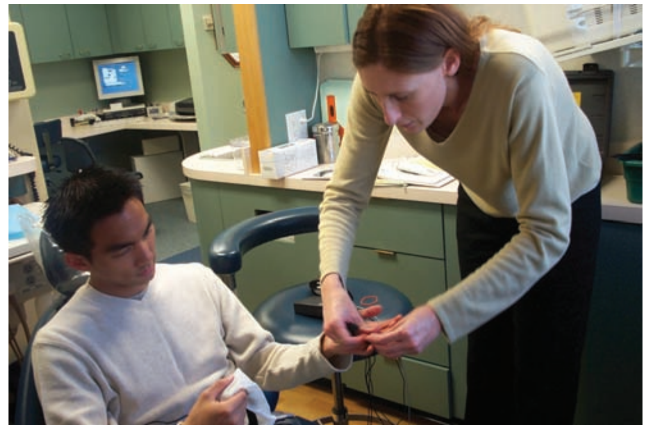

FIG. 3. Measurement without the virtual reality (VR) distraction system.

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.

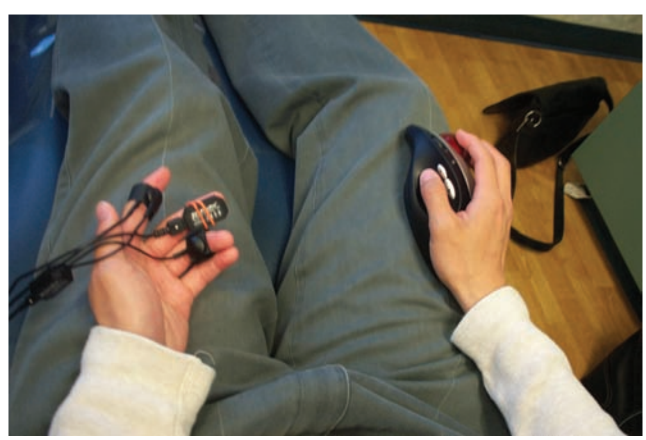

FIG. 4. Biofeedback sensors and wireless trackball.

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

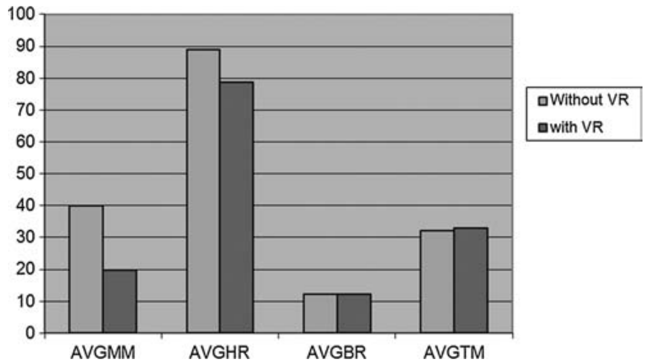

FIG. 6. Results show a trend of factors related to fear and anxiety reduction with VR distraction.

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.

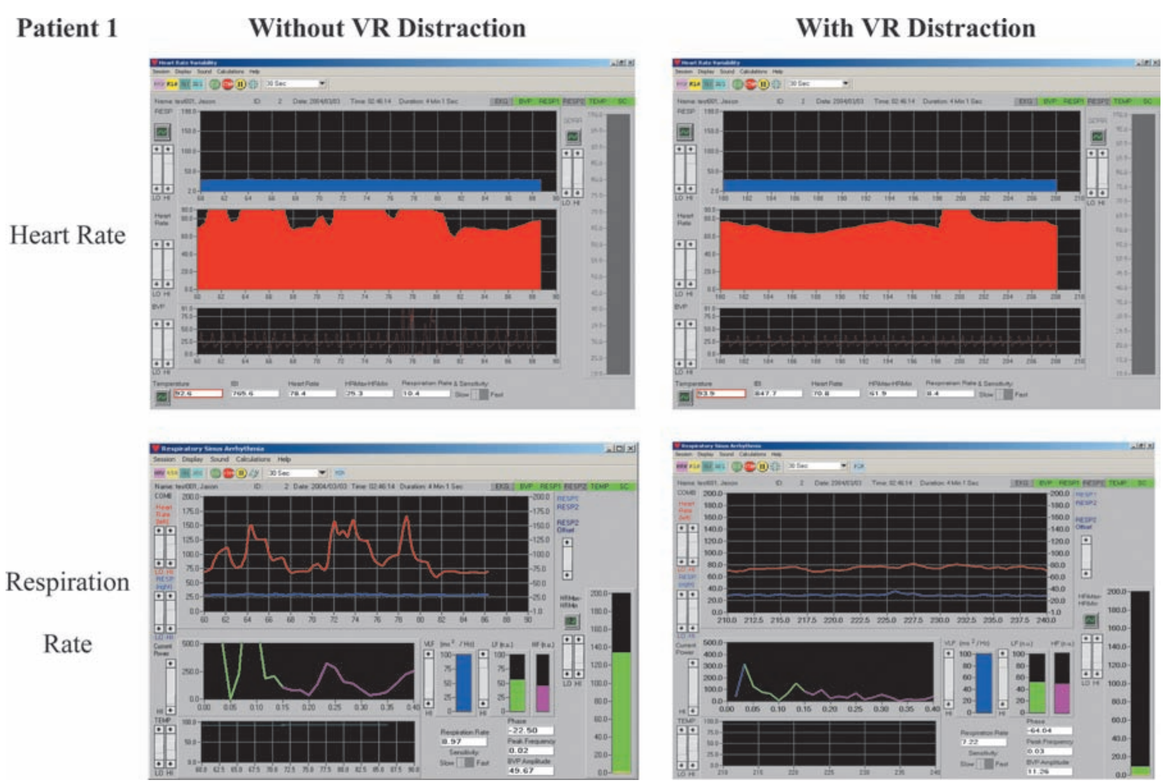

FIG. 7. Evaluation outcome chart (heart rate, respiration rate) example.

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

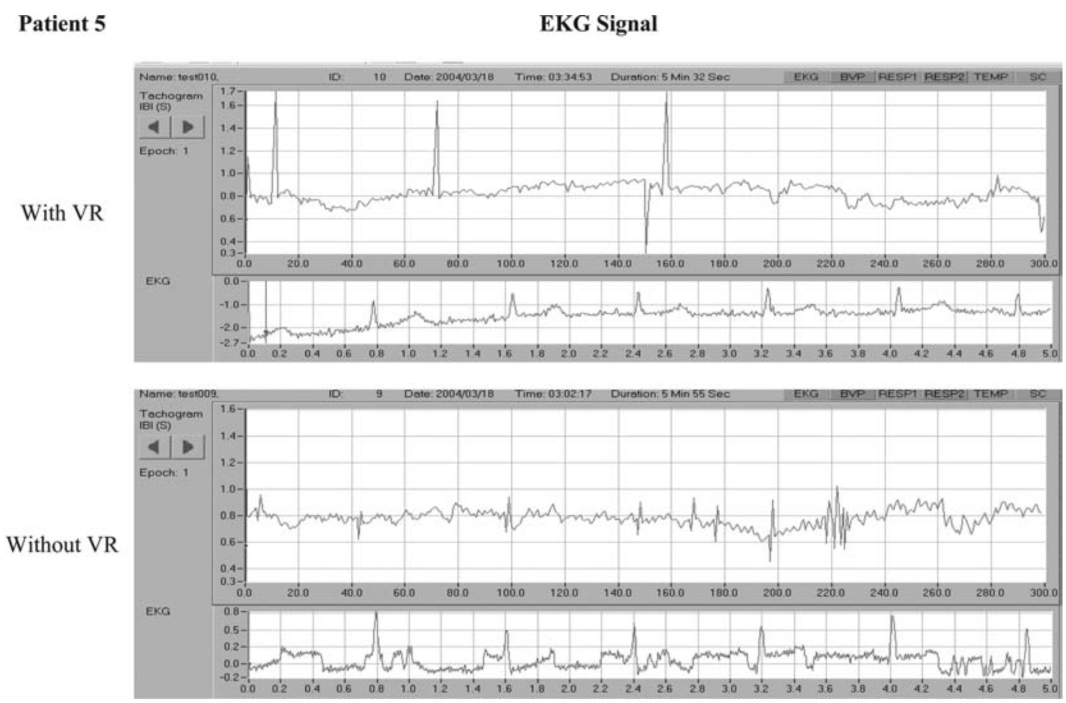

FIG. 8. EKG of patient 5 with and without VR distraction.

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

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Application of Virtual Body Swapping to Patients with Complex Regional Pain Syndrome: A Pilot Study

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Abstract

This study aimed to apply virtual body swapping through mental rehearsal for patients with complex regional pain syndrome (CRPS) and to investigate whether it is applicable to them. Ten patients who met the diagnostic criterion for CRPS type 1 were randomly assigned to either the treatment or control group. All participants were asked to watch the virtual body swapping training video clip with a head mounted display. The treatment group was additionally asked to assume a posture similar to the body on the screen and rehearse the movements mentally, as if the body presented on the screen was their body. No difference between the groups was found for pain intensity, however, the treatment group showed significantly more improvement in body perception disturbance (BPD) after the treatment than the control group. Even if the presented study is a preliminary one, the above results suggest that virtual body swapping through mental rehearsal is applicable for patients with CRPS and may be useful for improving BPD. The limitations of the study and the future investigations needed to provide clearer clinical suggestions are presented and discussed.

Introduction

Complex regional pain syndrome (CRPS) is a chronic progressive disease of unknown etiology characterized by a triad of severe pain; the threat of touch; abnormalities in temperature, color, and sweating; and disturbed body perception.[1,2] Due to its unknown etiology, conventional therapy for CRPS is mainly empirical for pain management and functional rehabilitation rather than mechanism-based treatment.[3,4] The extent of empirical treatment varies from the noninterventional to the interventional; however, both have limitations. Noninterventional treatments such as pharmacological treatment and physical therapy are often transient and usually end with the patient experiencing recurrent pain. In addition, there is controversy over the invasiveness and reliability of interventional treatments.[5,6] Recent brain studies on CRPS have contributed to a shift in treatment paradigms from an empirical one to a mechanism-based arena,[7] and accordingly, neural rehabilitation has recently been introduced as an alternative therapy for CRPS.[8] Such rehabilitation is expected to treat CRPS by correcting maladaptive cortical changes such as the disruption of the somatosensory cortical network,[9] dysfunction of the motor cortex,[10] and disrupted body schema.[11]

Mirror therapy is a representative treatment that reflects the principle of neural rehabilitation. Mirror therapy, which was originally used for phantom limb pain patients, has been introduced to manage pain and body perception disturbance (BPD) for patients with CRPS.[12,13] In mirror therapy, imaginary movement of the affected limb, which is actually a reflection of the patient's intact limb in a mirror, alleviates the patient's pain by correcting conflicts between visual feedback and proprioceptive representations of the affected limb.[14] Concurrent with previous studies, some researchers who have applied mirror therapy to patients with CRPS have found that mirror therapy is effective for relieving pain and restoring disturbed body perception.[15–17] However, mirror therapy appears to have limitations in that to be adopted for patients with CRPS, at least one limb should be intact. Patients with CRPS, however, may have an affected body part without a counterpart, such as the head, neck, or other body part, or the patient may have both limbs affected.

Therefore, inducing an illusionary body perception for the body instead of a single counterpart may overcome the limitations of mirror therapy. Body swapping is a way of evoking the perceptual illusion that a virtual body is perceived as his/her own body.[18,19] The illusion of body swapping can be induced as body ownership is shifted from the actual body to a virtual body by watching the virtual body moving or being touched while synchronous movement or tactile stimulation is performed.[20–22] Despite its potential implications, body swapping in the clinical setting, to our

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knowledge, has not been studied yet because even light tactile stimulation or movement can induce pain for patients with CRPS. For a treatment program for patients with CRPS to be applicable, it should (a) be available for the whole body part and limbs that are counterpart and (b) induce a low level of pain so as not to make the treatment session by itself aversive.

Our previous study opened the possibility of applying the virtual body swapping for patients with CRPS by employing mental rehearsal. Mentally rehearsing body movement without moving the actual body while watching virtual body moves in healthy participants has been found to evoke the illusion of virtual body swapping as much as physical rehearsal did.[23] This finding can be explained by the psychoneuromuscular theory, which postulates that mental rehearsal activates a network of neural pathways required for movements so that imagining movements means actually strengthening neural pathways of physical skill.[24,25] Given this, two clinical psychologists specializing in pain confirmed that virtual body swapping through mental rehearsal would be an appropriate way to evoke a body swapping illusion for patients with CRPS as it does not require any touches or gross muscular movements inducing pain.

This study aimed to apply virtual body swapping to patients with CRPS and to investigate whether it is applicable to them. As the first study to apply virtual body swapping to patients with CRPS, it is necessary to ascertain that the virtual body swapping is applicable in a small sample of patients with various pain sites. Given the findings of prior studies, we applied virtual body swapping to patients with CRPS and expected that the virtual body swapping illusion through mental rehearsal would reduce pain intensity and BPD in patients with CRPS (Hypothesis; H1).

Methods

Participants

Ten patients with CRPS type 1 were recruited from a tertiary university pain center in Seoul, Korea. The inclusion criteria for the present study fulfilled the diagnostic criteria for CRPS type 1 according to the International Association for the Study of Pain and pain doctors confirmed that the participants meet the criteria. Accordingly, the criteria included the presence of a noxious event unaccompanied by nerve lesion; continued pain, allodynia, or hyperalgesia; the region of pain suffers from edema, changes in skin blood flow, or pseudo motor activity; and the exclusion of other diagnoses.[26(p330)] Pain sites of each patients were various for the purpose of this study (entire body = 4, more than two limbs = 4, lower limb = 1, upper limb = 1). Patients were randomly assigned to either the treatment or control group. All participants were male and had at least high school education. The mean age of the sample was 39.30 years ($SD = 10.99$) and the median duration of pain was 52 months (range 33–120 months). The two groups were not significantly different in age [$t(8) = -1.59$, $p = 0.15$] or duration of pain [$t(8) = -0.98$, $p = 0.55$].

Measurements

Pain intensity was measured on an 11-point Likert scale ranging from 0 (no pain) to 10 (severe pain). The higher the score, the more intense the pain experienced by the patient at that moment.

The modified Body Perception Disturbance Questionnaire (BPDQ)[27] was used, which consists of nine items, such as sense of disownership, lack of attention to the limb, distorted mental visualization, impaired limb position sense, dislike, and different perception of size, shape, weight, pressure, or temperature of the impaired limb. Each item was rated on an 11-point scale ranging from 0 (not at all) to 10 (very likely). A sum total score was used in the analysis (from 0 to 90), with a higher score indicating greater BPD. Cronbach's alpha for the modified BPDQ in the present study was 0.73.

A single item of the virtual body swapping illusion asks to what extent participants perceived the virtual body's movement as being their own body's movement was created for this study and measured on a 7-point Likert scale ranging from 1 (not at all) to 7 (very much). The higher the score was, the more successful the virtual body swapping experienced.

Material and training program

The virtual body swapping training video for patients with CRPS was developed and has been found to successfully evoke virtual body swapping illusion in healthy participants.[25] The 3 minute and 20 second long video clip was filmed from the first person perspective and consisted of four physical movements. The first person perspective would help patients to feel as if they observed their body when they watch video, and four physical movements were ergonomically natural from the view (making fists and opening up the fingers, bending and unbending the elbows, bending the ankles forward and backward, and bending and unbending the legs). The video was presented using a head mounted display (HMD, VR2000; Virtual Realities, Ltd.; Fig. 1) in a dim light to help patients with CRPS be immersed in the training session by blocking other sensory information. Total training sessions was designed not to exceed 10 minutes as it has been known that training longer than 10 minutes may cause fatigue and difficulty in concentration.[27] The training program was delivered by one specialist in pain and two assistants (trained graduate students).

Procedure

Participants were asked to complete informed consent form and demographic information questionnaires. Participants also responded to a pain intensity question and completed the modified BPDQ to be used as baseline data. Subsequently, all participants were asked to lie down on the sofa and watch the experimental video clip with HMD. Participants in the treatment group were additionally asked to assume a posture similar to that of the body on the screen and rehearse the movements mentally, as if the body presented on the display was their own body. In contrast, participants in the control group were not asked to perform these last two tasks while watching the video clip, to rule out an alternative explanation of the experimental results (i.e., watching the video clip itself may influence pain intensity and BPD). The experimental video clip was played twice with a 1-minute break given between viewings. The participants were then asked to respond to the pain intensity question and the virtual body swapping question and to complete the BPDQ. As a final step, all participants were

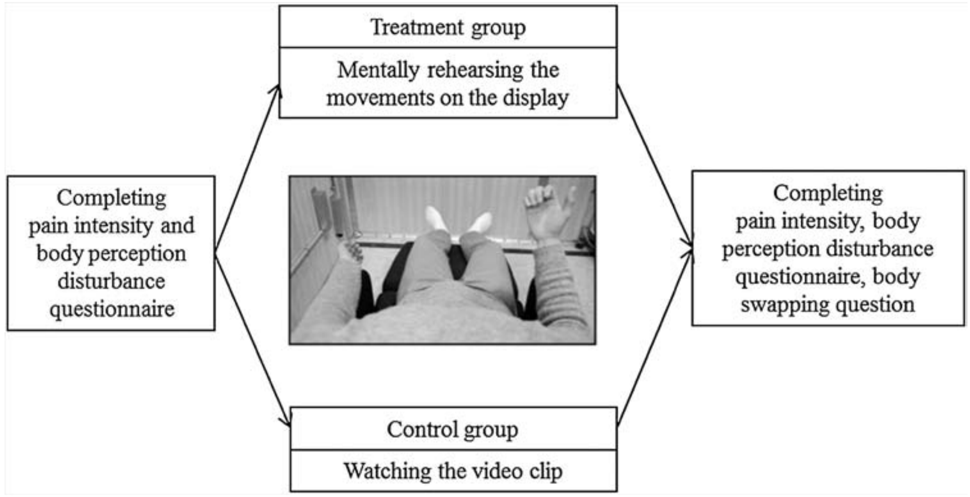

FIG. 1. Experimental procedure. The video was presented twice with one minute of short break.

debriefed on the experiment and compensated for their participation. The procedure is described in Figure 1.

Statistical analysis

One-way analysis of covariance (ANCOVA) using pretreatment condition (pain intensity and BPD) as covariates was conducted to analyze differences between the groups in post-treatment pain intensity and BPD scores. Pretreatment pain intensity and BPD were controlled in each analysis to reduce the variance of the baseline, respectively. The bootstrapping method was used to increase the robustness of small-sample analyses.[28] In the present set of analyses, parameter estimates were based on 1,000 bootstrap samples with 95% confidence intervals. An independent *t* test was used to investigate the difference in virtual body swapping scores between the two groups. SPSS 17.0 for windows was used for these analyses.

Results

Pain intensity and BPD

One-way ANCOVA for post-treatment pain intensity and BPD, using pretreatment pain intensity and BPD as covariates was conducted. Bootstrapped descriptive statistics are described in Table 1. There was no significant difference between the groups in pain intensity, $F(1, 7) = 0.05$, $p = 0.81$. For BPD, the result showed a significant difference between the groups, $F(1, 8) = 16.22$, $p = 0.01$, $\eta_p^2 = 0.70$. These results indicate that the treatment group reported less BPD after treatment than did the control group (Fig. 2).

Virtual body swapping illusion

An independent *t* test was conducted to compare virtual body swapping illusion between the treatment and control group. A significant difference in virtual body swapping scores between the treatment and control group was found, $t(8) = 2.40$, $p = 0.04$, indicating that the treatment group experienced greater virtual body swapping illusion than did the control group.

Table 1. Bootstrapped Statistics on Body Perception Disturbance [Mean (*SD*)]

Condition	Statistics	95% confidence interval: Upper	95% confidence interval: Lower
Treatment	52.60 (24.43)	31.83 (6.87)	75.00 (32.53)
Control	61.80 (21.95)	55.74 (2.29)	84.50 (20.98)

Discussion

The present study aimed to apply virtual body swapping to patients with CRPS and to investigate its treatment effects on pain intensity and BPD. Patients with CRPS seemed to accommodate themselves in the treatment session well and they reported that the training program did not induce aversive pain. In addition, the training program evoked illusionary body perception. As a consequence, the treatment group showed more significant improvement in BPD after the treatment than the control group. However, no difference between the groups was found for pain intensity.

The technique of virtual body swapping therapy on BPD is consistent with novel therapies such as mirror therapy and motor imagery with respect to normalizing sensory-motor cortical representation by manipulating corrective visual information input.[29,30] Functional brain imaging studies have demonstrated that representation of the affected limb is enlarged or reduced on sensory-motor cortices, and a correlation between corrective cortical reorganization and pain

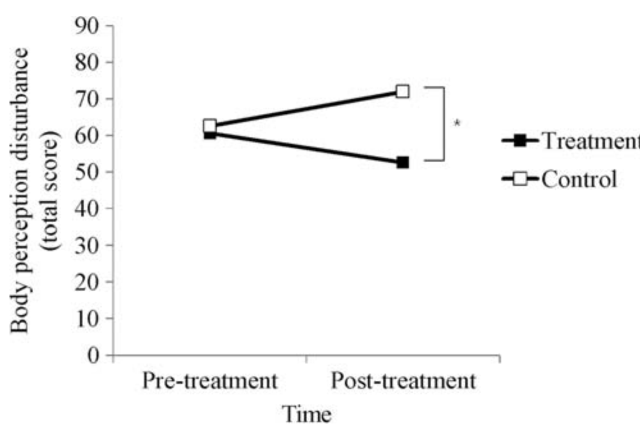

FIG. 2. Body perception disturbance scores for treatment and control groups with time $*p < 0.05$.

reduction has been found.[31,32] These results imply that BPD correlates with the abnormal change in body schema and that restoring body schema can benefit BPD. Body schema can be altered because our body representation is a complex combination of vision, somesthesis, and motor feedback rather than a simple registration of body location.[33,34] Therefore, BPD can be induced when appropriate visual, somesthetic, or motor feedback is not given when moving the body.[35] In the present study, normal body and normal movement are projected onto the patients with CRPS as corrective visual information, while the patients mentally rehearse the movement to provide cognitive and motor input. As mental rehearsal has been used to enhance functional recovery of patients with physical disabilities,[36] it seems promising that virtual body swapping through mental rehearsal could improve physical function of patients with CRPS.

Despite the fact that the virtual body swapping through mental rehearsal was helpful in improving BPD, there was no significant group difference in post-treatment pain intensity. This finding may reflect that single-session treatment is not sufficient to relieve pain intensity. There are incoherent results regarding how many sessions are necessary for treatment using corrective visual feedback, such as mirror visual feedback and augmented reality, to achieve effective pain reduction. Sato et al.[37] reported that even single-session treatment could reduce pain intensity in some patients, but most researchers preferred multiple-session treatment, from one session per week for several weeks to daily basic intense training.[13,32,37] Otherwise, our treatment requires preparatory staging before actual virtual body swapping is applied. Because a mismatch between motor intention and proprioceptive feedback causes pain in many pathological chronic pain conditions including CRPS,[38,39] even inducing movement intention by virtual body swapping could elicit pain. In this regard, Moseley[8,32] suggested and proved the efficiency of an additional training phase before mirror visual feedback to restore body scheme with laterality training and to acclimate to following movement using motor imagery.

The results of this study have important clinical implications for patients with CRPS. Above all, to our knowledge, this study is the first attempt to apply virtual body swapping through mental rehearsal for patients with CRPS. Other treatments using illusionary body perception have been limited because traditional techniques require at least one intact limb or accompanying pain, while virtual body swapping through mental rehearsal extended the clinical venue of CRPS beyond these limitations. Second, most clinical approaches to CRPS have focused on pain reduction. However, this research targeted BPD and pain as one of the main symptom of CRPS and suggested a promising treatment. Moreover, the virtual body swapping is a mechanism-based treatment that aims to normalize a distorted body scheme and resolve conflict between neural networks rather than to transiently relieve pain.

Notwithstanding the above implications, some limitations remain. First of all, the small male-specific sample was utilized as a preliminary study to explore the applicability of a novel treatment program; thus alternatively, bootstrapping method was used in the present study. Bootstrapping method has been known to be useful in solving distribution problem and small sample size analysis as it estimates statistics in prospective big sample from observed data.[28] Nevertheless in further research, a larger sample size with a balanced gender ratio is required to confirm the results of this study. Second, we relied on a single item to measure the virtual body swapping illusion, which may not accurately reflect it. Thus, further research needs to employ more reliable measurements such as a multiple-item measure and brain imaging. Third, the treatment was conducted only once without any preparatory stage. Although there was improvement in BPD in one treatment session, this does not constitute conclusive evidence that one session is enough. In addition to this limitation, the baseline was measured only once and this occurred just before the treatment. Additionally, a followup to determine any long-lasting effects was not conducted. In further research, the baseline should be measured several times before the initial treatment session to obtain a stable baseline, and a followup is necessary to determine the sustainability of the effect after the treatment is terminated.

The result of the present study has demonstrated that the virtual body swapping through mental rehearsal can be useful for improving BPD in patients with CRPS. This finding can be especially beneficial for patients who have difficult body conditions and have been unable to benefit from previous visual feedback therapies because either both limbs are affected or the affected body part has no counterpart. Further studies in a larger and various samples are necessary to establish the virtual body swapping through mental rehearsal as a clinical training program for CRPS.

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Author Disclosure Statement

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Virtual Reality for Pain Management in Cardiac Surgery

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Abstract

Surgical anxiety creates psychological and physiological stress, causes complications in surgical procedures, and prolongs recovery. Relaxation of patients in postoperative intensive care units can moderate patient vital signs and reduce discomfort. This experiment explores the use of virtual reality (VR) cybertherapy to reduce postoperative distress in patients that have recently undergone cardiac surgery. Sixty-seven patients were monitored at IMSS La Raza National Medical Center within 24 hours of cardiac surgery. Patients navigated through a 30 minute VR simulation designed for pain management. Results were analyzed through comparison of pre- and postoperative vital signs and Likert scale survey data. A connection was found in several physiological factors with subjective responses from the Likert scale survey. Heavy positive correlation existed between breathing rate and Likert ratings, and a moderate correlation was found between mean arterial pressure and Likert ratings and heart rate and Likert ratings, all of which indicated lower pain and stress within patients. Further study of these factors resulted in the categorization of patients based upon their vital signs and subjective response, providing a context for the effectiveness of the therapy to specific groups of patients.

Introduction

When faced with upcoming surgeries, patients often claim a psychological fear of surgical failure, anesthesia, or the "unknown."[1] A widely accepted cause of surgical anxiety is the recently increasing demands for efficiency in hospital operations, leading to less time spent by healthcare professionals to assure patients of their well-being. Patients also suggest personal reasons for experiencing surgery-related anxiety, including sociodemographic or psychological variables, or past surgical experiences.[2] Patients under surgical distress can experience adverse effects on their mental and physiological states, and slowed postoperative recovery.[3] Even patients who report rare accounts of anxiety are susceptible to physiological changes, including increased respiratory rate, heart rate, blood pressure, vasoconstriction, and gastric stasis.[4] Intense forms of surgical distress can activate the sympathetic nervous system and downregulate immune functions.[5]

By addressing this issue, hospitals would improve surgery outcomes, patient recovery, and patient psychological and physical well-being. Efforts are currently centered on preoperative anxiety. Medical interventions, such as midazolam, and therapeutic attempts, such as music in waiting rooms, have shown mixed results.[6]

Virtual reality (VR) methods have been previously explored for postoperative cases, most of which have focused on two cases: burn victims and children (see Table 1). Burn victims have shown to be a popular application of VR therapy due to the painful nature of postburn physical therapy. Past studies have explored pain management of burn injuries by measuring pain scores, as well as maximal joint range of motion immediately and after therapy. Results indicate that post-therapy pain ratings dropped, patients spent less time thinking about the pain, and a vast majority enjoyed the simulation. Similarly, distraction techniques have shown promise in use with pediatric operations. While some studies show subjective pain measurements decreased under VR conditions, others show that no measureable differences were found in either pain or distress, but the simulations were qualified as distracting.

In this study, we aim to address postoperative anxiety through the application of VR distraction therapy. Advancements in technology have allowed the use of VR in intensive care units (ICUs) to complement standard pain management techniques. A report by Kho et al. concluded that VR techniques are promising in their study of the efficacy of video games as an additional tool in physical therapy ICU patients.[7] Another study at the Virtual Reality Medical Center correlates immersion in a virtual world with patients'

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

Title/authors	*Method*	*Results*
The Use of the Virtual Reality as Intervention Tool in the Postoperative of Cardiac Surgery[10] Cacau Lde A, Oliveira GU, Maynard LG, Araújo Filho AA, Silva WM Jr, Cerqueria Neto ML, Antoniolli AR, Santana-Filho VJ	Patients were randomized into two groups: VR (VRG, $n=30$) and control (CG, $n=30$). The response to treatment was assessed through the functional independence measure (FIM), by the 6-minute walk test (6MWT) and the Nottingham Health Profile (NHP). Evaluations were performed preoperatively and postoperatively.	On the first day after surgery, patients in both groups showed decreased functional performance. However, the VRG showed lower reduction (45.712.3) when compared to CG (35.0612.09, $p<0.05$) on the first postoperative day, and no significant difference in performance on discharge day ($p>0.05$). In evaluating the NHP field, we observed a significant decrease in pain score at third assessment ($p<0.05$). These patients also had a higher energy level in the first evaluation ($p<0.05$). There were no differences with statistical significance for emotional reactions, physical ability, and social interaction. The length of stay was significantly shorter in patients of VRG (9.410.5 days vs. 12.2 1 0.9 days, $p<0.05$), which also had a higher 6MWD (319.9119.3 meters vs. 263.5115.4 meters, $p<0.02$).
Managing Pain in Military Populations with Virtual Reality[11] Wiederhold BK, Wiederhold MD	By constantly being exposed to combat and living in war zones, servicemen and women face increased risk of complicated injuries, including amputations, penetrating wounds, spinal cord injuries, and traumatic brain injuries (TBIs). In addition, many service members may undergo multiple surgical procedures as a result of serious injury. The incidence of pain syndromes is significantly higher when present with posttraumatic stress disorder (PTSD) and other psychiatric disorders such as depression. The combination of these ''poly-trauma'' events makes the management of both acute and chronic pain in military populations challenging.	A multifactorial approach is necessary, and the introduction of new approaches and technology can increase the numbers of tools available to combat this significant health issue in troops.
Comparing Distraction/Relaxation Modalities with Chronic Pain Patients[12] Stetz MC, Brown KS, Folen RA, Nelson KL, Wiederhold BK	At the present time, most providers treat chronic pain patients with a combination of analgesics and nondrug approaches. That said, many of these professionals are also starting to incorporate the use of technology (e.g., VR and biofeedback) into their practice. The purpose of this study was to compare standard chronic pain treatment (i.e., assisted relaxation with a clinician) with technology-assisted relaxation without a clinician.	Results suggest that there was a greater reduction in self-rated pain when participating in the relaxation imagery session enhanced with technology.
Virtual Reality Pain Control During Burn Wound Debridement of Combat-Rrelated Burn Injuries Using Robot-Like Arm Mounted VR Goggles[13] Maani CV, Hoffman HG, Morrow M, Maiers A, Gaylord K, McGhee LL, DeSocio PA	Patients were U.S. soldiers burned in combat attacks involving explosive devices in Iraq or Afghanistan. During the same wound care session using a within-subject experimental design, 12 patients received half of their severe burn wound cleaning procedure ($\sim$6 minutes) with standard of care pharmacologies and half while in VR (treatment order randomized). Three 0 to 10 Graphic Rating Scale pain scores for each of the treatment conditions served as the primary variables.	Patients reported significantly less pain when distracted with VR. ''Worst pain'' (pain intensity) dropped from 6.25 out of 10 to 4.50 out of 10. ''Pain unpleasantness'' ratings dropped from ''moderate'' (6.25 out of 10) to ''mild'' (2.83 out of 10). ''Time spent thinking about pain'' dropped from 76% during no VR to 22% during VR. Patients rated ''no VR'' as ''no fun at all'' (<1 out of 10) and rated VR as ''pretty fun'' (7.5 out of 10). Follow-up analyses showed VR was especially effective for the six patients who scored 7 out of 10 or higher (severe to excruciating) on the ''worst pain'' (pain intensity) ratings.

(*continued*)

Table 1. (Continued)

Title/authors	*Method*	*Results*
Virtual Reality and Interactive Simulation for Pain Distraction[8] Wiederhold MD, Wiederhold BK	Current advances are being made to control pain by integrating both the science of pain medications and the science of the human mind. Various psychological techniques, including distraction by VR environments and the playing of video games, are being employed to treat pain. In VR environments, an image is provided for the patient in a realistic, immersive manner devoid of distractions. This technology allows users to interact at many levels with the VE, using many of their senses, and encourages them to become immersed in the virtual world they are experiencing.	When immersion is high, much of the user's attention is focused on the virtual environment (VE), leaving little attention left to focus on other things, such as pain. In this way, VR provides an effective medium for reproducing and/or enhancing the distractive qualities of guided imagery for the majority of the population who cannot visualize successfully.
The Effect of Virtual Reality on Pain and Range of Motion in Adults with Burn Injuries[14] Carrougher GJ, Hoffman HG, Nakamura D, Lezotte D, Soltani M, Leahy L, Engrav LH, Patterson DR	Thirty-nine inpatients, aged 21 to 57 years (mean 35 years), with a mean TBSA burn of 18% (range = 3–60%) were studied using a within-subject, crossover design. All patients received their regular pretherapy pharmacologic analgesia regimen. During physical therapy sessions on two consecutive days (VR one day and no VR the other day; order randomized), each patient participated in active-assisted ROM exercises with an occupational or physical therapist. At the conclusion of each session, patients provided 0 to 100 Graphic Rating Scale measurements of pain after each 10 minute treatment condition. On the day with VR, patients wore a head-position-tracked, medical care environment excluding VR helmet with stereophonic sound and interacted in a VE conducive to burn care. ROM measurements for each joint exercised were recorded before and after each therapy session.	Because of nonsignificant carryover and order effects, the data were analyzed using simple paired *t* tests. VR reduced all Graphic Rating Scale pain scores (worst pain, time spent thinking about the pain, and pain unpleasantness by 27%, 37%, and 31% respectively), relative to the no VR condition. Average ROM improvement was slightly greater with the VR condition. However, this difference failed to reach clinical or statistical significance ($p = 0.243$). Ninety-seven percent of patients reported zero to mild nausea after the VR session.
Virtual Reality on Mobile Phones to Reduce Anxiety in Outpatient Surgery[15] Mosso JL, Gorini A, De La Cerda G, Obrador T, Almazan A, Mosso D, Nieto JJ, Riva G	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 an 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. After 90 minutes, the reduction was larger in the experimental group than in the control group.
The Use of Virtual Reality for Needle-Related Procedural Pain and Distress in Children and Adolescents in a Paediatric Oncology Unit[16] Nilsson S, Finnström B, Kokinsky E, Enskär K	Twenty-one children and adolescents were included in an intervention group with nonimmersive VR and another 21 children and adolescents in a control group where they underwent either venous punctures or subcutaneous venous port devices. Self-reported pain and distress, heart rate, and observational pain scores were collected before, during, and after the procedures. Semi-structured qualitative interviews were conducted in conjunction with the completed intervention.	Self-reported and observed pain and distress scores were low, and few significant differences of quantitative data between the groups were found. Two themes emerged in the analysis of the interviews; the VR game should correspond to the child and the medical procedure and children enjoyed the VR game and found that it did distract them during the procedure.

(*continued*)

Table 1. (Continued)

Title/authors	*Method*	*Results*
Using Cybertherapy to Reduce Postoperative Anxiety in Cardiac Recovery Intensive Care Units[17] Vazquez JLM, Santander A, Gao K, Wiederhold MD, Wiederhold BK	Twenty-two patients were monitored at IMSS La Raza National Medical Center within 24 hours of cardiac surgery. Patients navigated through a 30 minute VR simulation designed for pain management. Results were analyzed through comparison of pre- and postoperative vital signs and Likert scale survey data.	Likert test data showed that 21 of 22 subjects reported less discomfort after navigating through the VE. Physiological data generally supported the Likert data, with 64% of patients lowering respiratory rate, moderated blood carbon dioxide levels, and decreased diastolic blood pressures in another 64% of patients.
Virtual Reality as a Pediatric Pain Modulation Technique: A Case Study[18] Steele E, Grimmer K, Thomas B, Mulley B, Fulton I, Hoffman H	This case study explored the use of VR analgesia with a 16-year-old patient with cerebral palsy participating in a twice daily physiotherapy program following Single Event Multi-Level Surgery. Over 6 days, the patient spent half of his physiotherapy sessions using VR and the other half without (order randomized). Traditional pharmacological pain management was administered throughout the trial.	Using a subjective pain scale (5 faces denoting levels of pain), the patient's overall pain ratings while in the VR (experimental) condition were 41.2% less than those in the no-VR (control) condition.
Cybertherapy—New Applications for Discomfort Reductions. Surgical Care Unit of Heart, Neonatology Care Unit, Transplant Kidney Care Unit, Delivery Room-Cesarean Surgery and Ambulatory Surgery, 27 Case Reports[19] Mosso JL, Rizzo S, Wiederhold B, Lara V, Flores J, Espiritusanto E, Minor A, Santander A, Avila O, Balice O, Benavides B	27 patients have been participated in this preliminary report from 3 public hospitals from Mexico city in 2006. The VR scenarios were developed in the Virtual Reality Medical Center of San Diego CA, and the HMD is from the Southern University of los Angeles, CA.	The majority of patients demonstrated comfort with virtual scenarios during surgical procedures or hospitalization.

attention to the virtual environment (VE) as opposed to pain.[8] Immersiveness also has been shown to have beneficial effects on various physiological factors that link to anxiety, such as heart rate, respiratory rate, skin temperature, and skin resistance.[9]

Methodology

Patients ($n=67$; 25 female, 42 male) in the cardiac surgery department of IMSS La Raza National Medical Center were asked to participate in the study. Each patient was monitored in hyperacute units within 24 hours of their cardiac surgery, which included mitral valve replacement, aortic valve replacement, tricuspid valve replacement, coronary stent insertion, coronary revascularization, tricuspid plasty, ventricular communication repair, and bridge tricuspid resection.

The clinical team consisted of four physicians, nurses, and technicians. Procedural instructions were given to the patients after their admission to the ICU. Consent to participate and basic demographic information were collected. A clinical professional recorded relevant vital signs and administered the presimulation questionnaire to measure patient discomfort. Once all preliminary data were collected, the physician installed the head-mounted display on the patient's head to display a VR simulation. Meanwhile, a projector emitted the same simulation on the unit wall so the clinical team could follow along. The simulation consisted of a set of five cybertherapy environments (developed by the Virtual Reality Medical Center in San Diego, CA): Cliff, Dream Castle, Enchanted Forest, Icy Cool World, and Drive, Walk, Bike. The patient was allowed to explore the VE for 30 minutes. Throughout the simulations, all patients were conscious, had normal vision, free movement of limbs, and did not have airway cannulation or hemodynamic disorders. Postsimulation data were collected through a questionnaire and vital signs.

Results

Data analysis is composed of comparisons between pre and post cybertherapy vital signs and subjective scale results using a Likert scale design. Complications included a 68 year old female patient who experienced cardiac arrhythmia during treatment, and three patients who presented signs of nausea and vertigo that interrupted the cybertherapy session.

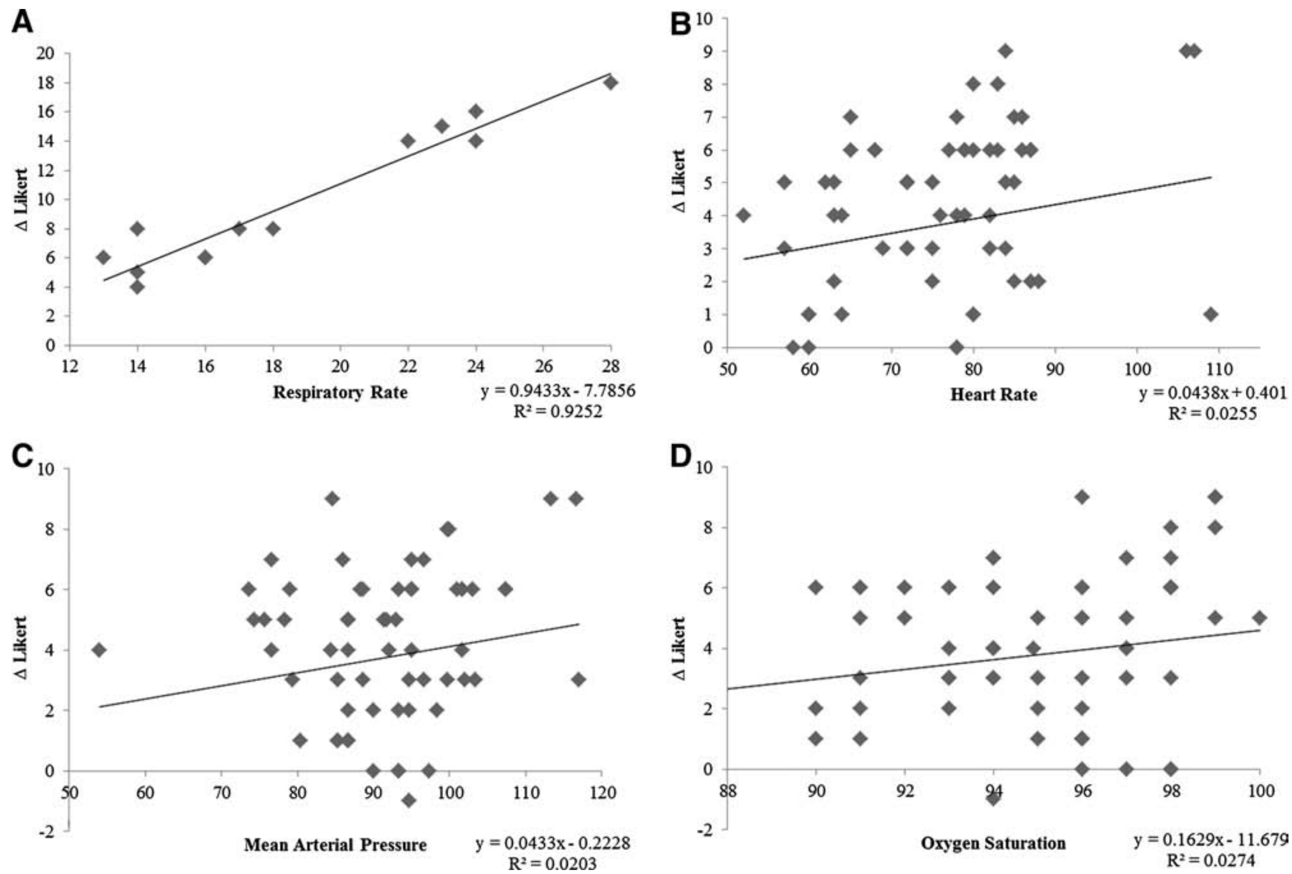

FIG. 1. Correlation of physiological factors with change in subjective pain measurements. **(A)** Patients' initial respiratory rates and change in subjective responses were measured against each other. Upwards trend line indicates that patients with higher respiratory rates experienced a larger decrease in their reported pain. **(B)** Subjects with higher initial heart rates generally reported a larger decrease in pain post-therapy, while other subjects with lower to normal heart rates indicated little to no change in pain. **(C)** Initial mean arterial pressure and change in subjective ratings showed slight positive correlation. **(D)** Initial oxygen saturation and change in subjective pain responses showed slight correlation, possibly explained by the small range of possible oxygen saturation within healthy subjects.

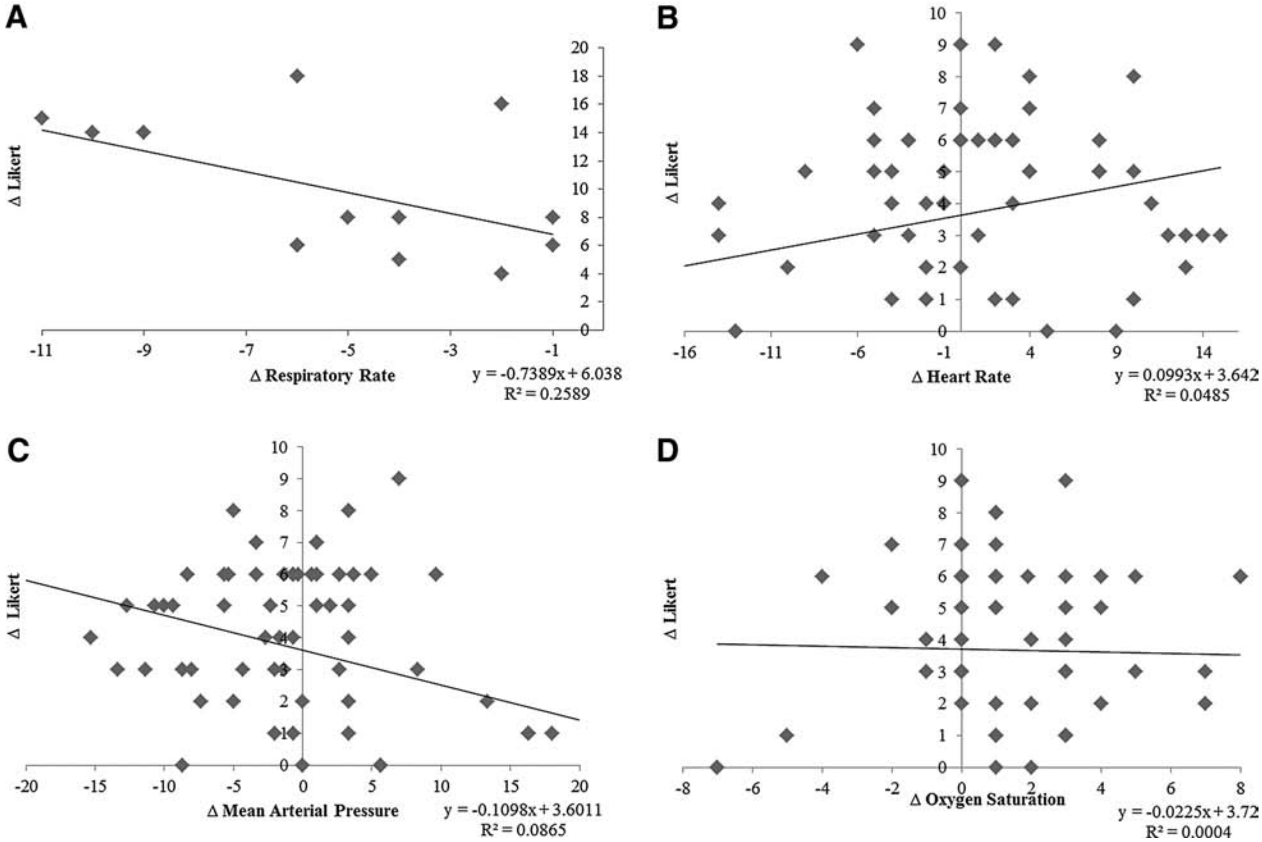

FIG. 2. Correlation of change in physiological factors with change in subjective pain measurements. **(A)** Significant correlation existed between change in Likert scale responses and respiratory rate. **(B)** A positive sloping trend line for change in heart rate and change in subjective responses positively supports the calming effect of the simulation. **(C)** As opposed to heart rate, a decreasing trend for change in mean arterial pressure and change in Likert ratings indicates the same pain reducing effect. **(D)** Change in oxygen saturation and Likert responses showed little correlation, again, most likely due to the small range of oxygen saturation.

Overall, the results of the therapy were positive (see Fig. 1). Of the 67 patients, 59 patients (88%) reported a decreased level of pain experienced post-therapy. The mean change in the Likert scale was 3.75, which corresponds to a decrease from ''severe'' to ''moderate'' or ''moderate'' to ''light.'' Physiologically, 25 patients (37.3%) experienced reduced heart rates, 35 (52.2%) experienced reduced mean arterial pressure, and 14 (64%) of 22 patients tested for respiratory rate experienced a reduction.

Respiratory rate measurements were plotted against the change in subjective responses before and after the therapy treatment. The correlation had a linear fit, with an R^2 value of 0.925. Similarly, heart rate and mean arterial pressure were plotted against the survey responses, showing positive correlation but with much higher variation ($R^2=0.025$ and $R^2=0.02$ respectively). Oxygen saturation showed similar trends. However, they were not as substantial as respiratory rate, heart rate, or mean arterial pressure.

Interestingly, when the changes in the physiological factors were analyzed against the change in Likert scales, similar correlations existed (see Fig. 2). Thus, not only is there a trend in the match between objective and subjective pain measurements, but the level of pain reduction matches as well.

To provide further context to the patients who were positively affected by the therapy, patients were categorized using Boolean values based upon their change in responses (see Fig. 3). For each physiological factor, for example heart rate, patients were identified with ''improvements in heart rate and reported survey response,'' ''improvement in heart rate, but not survey response,'' ''improvement in survey response, but not in heart rate,'' and ''improvement in neither heart rate nor survey response.'' By categorizing patients into these groups, a visual representation of the type of patients that should undergo this therapy can be seen. Respiratory rate was not taken into consideration for this analysis due to the small sample size.

Discussion

After cardiac surgery, it is common for patients to show symptoms of worry, apprehension, and depression. The melancholic state can last many weeks and disrupt recovery, both psychologically and physiologically. Patient relaxation can reduce postsurgical pain, improve overall well-being, and prevent hematomas and other complications. This experiment has shown that navigating through a VE can reduce psychological stress. Improvements could be made to the therapy content or procedure to benefit those who did not report positive changes in vital signs or discomfort, although we recognize that cybertherapy may not be suitable for some patients.

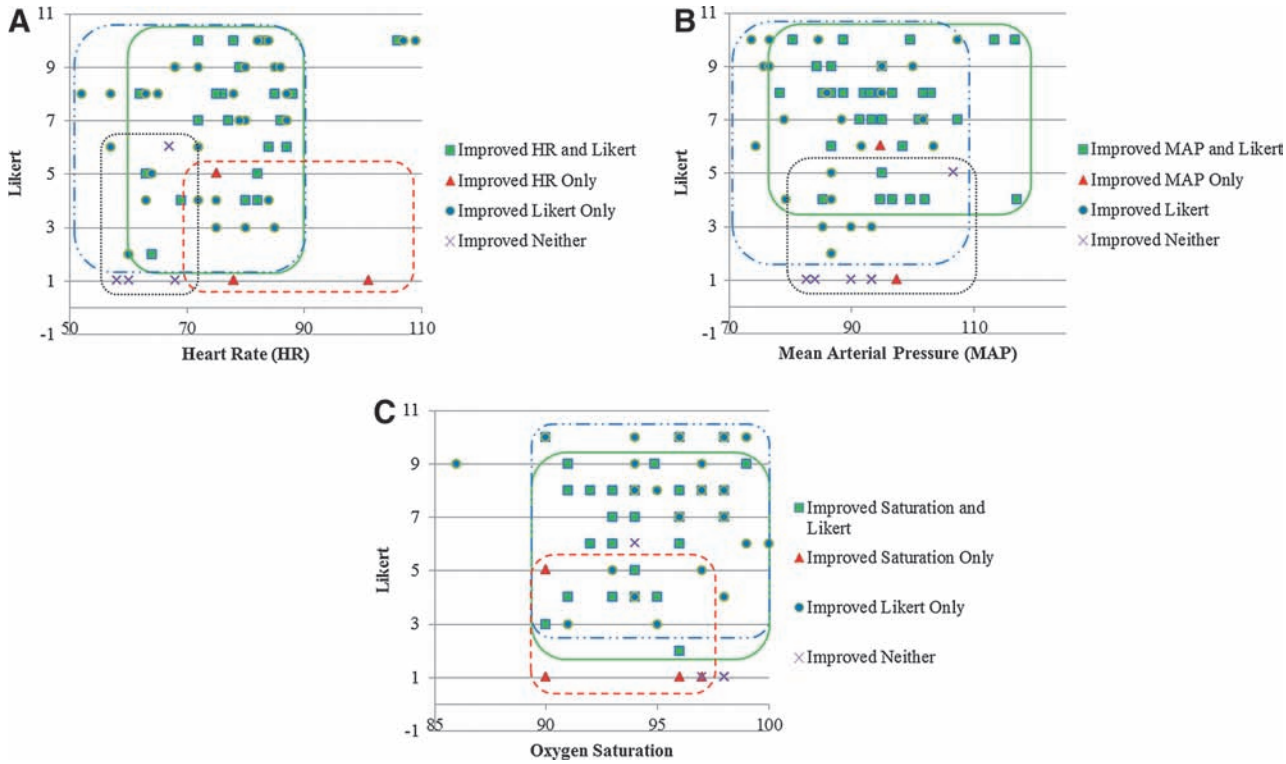

FIG. 3. Categorization of patients using Boolean values. **(A)** Four distinct groups are seen using heart rate and subjective responses. Notably, those who improved in neither category had initially low heart rates and pain responses, whereas those who improved in both started with higher values. **(B)** Three groups are visualized, with patients that improved in MAP and Likert categories having a wide range of MAP but high pain ratings. **(C)** As expected, oxygen saturation values were evenly distributed across the healthy range.

It is evident from past studies to date that presence is an important factor in delivering pain distraction. Hoffman et al. describes how immersion and presence enhances distractive properties of the VE.[20] Wiederhold et al. presented comparisons of subjects that experienced varying levels of VR immersion, noting significant differences in not only subjective responses but also physiology.[9] Considering the influence of immersion on the efficacy of pain distraction, a future improvement to this study could correlate the change in reported Likert pain ratings to a presence rating.

This is an uncontrolled study, possibly leading to overestimation of effectiveness. While not as extensive as a controlled trial, it is conclusive that there are changes in physiology before and after the virtual simulation, especially in the patient-reported discomfort scale. As this study was performed under real-world clinical conditions, the validity and clinical utility of the observed data are significant.

VR has shown to be a noninvasive and innocuous procedure to improve postsurgical distress in ICUs. Using this technology allows patients to interact at many levels with the VE, using multiple senses, and encourages them to become immersed in the virtual world they are experiencing. In this way, VR provides an effective medium for reproducing and/or enhancing the distractive qualities of a pain treatment. VR in ICUs represent a tremendous social impact in patients that are in critical condition by acting as additional support mechanism to avoid and reduce postsurgical distress.

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Author Disclosure Statement

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Virtual Reality for the Induction of Positive Emotions in the Treatment of Fibromyalgia: A Pilot Study over Acceptability, Satisfaction, and the Effect of Virtual Reality on Mood

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Abstract

One of the most important aspects of fibromyalgia syndrome (FMS) is its impact on quality of life, increasing negative emotions and dysfunctional coping strategies. One of these strategies is to avoid activities, especially meaningful activities, which reduces positive reinforcement. Commencing significant daily activities could enable chronic patients to experience a more fulfilling life. However, the main difficulty found in FMS patients is their willingness to start those activities. Promoting positive emotions could enhance activity management. The aim of this paper is to present a description of a system along with data regarding the acceptability, satisfaction, and preliminary efficacy of a virtual reality (VR) environment for the promotion of positive emotions. The VR environment was especially designed for chronic pain patients. Results showed significant increases in general mood state, positive emotions, motivation, and self-efficacy. These preliminary findings show the potential of VR as an adjunct to the psychological treatment of such an important health problem as chronic pain.

Introduction

Fibromyalgia syndrome (FMS) is a chronic musculoskeletal pain condition of unknown etiology, characterized by widespread pain and muscle tenderness, and often accompanied by fatigue, sleep disturbance, and depressed mood.[1] It is estimated that around 2–4% of the general population suffer from FMS.[2] FMS is a complex condition involving biological, psychological, and social factors, which cause a negative impact on patients' quality of life. This condition is becoming an important public health problem because it is associated with an increased use of health services, emergency room visits, and medication, and increased work disability.[3,4] The treatment of FMS has a poor prognosis for recovery,[5] and it is considered a challenge for health professionals. Several studies support that FMS is better addressed from a multidimensional perspective, being more effective than management from single approaches.[6] In this sense, psychological aspects are among the best predictors of disability caused by chronic pain[7] and constitute a promising component in the treatment for FMS. Such programs include various components such as relaxation, mindfulness, cognitive therapy, and activity management. Several studies have tested the efficacy of psychological programs for FMS and have revealed small yet robust effect sizes of short- and long-term efficacy.[8] The conclusion was that psychological programs are promising interventions for FMS, even though there is still room for improvement. Further research is needed to respond more appropriately to patients with FMS.

The use of information and communication technologies (ICTs) in the field of psychological treatments has developed at a fast pace in recent years. ICTs offer different methods that can help to improve the effectiveness of some components of treatment. One of these elements is virtual reality (VR), used for treating a range of psychological disorders.[9,10] In the field of pain, VR has been used mainly in the treatment of acute pain associated with medical procedures.[11,12] However, the use of VR in chronic pain is scarce. A recent systematic review about the use of VR found promising results for the efficacy of distraction for pain reduction.[13] Some researchers have explored the use of a VR mirror in the treatment of complex regional pain syndrome and phantom limb pain.[14,15] The literature on the applications of VR in the field of chronic pain is very scarce. Keefe et al.[16] conducted a review of this issue and found some preliminary studies where VR could be a good approach to

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expose patients to movements that they may fear or avoid due to pain. It has been suggested that mirrors and VR could be potential new treatments for this condition. Our research team realized a pilot study showing the utility of VR to induce relaxation in FMS.[17] Our aim is to contribute to the exploration of the use of VR in the treatment of chronic pain.

Chronic pain is characterized by a loss of valued activities, which has an effect on the mood of the sufferer. The task of making FMS patients become more active is challenging. As a chronic condition, it leads to a dysfunctional pattern of activity that is very difficult to reverse. The activity management component of the program consists of setting goals related to activities that are significant for the patients and getting patients to perform those activities progressively, balancing the period of rest and activity. Feelings such as low mood and fear and symptoms of the condition—pain and, more importantly, fatigue—get in the way of the willingness to perform the activities, causing low motivation and a poor sense of self-efficacy. Positive emotions can help to counteract the effect of these aspects. The influence of positive emotions influences cognitive processes, well-being, and health,[18,19] promoting flexible and creative thinking and playing an important role in building of psychological strength and intellectual and social resources.[20] The promotion of positive emotions may help in the regulation of negative emotions or, in promoting the increase of available resources, to maintain long-term gains and to provide people with the strength to become more resilient. Our research team is currently working on the study of the effect of positive emotions in the treatment of mental and health problems, and in the use of technology to promote well-being.[21]

To achieve this goal, we rely on the potential of VR. We have developed a VR component using an adaptive display for the delivery of an adjunct to the activity management component.[22] The use of multiple sensory multimedia cues (music, images, and videos) that VR offers prompted us to use this technology for inducing positive emotions in FMS patients. Before carrying out a controlled study to analyze the effectiveness of the VR, a pilot study was designed to explore users' opinions and acceptance, and to collect some initial data about its utility to increase positive emotions and promote motivation and self-efficacy.

Materials and Method

Participants

The sample comprised 40 patients, all women ranging in age from 27 to 66 years ($M = 48.8$; $SD = 9.3$) and diagnosed with FMS according to ACR criteria.[23] Of these, 52.5% had an additional diagnosis of anxiety disorder, and 65% of depressive disorder. They have suffered chronic pain for a range of 1–30 years ($M = 10$; $SD = 7.1$). Most of the sample (55%) had an elementary level of education, 12.5% had not finished elementary studies, 15% finished high school, and 17.5% had a university degree. Regarding work status, 47.5% were active workers, 32.5% were housewives, and 20% did not work. Of those who were not working, 12.5% were on sick leave.

Exclusion criteria included severe mental illness, mental retardation, or being involved in the process of obtaining disability compensation. All participants agreed to participate and signed an informed consent form before starting the study.

Measures

Screening and psychological diagnostic assessment was conducted using the Structured Clinical Interview for DSM-IV Axis I Disorder (SCID-I)[24] and the Structured Clinical Interview for DSM-IV Axis II Personality Disorder (SCID-II).[25]

The outcome measures chosen to determine if the VR procedure could produce changes from pretest to posttest were:

- Mood state (MS): Patients were asked to assess their general mood state, using a pictorial scale with seven facial expressions ranging from "very sad" to "very happy."
- Pain and fatigue intensity: Patients were asked to assess their pain and fatigue intensity, using a numeric rating scale (NRS) comprising 11 points, ranging from 0 = "no pain or fatigue" to 10 = "worst pain or fatigue."
- Motivation and self-efficacy: Patients were asked to assess their motivation and sense of self-efficacy regarding specific activities that they chose in a previous session, using a NRS comprising 7 points, ranging from 1 = "none" to 7 = "very much."
- Intensity of several emotions: Participants were asked to rate the intensity of different emotions (joy, sadness, anger, surprise, anxiety, relaxation, and vigor/energy), from 1 = "not at all" to 7 = "completely."

Following induction, an opinion questionnaire was administered to assess the participants' acceptability and satisfaction regarding the VR. Participants rated four topics using a scale from 1 to 10: "To what extent are you satisfied with the VR component that you received?"; "To what extent do you feel that VR was useful for you?"; "To what extent do you feel that VR annoyed you?"; "To what extent would you recommend VR to others with the same problem as you?"

In addition, five more questions were administered in order to compare before induction with after induction. Participants were asked to rate on a scale where 1 = "much worse" to 7 = "much better" the change from before induction to after induction in pain, fatigue, general mood state, motivation, and self-efficacy.

Virtual environment

The configuration used a range of devices: two PC computers, a 3 × 4 meter screen made of reflective material, two projectors, and a Dolby 7.1 surround sound audio system. The first PC had the graphical outputs from its graphic card connected to the projector, which were used to project the environment onto a metacrilate screen. The second PC hosted the therapist's application and controlled the features of the virtual environment that were shown to the patient.

Participants were placed in front of the screen in groups of six people. One of the therapists was in charge of operating the VR system during the 20 minute session.

The VR environment was an adaptive display named EMMA, developed in the framework of EU funded Project (IST-2001-39192-EMMA, Engaging Media for Mental Health Applications). EMMA is a flexible VR environment that includes five predefined scenarios aimed to induce emotions (desert, beach, forest, snowy landscape, and a meadow). It is possible to change the weather or the time (day and night), and to include sounds, images, and videos. This VR environment has demonstrated its capacity to

FIG. 1. Treatment setting for the delivery of virtual reality (VR) sessions.

induce several emotions[26] and its efficacy in the treatment of stress-related disorders.[27]

In this study, the scenario chosen was the beach, including music, sounds, narratives, and images selected especially to induce positive emotions and promote motivation, self-efficacy, and behavior activation. Figures 1, 2 and 3 show images of the setting and the VR environment.

Melodies with positive valence and high arousal were included from the International Affective Digitized Sounds.[28,29] Besides, other melodies were selected, following two rules: tempo and mode.[30] Research suggests that a fast tempo evokes energy and activation, and a major mode is related to positive mood.[31]

Images were selected from the International Affective Picture System,[32] meeting the criteria of positive valence and high arousal. Other images were also included, selected according to three dimensions: color, brightness, and saturation. Research indicates to evoke positive emotions, it is important to use images with bright and high saturated colors, with a prevalence of green and blue colors.

Table 1. Fragment of the Narrative Included in the VR Procedure

Pain is an important challenge, but with perseverance, courage, optimism and determination you can get what you want to achieve your goals. Don't let pain prevent you from doing what you want to do. Begin with small and short-term goals, and, little by little, progress to bigger and long-term goals. Remember that there is something in you that is bigger than any obstacle.
Now, write your goal on this board, a little goal for this week. Write: I will. … Read it out loud. Your strength is your determination and courage, courage that is inside you, courage that you demonstrate every day, facing pain.
Now, let's walk around the room showing off your goals [walk with the board].
Start doing this activity today; include it in your routine because it is something you want to do. When your energy goes down, remember this session.
If you believe you are tired, you are tired.
If you believe you won't be able to do it, you won't do it.
If you believe that you would like to win, but you won't be able to, you will lose.
If you believe you will lose, you have already lost.
Because life teaches us
That success begins with the willingness to succeed.
Everything is in our minds.
Think big and your facts will grow.
Think small and you will be left behind.
Believe you can, and you will.
Everything is in your mind.
If you believe you are advanced, you really are.
Positive thoughts bring positive energy.
Only when you think positively
Can you start to change your world.
You make the change possible.
The battle of life is not won by the strongest or fastest man,
Because, sooner or later, the man who wins is the one who believes he can win.

FIG. 2. An example of narratives and images offered to the participants during the induction.

FIG. 3. Another example of narratives and images offered to the participants during the induction.

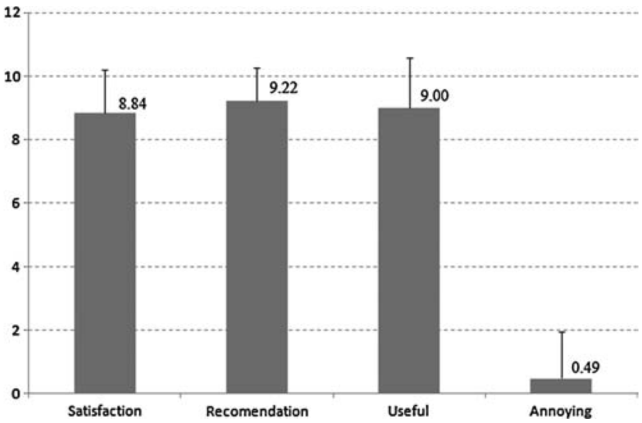

FIG. 4. Mean and standard deviation of the opinion and acceptability of the system.

In addition, we included narratives designed by a team of therapists with expertise in CBT treatment for chronic pain in order to induce motivation and positive emotions in FMS sufferers (see Table 1).

The characteristics of this VR environment allow VR sessions to be performed in a group. This is important in the case of FMS, given that group therapy is recommended for chronic pain sufferers.[33]

Procedure

Participants were recruited from the rheumatology unit of the Hospital General de Castellon. The rheumatologist gave general information about the study and referred FMS patients to LabPsitec at Jaume I University. All subjects attended voluntarily. Once the participants gave written informed consent, the SCID-I and SCID-II were administered to determine if the patients met the inclusion criteria. The group therapy sessions lasted 2 hours and were attended by six patients and two therapists in each session. After this, all participants received two sessions of psycho-education about FMS and about the activity management component. The third session included information about how to program an activity management plan and looked at choosing the activities for each patient. At the end of the third session, patients chose the activities to be performed on the following week and went through the VR component as an adjunct to increase motivation related to the performance of the chosen activities. The induction lasted approximately 20 minutes. Before and after going through the VR environment, participants filled out the outcome measures. Participants received three more therapeutic sessions to progress in the activity management program.

Results

Figure 4 displays the mean and standard deviation of the opinion and acceptability of the VR system. Results showed a high level of satisfaction with the VR ($M=8.84$; $SD=1.365$), and participants recommended the use of the VR to others ($M=9.22$; $SD=1.058$). Regarding the usefulness, participants considered the VR to be highly useful ($M=9.00$; $SD=1.592$). In addition, participants considered that the VR was not annoying ($M=0.49$; $SD=1.465$).

Table 2 summarizes the results of the *t* test for related samples and the Cohen's *d* calculated to examine the before and after induction results. Regarding pain and fatigue intensity, there was a decrement from pretest to posttest, but it was not statistically significant. However, there was a significant improvement in mood state from pre- to post-session with a moderate effect size. Regarding self-efficacy and motivation related to meaningful activities, there was a significant increase in both variables with small effect sizes. Finally, for intensity of emotions, results showed significant increases in joy, surprise, calmness, and vigor. In addition, significant decreases in sadness and anxiety were observed. The biggest effect sizes were found in calmness and joy. No differences were found in anger.

Table 3 summarizes the percentage results for the comparison questions before and after induction. The results show that 52.63% of participants felt somewhat better after induction regarding their pain, 21.05% felt the same, 15.79% felt better, and 10.52% felt much better. Only 7.5% reported

Table 2. Results of the Efficacy of the VR Induction Procedure

	n	*Pretest Mean* (SD)	*Posttest Mean* (SD)	t	p	*Cohen's* d[a]
Pain	40	5.07 (2.03)	4.82 (2.24)	1.759	0.086	0.12
Fatigue	40	4.36 (2.49)	4.18 (2.49)	0.764	0.449	0.07
Mood State	39	4.69 (1.26)	5.21 (1.17)	−4.687	0.000	−0.43
Activities						
Self-efficacy	36	4.66 (1.70)	5.11 (1.52)	−2.394	0.022	−0.30
Motivation	32	4.55 (1.65)	4.96 (1.65)	−2.652	0.012	−0.25
Emotion						
Joy	40	4.25 (1.53)	4.80 (1.44)	−3.626	0.001	−0.37
Sadness	40	2.43 (1.52)	2.07 (1.44)	2.211	0.033	0.24
Anger	39	1.44 (1.02)	1.28 (0.76)	1.030	0.310	0.18
Surprise	40	2.40 (1.82)	3.05 (2.01)	−2962	0.005	−0.34
Anxiety	39	2.26 (1.52)	2.10 (1.54)	1.098	0.279	0.10
Calmness	40	3.60 (1.95)	4.73 (1.60)	−3.984	0.000	−0.63
Vigor/Energy	40	3.73 (1.65)	4.35 (1.63)	−3.007	0.005	−0.38

[a]What Cohen (1988) defines as $d=0.2$ are regarded as a ‘‘small'' effect size, $d=0.5$ as ‘‘medium,'' and $d=0.8$ as ‘‘large.''

Table 3. Results in Percentage for the Comparison Questions Before and After Induction in Pain, Fatigue, Mood State, Self-Efficacy, and Motivation

	Pain	*Fatigue*	*Mood state*	*Self-efficacy*	*Motivation*
Much worse	0	0	0	2.5	2.5
Worse	0	0	0	2.5	0
Somewhat worse	7.5	2.5	0	0	2.5
Same	27.5	33.3	21.1	17.9	12.5
Somewhat better	42.5	41.7	44.7	33.3	35.9
Better	12.5	11.1	15.8	30.8	33.3
Much better	10.0	11.1	18.4	12.8	12.8

feeling a little worse. Regarding fatigue, 50% of participants felt the same, 37.5% felt somewhat better, and 12.5% felt better. Only one participant reported feeling somewhat worse. Regarding general mood state, 33.33% of participants felt somewhat better after induction, 27.78% felt the same, 27.78% felt better, and 11.11% felt much better. In the same way, 57.9% of participants felt better after induction in terms of their sense of self-efficacy regarding the activities chosen in the activity management plan, 15.79% felt the same, 15.79% felt somewhat better, and 10.52% felt much better. Only two participants reported feeling worse or much worse. With regard to motivation, 57.9% of participants felt better after induction, 21.05% felt somewhat better, 10.52% felt the same, and 10.52% felt much better. Only two participants reported feeling somewhat worse or much worse.

Discussion

This study presents data of the opinion, acceptance, and preliminary efficacy of a VR procedure for the induction of positive emotions and motivation as an adjunct to an activity management component for the psychological treatment of FMS.

Forty patients received this procedure within the content of a CBT group session. Most patients reported feeling better after going through the VR procedure and being more motivated to become involved in meaningful activities, showing that it is feasible to deliver a VR procedure for the induction of positive emotions as an adjunct to the activity management component, and it had a positive effect on patients. Furthermore, all patients highly recommend the use of VR and considered it was a useful tool in their treatment.

This is an important result, given that the chronicity of the dysfunctional behavior pattern in FMS sufferers makes the task of becoming active very challenging. The activity management component consists of setting goals related to activities that are meaningful for the patients and progressively encouraged them to perform those activities in a balanced way. Negative emotions are a barrier to achieving therapeutic goals, causing low motivation and low self-efficacy. Our VR environment was designed to promote positive emotions and motivation, and offers preliminary data on the possibility of using its positive effects in encouraging FMS sufferers to become involved in meaningful activities to improve their mood, emotional well-being, and quality of life.

This work contributes to the use of ICT and, specifically, VR in a field where research is still very scarce—chronic pain.[16] This is the first study testing a VR procedure for induction of positive emotions, and could be an important step for the improvement of psychological treatments in chronic pain patients, given the importance of positive emotions to promote significant activities as an essential component of well-being. These findings encourage us to continue with this line of research, to explore concretely the efficacy of this procedure in a controlled study in order to improve patients' quality of life.

Our work also contributes to a different way of delivering VR. We used a large screen and not a head mounted display, as it is usual in VR therapy. Our study demonstrated that it is possible to deliver a VR therapeutic component in a group setting. This is important in the case of FMS, given that group therapy is recommended for chronic pain sufferers.[33]

The main limitation of this study is that our data are from a single VR induction, without an evaluation of a long-term effect. Our main aim was to explore if it was feasible to use the VR procedure in this population. Given their dysfunctional and chronic condition, we wanted to examine if patients felt comfortable with the use of VR in a usual CBT group session. This aim was achieved in a significant number of participants, where not only was not only feasible, it also had positive effects. Further research is needed to explore the efficacy of the repeated use of this VR procedure within a CBT program. Another limitation of this study is the absence of a control group, but our aim was to develop a VR procedure designed for a specific population and test it in the context of real treatment. Our next step will consist of designing a control study in order to compare the VR procedure with other VR environments validated as mood induction procedures.

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Author Disclosure Statement

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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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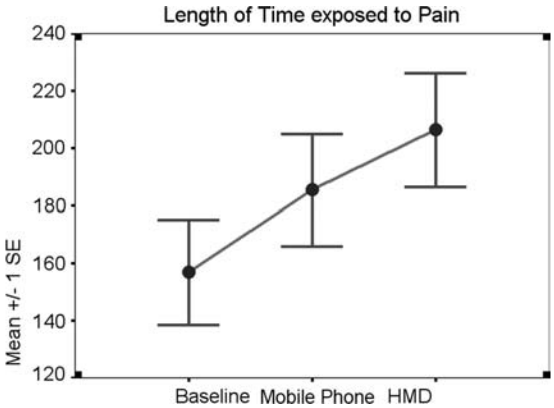

FIG. 1. Time of pain exposure comparison. HMD, head-mounted display.

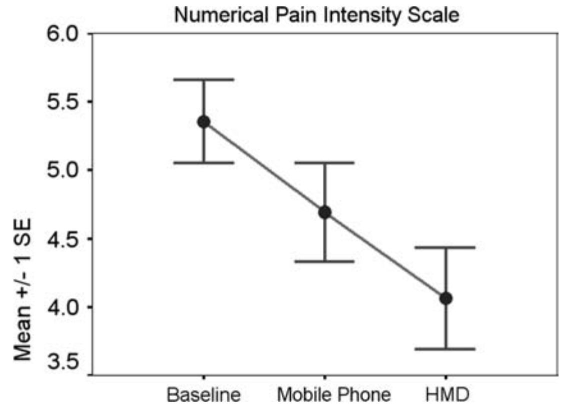

FIG. 3. The numerical pain scale decreased when subjects were using the mobile phone (mean score decreased by 0.66, $p < 0.002$), and it further decreased by 0.32 when patients used the HMD.

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]

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

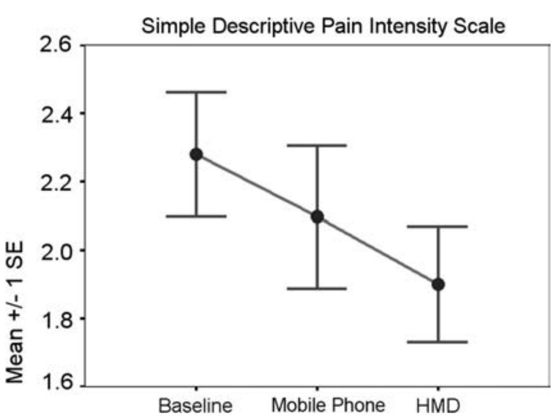

FIG. 2. Compared to baseline, the Simple Descriptive Pain (SDP) intensity scale decreased when patients used the mobile phone (mean score decreased by 0.3). The SDP scale decreased further when patients were using the HMD (mean score decreased by 0.355, $p < 0.05$).

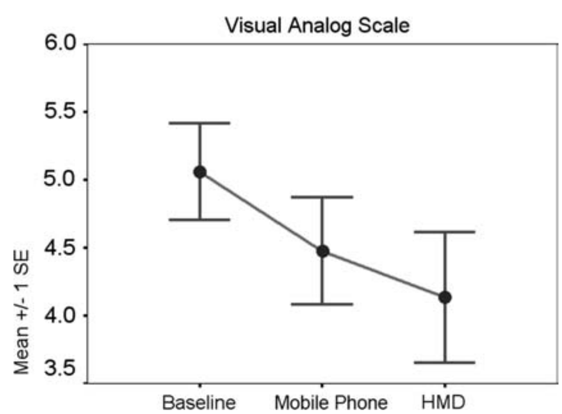

FIG. 4. The Visual Analog Pain Scale decreased when subjects were using the mobile phone pain distraction (mean score decreased by 0.58, $p < 0.02$), and it further decreased by 0.445 ($p < 0.04$) when the HMD was used.

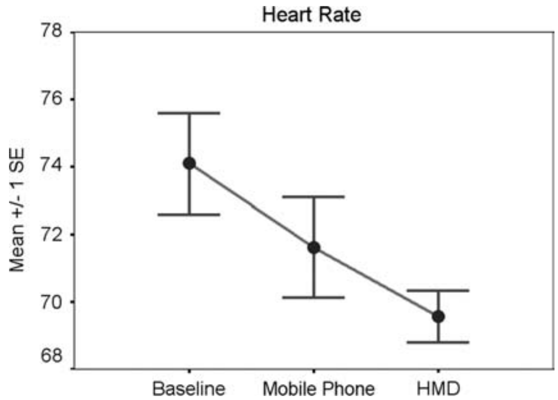

FIG. 5. At baseline, the mean heart rate was 74 beats per minute (bpm). When subjects used the mobile phone pain distraction, the mean heart rate decreased to 72 bpm, and then decreased to 70 bpm when subjects used the HMD.

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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Virtual Reality and Musculoskeletal Pain: Manipulating Sensory Cues to Improve Motor Performance During Walking

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Abstract

Musculoskeletal pain (MSP) is the most expensive nonmalignant health problem and the most common reason for activity limitation. Treatment approaches to improve movement without aggravating pain are urgently needed. Virtual reality (VR) can decrease acute pain, as well as influence movement speed. It is not clear whether VR can improve movement speed in individuals with MSP without aggravating pain. This study investigated the extent to which different audio and optic flow cues in a VR environment influenced walking speed in people with and without MSP. A total of 36 subjects participated, 19 with MSP and 17 controls. All walked on a motorized self-paced treadmill interfaced with a three-dimensional virtual walkway. The audio tempo was scaled (75%, 100%, and 125%) from baseline cadence, and optic flow was either absent, or scaled to 50% or 100% of preferred walking speed. Gait speed was measured during each condition, and pain was measured before and after the experiment. Repeated measures analysis of variance showed that audio tempo above baseline cadence significantly increased walking speed in both groups, $F(3, 99) = 10.41$, $p < 0.001$. Walking speed increases of more than 25% occurred in both groups in the 125% audio tempo condition, without any significant increase in pain. There was also a trend toward increased walking speeds with the use of optic flow, but the results in this study did not achieve significance at the $p < 0.05$ level, $F(2, 66) = 2.01$, $p = 0.14$. Further research is needed to establish the generalizability of increasing movement speed across different physical performance tasks in VR.

Introduction

Pain remains a pervasive, complex, and challenging phenomenon associated with tremendous human and financial costs. Musculoskeletal pain (MSP) is the most expensive nonmalignant health problem affecting the working age population and is the most common reason for activity limitation. In the United States, chronic pain is estimated to affect 100 million adults and costs $560–635 billion annually.[1] Although pain is frequently a symptom of tissue injury or illness, persistent pain is now also recognized as a disease per se.[2] Regardless of its genesis, pain is associated with compromised mood and movement across health conditions.

Generalized psychomotor slowing is commonly associated with pain, as individuals appear to have difficulty generating or withstanding the relatively higher forces associated with faster movements. Psychomotor slowing frequently persists despite the apparent resolution of injury or illness. This failure to resume usual movement speed leads to prolonged reduction in activity and increased disability.[3,4] Research has shown that individuals with pain and illness can move faster when challenged to but tend not to if unchallenged.[5] Thus, therapeutic approaches that enhance movement speed without increasing perceived pain or effort may help patients recalibrate their expectations and subsequently resume optimal and efficient movement speeds that decrease disability.

The benefits of virtual reality (VR) for rehabilitation are known to include increased engagement with therapy[6–8] and distraction from pain.[9,10] If this ability of VR to distract from pain can be leveraged while employing techniques to facilitate faster movement, it could offer significant potential for locomotor rehabilitation for conditions associated with MSP.

VR and analgesia

Evidence from a number of studies has demonstrated an analgesic effect of VR for acute pain, primarily with pain due to burns or medical procedures,[9,10] but the effect on active movement was not assessed. Furthermore, a recent systematic review reported strong evidence for the analgesic effect of

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immersive VR on acute pain in adults, but found insufficient evidence supporting the effectiveness of VR for reducing chronic pain.[11] Thus, while it is clear that VR may be useful for the amelioration of pain in some settings, it is not known how patients with chronic MSP might respond, particularly during active motion, which would normally elicit increased levels of perceived pain.

To date, the mechanisms that account for a potential analgesic effect of VR are not clear, but are probably due in part to VR affording a means of attracting an individual's attention toward an alternative visual and auditory stimulus and thereby reducing the magnitude of attention available to focus on pain. Moreover, given that attention to visual and auditory stimuli in VR limits attention to pain stimuli, it is plausible that the addition of movement during VR could demand even more attention and thereby further enhance analgesia—or at least not allow for an increase in pain related to movement.

VR to improve walking speed

Applications to support walking in VR generally use a treadmill or similar device interfaced to the VR software to create the illusion of moving through the virtual environment.[12,13] However, the interactions between a user and a VR system can be complex, and there is evidence that even small changes in factors within a VR system can have a significant effect on movement and movement perception.[14]

Fixed pace treadmills are known to disrupt the spatiotemporal control of gait,[15] and self-paced treadmills interfaced to VR are increasingly widely used,[12,13] as they support the natural walking ratio.[15] However, they also tend to be associated with a decrease in walking speed when users are free to self-select their own pace,[13–16] and this is true both for healthy adults and for patients with MSP.[15] Thus, if the analgesic effect of VR and the natural walking support of the self-paced treadmill are to be leveraged for effective rehabilitation protocols, they need to be combined with techniques to facilitate or encourage increased walking speeds.

Optic flow (the apparent motion of objects, surfaces, and edges in a visual scene caused by the relative motion between an observer or virtual camera and the scene) is used as a powerful cue to determine self-motion. It has previously been demonstrated that altering the rate of optic flow in a virtual environment can influence walking speeds in a healthy population, with lower flow rates being associated with faster walking speeds,[16–18] but this has not yet been demonstrated in patients with pain. However, it is plausible that the slowing of optic flow rate, and the associated reduction in perceived self-motion, may reduce the fear of pain associated with increased walking speeds in people with MSP, reducing the inhibitory effect of anticipatory pain on walking.

In addition, there is a strong link between auditory rhythms and motor activity, and the motor system is physiologically sensitive to arousal by the auditory system.[19] A number of studies in non-VR settings indicate that the use of audio cues can facilitate improved walking speed and quality,[20–23] and more recently it has been demonstrated that this audio cue facilitating effect can also be seen in treadmill-mediated VR.[24] Not only has this effect been seen in healthy populations, there are also data to suggest that audio cues can improve walking speed and cadence in Parkinson's disease[19,23,25–27] and also in stroke patients.[20,22] However, both Parkinson's disease and stroke are associated with neurological deficits resulting in motor dysfunction, and it cannot be assumed that similar facilitation would be observed in populations with MSP, where slow movement has a less direct neurological etiology. Furthermore, chronic pain demands a high level of attention, which may distract attention from other tasks,[3,28] and therefore it may be the case that patients with chronic pain would be less able to attend to the visual and auditory cues that would otherwise lead to faster walking speeds.

The purpose of this study was to examine the extent to which audio and visual cues in treadmill-mediated VR can increase gait speed for people with slowed movement due to pain.

Materials and Methods

Previous work identified that presenting an optic flow speed of 0.5 times normal (non-VR) walking speed was associated with a significant increase in walking speed,[16] and so this was selected as a level for this experiment. To provide a comparison and control, two other visual conditions were also included: optic flow matched to baseline treadmill walking speed,[a] and absent optic flow (static image). The experiment used a virtual environment that was designed to provide high contrast peripheral visual cues to improve self-motion perception[29] without any central visual clutter or obstacles.[30] The audio cue rates were scaled from the baseline cadence using the same scaling as in our previous work (75%, 100%, and 125% of baseline cadence).[24]

The experimental design was a mixed $3\times4\times2$ factorial experiment with two within-subjects factors (optic flow$\times$audio) (Table 1), and one between subjects factor (pain). Audio cue tempo, optic flow rate, and presence of pain were the independent variables. Walking speed was the dependent variable. In addition, the pre- and post-experiment pain intensity and pain affect were recorded as dependent variables for the MSP group.

Apparatus

The treadmill used in this study was a self-paced motorized treadmill.[31] The treadmill responded dynamically to the speed of the user in real time. The belt speed was recorded to

Table 1. The Combination of Audio and Visual Cues for the Experimental Conditions for the Two Experimental Groups

	No audio	*Audio rate 75% baseline cadence*	*Audio rate 100% baseline cadence*	*Audio rate 125% baseline cadence*
No optic flow	Condition 1	Condition 4	Condition 7	Condition 10
Optic flow 50% baseline speed	Condition 2	Condition 5	Condition 8	Condition 11
Optic flow 100% baseline speed	Condition 3	Condition 6	Condition 9	Condition 12

FIG. 1. The high contrast walkway with vertical peripheral cues used to generate the optic flow.

a computer using an optical sensor at a resolution of 0.01 meters per second.

The treadmill was placed 1.5 meters in front of a 2.44 meters × 3.05 meters screen. A three-dimensional model of a virtual walkway was created using SoftImage XSI software. The scene consisted of two parallel rows of vertical columns on either side of a walkway (Fig. 1).

The virtual camera was set to match the starting position of the participant, with a horizontal field of view of 80° and a height of 1.6 meters above the ground plane. The scene was back-projected onto the screen using a single (monoscopic) projector. To minimize visual distraction, the room was darkened for the experiment, with the main light source being the display screen itself.

CAREN D-flow software (Computer Assisted Rehabilitation Environments, Motek BV) was used to control the hardware system and synchronize the instantaneous treadmill speed and scene progression via a software gearing module. The audio component was also synchronized by the D-flow software. The audio was the sound of a footstep on a hard surface, loaded as a .wav file into the application. The sample sound was 0.2 seconds long, sampled at 705 kbps. It was delivered to the participant via Logitech ClearChat™ wireless stereo headphones.

Participants

A total of 36 volunteers participated in the experiment. Patients with MSP on walking were recruited from the Jewish Rehabilitation Hospital (Laval, Quebec) and the Constance Lethbridge Rehabilitation Centre (Montreal, Quebec). Healthy volunteers were recruited from the staff and student body of the Jewish Rehabilitation Hospital, the Constance Lethbridge Rehabilitation Centre, and McGill University (Montreal, Quebec).

The participants were assigned to one of two groups based on the presence ($n=19$) or absence ($n=17$) of MSP in the upper or lower limb that compromised walking (Table 2). All were able to walk independently and had no other medical condition that limited walking (e.g., stroke, Parkinson's disease, heart disease, etc.).

Table 2. Demographic Details of Participants

	Age	*Sex*	*Pain intensity*	*Pain affect*
No pain ($n=17$)	22–68 ($M=46.9$)	8 female/ 9 male	N/A	N/A
Pain ($n=19$)	24–80 ($M=54.8$)	13 female/ 6 male	$M=3.9$ (2.5)	$M=2.8$ (2.8)

Pain intensity and pain affect scored on a 1–10 Numeric Rating Scale on day of testing (standard deviation [*SD*] in parentheses).

Ethical approval was obtained from the Comité d'éthique de la recherche des établissements du CRIR (Montreal, Canada). All participants were able to converse fluently in either English or French, and gave their informed consent prior to inclusion in the study.

Procedure

The participants walked in each of the experimental conditions in a counterbalanced order. For the visual cues, the preferred walking speed was used to scale the optic flow by a factor of 0, 0.5, or 1, and the rate of apparent motion through the virtual environment was maintained at this speed for the duration of the trial. For the audio cues, the baseline cadence was used to scale the audio tempo by a factor of 0, 0.75, 1, or 1.25, and the footstep beat was played at this tempo for the duration of the trial.

During pilot testing, it was found that 2 minutes of walking was sufficient to obtain consistent walking speed data, and therefore each of the trials was limited to a duration of 2 minutes.

For each of the trials, the participants were asked to walk at their preferred (baseline) speed on the treadmill. At the start of each trial, treadmill walking was initiated in the absence of optic flow or audio. When participants reached 75% of their preferred walking speed, the visual/audio cues for the trial condition were initiated automatically. The participants then continued to walk on the treadmill for 2 minutes, while being presented with the combinations of audio and visual cues. The participants were able to rest between trials as required, and completed a total of twelve 2 minute trials.

Participants were instructed to walk at a self-selected pace for the duration of each 2 minute trial. No instructions were given regarding whether they should attempt to synchronize with the audio beat.

Participants from the pain group were asked to notify the experimenters of any significant change in pain, and to give a verbal Numeric Rating Scale (NRS) rating of perceived pain intensity and pain affect immediately after completing the experiment.

Results

The effect of audio and visual cues on walking speed

The walking speed of the participants was automatically recorded to the treadmill control computer during each trial, and the mean walking speed (m/s) was calculated from these data (Table 3). A repeated measures analysis of variance (ANOVA; optic flow × audio cue tempo × pain) demonstrated a significant effect of audio tempo on walking speed,

Table 3. Overall Mean Walking Speeds in Each of the Experimental Conditions

	No audio		*Audio rate 75% baseline cadence*		*Audio rate 100% baseline cadence*		*Audio rate 125% baseline cadence*	
	Pain	*No pain*	*Pain*	*No pain*	*Pain*	*No pain*	*Pain*	*No pain*
No optic flow	0.88 (0.33)	1.08 (0.30)	1.10 (0.35)	1.47 (0.28)	1.07 (0.41)	1.37 (0.35)	1.12 (0.40)	1.40 (0.29)
Optic flow 50% baseline speed	1.06 (0.36)	1.39 (0.24)	1.04 (0.38)	1.38 (0.33)	1.06 (0.34)	1.36 (0.30)	1.09 (0.34)	1.46 (0.28)
Optic flow 100% baseline speed	1.06 (0.39)	1.37 (0.26)	1.08 (0.29)	1.33 (0.30)	1.03 (0.36)	1.22 (0.48)	1.09 (0.36)	1.36 (0.28)

SD in parentheses.

$F(3, 99) = 10.41$, $p < 0.001$, but no significant effect of optic flow on walking speed, $F(2, 66) = 2.01$, $p = 0.14$.

Although there was no statistically significant effect of optic flow, there was a trend toward increased walking speeds when the treadmill was linked to the virtual environment, particularly in the no pain group and the slow optic flow condition, with >20% mean walking speed increases (Fig. 2).

Post hoc analysis revealed that the walking speed in the fast audio condition was significantly faster than the no audio condition ($p < 0.001$) and faster than the 100% audio condition ($p < 0.05$), but was not significantly different from the slow audio condition ($p = 0.3$). The walking speed in the slow audio condition was also significantly faster than in the no audio condition ($p < 0.001$). There was no significant difference between any other pairs of audio conditions. Walking speed in all audio conditions was faster than without audio cues (Fig. 3).

There was no significant interaction effect, $F(1, 33) = 0.074$, $p = 0.79$, between pain and audio, and no significant interaction, $F(1, 33) = 0.29$, $p = 0.56$, between pain and visual cues. However, there was a significant interaction, $F(6, 198) = 12.31$, $p < 0.001$, between audio and visual cues.

There was a significant difference between the no pain and pain groups, $F(1, 33) = 8.08$, $p < 0.01$). The mean walking speed of the pain group was lower than the no pain group across all conditions.

Comparison of pain at the start and end of the experiment

Repeated measures analysis (paired *t* test) showed no significant difference in the pain intensity, $t(16) = 0.46$, $p = 0.65$, or the pain affect, $t(16) = 2.12$, $p = 0.06$, between the beginning and end of the experiment (after 12 trials) for the pain group (Fig. 4). Pain intensity and affect were not measured for the no pain group.

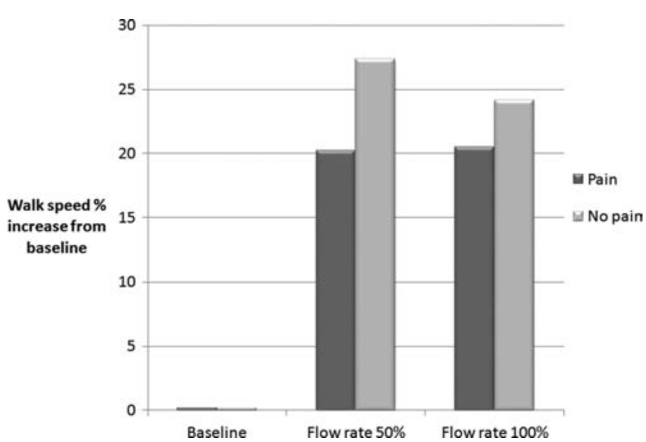

FIG. 2. The percentage increase in mean walking speed from baseline with varying optic flow rates.

Discussion

The effect of audio and visual cues on walking speed

The use of audio cues above baseline cadence was associated with faster walking speeds in both the pain and no pain groups. There was no difference in the direction or magnitude of the effect between the group with pain and the group without pain. This supports and extends the findings of our previous work[24] and suggests that audio cues may be effective in facilitating faster walking in patients with chronic pain as well as in healthy adults.

It was somewhat surprising to find that the speed increase was similar in both the slow and fast audio cue conditions. However, previous studies have noted the ability to synchronize to twice the speed of a slow tempo (''doubling'' the tempo),[32] and this would be consistent with the speed increase seen with this cue frequency, where the response to the 75% tempo is similar to the response to the 125% tempo. Further work is underway to investigate a wider range of audio tempos.

There was a significant interaction between the audio and visual cues, with slower walking speeds when optic flow was present compared with audio alone (no optic flow). This might be explained by the model of competing attentional demands. Auditory and visual stimuli both require attention, which can be considered to be a finite shared resource.[28] In the presence of audio cues alone, there is sufficient attention to respond to the cues, but by adding the visual cues, the attention is divided between two cues.[21] Audio cues that are in conflict with the preferred cadence may disrupt the automatic synchronicity of walking, necessitating more conscious attention. The suppression of the effect of audio on walking speed by the addition of optic flow may therefore be attributable to a reduction of attention to the audio cues in the presence of a competing attentional load. However, the data in this experiment do not display a robust enough pattern to be certain of the underlying mechanisms, and further investigation is necessary to establish whether other attentional loads also reduce the influence of audio cues on walking.

In contrast to earlier studies,[16–18] altering the optic flow rate did not have a significant effect on walking in either the pain or no pain populations (although there was a trend toward faster walking speeds in the optic flow conditions

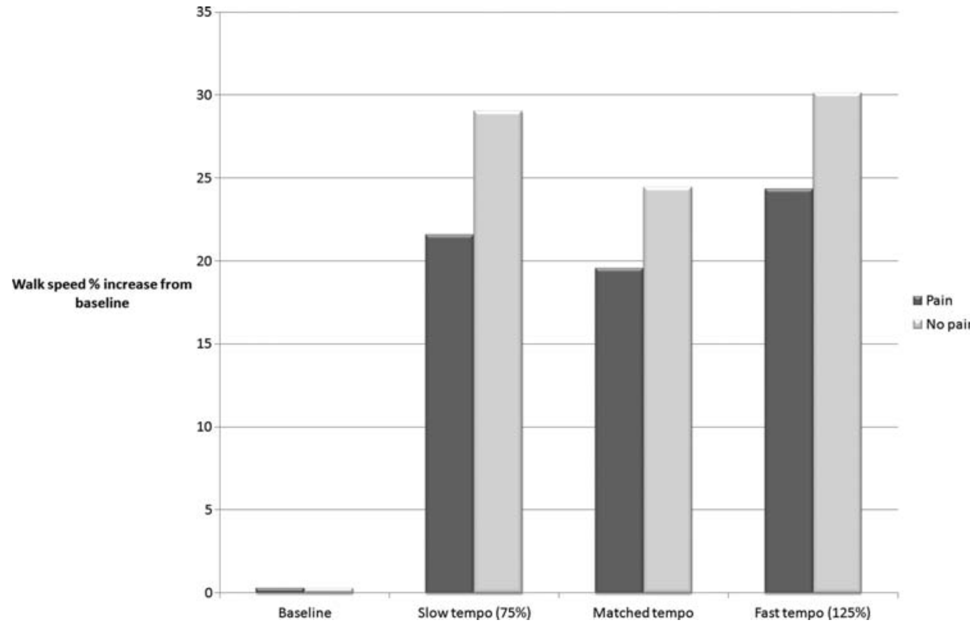

FIG. 3. The percentage increase in mean walking speed from baseline with varying audio cue tempo.

compared to a static scene). If this had been noted in just the pain group, it might have been concluded that the presence of pain was sufficient distraction to prevent a normal response to the optic flow. However, neither group demonstrated any significant effect of optic flow rate, and since this is in direct contrast to most previous studies, it warrants some examination of the experimental design. The virtual environment, screen size, treadmill type, and optic flow rate were all similar to those used in our previous work.[16] However, due to the equipment constraints in the clinical laboratory, the projection was monoscopic, whereas stereoscopic projection was used previously. It has been noted that depth judgments and self-speed perception in VR are influenced by the use of binocular disparity cues,[33,34] and it may be that the lack of visual depth cues altered the perception of the speed of optic flow, reducing the strength of its effect. A further study comparing the effect of optic flow in mono and stereo virtual environments is required to establish if this is the cause of the unexpected result in this study. If so, it may have significant implications for virtual environment design for rehabilitation applications.

Patients with pain walked on average 21% slower (1.06 m/s) across all conditions than the no pain group (1.35 m/s), similar

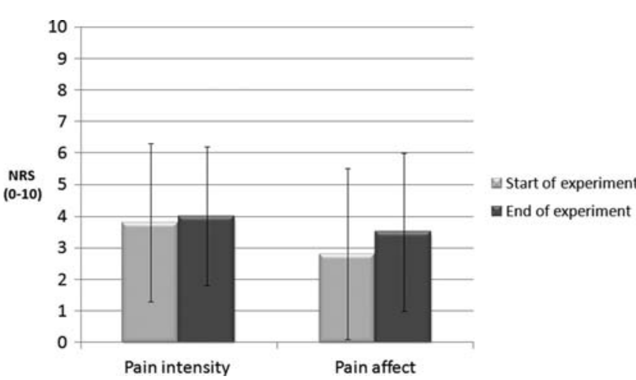

FIG. 4. Comparison of pain intensity and pain affect at the start and end of the experiment.

to the findings in our previous study with this patient group.[15] However, when the 75% or 125% audio cues were present, in the absence of optic flow, the pain group showed speed increases of up to 27% above their preferred treadmill walking speed, achieving speeds higher than the baseline treadmill walking speed of the no pain group (Table 3). This supports previous observations that individuals with pain can move faster but don't.[4]

In total, the participants in this study undertook around 30 minutes walking, albeit in short blocks, and much of this walking was at or above the preferred (baseline) treadmill walking speed. However, there was no significant increase in reported pain intensity or pain affect. While it would be anticipated that in normal treadmill walking, patients with chronic MSP would notice an increase in pain over time, this study did not have a control MSP group walking on the treadmill without any audio or visual cues. To answer the question as to whether the treadmill-mediated VR suppressed the perception of increased pain, a study comparing a VR intervention with non-VR treadmill walking would be necessary.

The ability to disengage from pain relates to the perceived threat,[35] and since patients systematically overestimate the pain associated with fast movements, this may act as a barrier to voluntary increases in speed.[4] Pain demands attention, and chronic pain involves continual switching between pain and other attentional demands.[28] Attending to visual or auditory cues also requires attention, and if this provides a sufficient distraction to enable some disengagement from the pain, then this may reduce the hindrance to faster walking. Indeed, this is supported by the finding that walking speed is higher in all cueing conditions compared with preferred speed measured at the start of the study. Previous studies have demonstrated that immersive VR can reduce perceived pain during passive procedures,[36,37] and the results of this study suggest that it is possible that the pain-reducing properties of VR may also be effective during active rehabilitation procedures.

It is evident that with careful VR design, patients with pain can improve walking speeds to a level commensurate with effective rehabilitation, and this can be achieved without concomitant increases in pain. This demonstrates the potential of VR in the rehabilitation of patients with MSP, and may offer some support in breaking the pain/reduced movement cycle.

Conclusion

Chronic pain (>6 months) can result in a cyclic disability-enhancing pattern of further decreased activity and avoidance that prevents normal restoration of function and perpetuates painful experiences,[3] and thus interventions are needed that can distract from or reduce the perceived pain while supporting improved movement.

VR offers recognized benefits of increased engagement and decreased pain perception, and it is clear from this study that the manipulation of audio and visual cues in VR can improve walking speed, even in patients with chronic MSP. Incorporating audio cues into a VR application that were presented at a tempo 25% above the normal preferred cadence facilitates increased walking speeds by around 27%, and this was achieved without a significant increase in either pain intensity or pain affect. This improvement in walking also appeared to be influenced by the rate of optic flow, although further work with stereoscopic projection is necessary to quantify this effect properly.

Since both auditory and visual sensory output is an integral component of most virtual rehabilitation systems, VR designers should incorporate these factors in a systematic manner to improve rehabilitation outcomes.

Acknowledgments

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Author Disclosure Statement

No competing financial interests exist.

Notes

a. Prior to conducting the experiments, all participants were familiarized with the self-paced treadmill, and when they were able to maintain a steady speed and cadence, they completed a treadmill 3 minute walk test, with no audio or visual cues. Average walking speed and cadence were recorded, and used as baseline measures for the experimental cue conditions.

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Feasibility of Articulated Arm Mounted Oculus Rift Virtual Reality Goggles for Adjunctive Pain Control During Occupational Therapy in Pediatric Burn Patients

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Abstract

For daily burn wound care and therapeutic physical therapy skin stretching procedures, powerful pain medications alone are often inadequate. This feasibility study provides the first evidence that entering an immersive virtual environment using very inexpensive (~$400) wide field of view Oculus Rift Virtual Reality (VR) goggles can elicit a strong illusion of presence and reduce pain during VR. The patient was an 11-year-old male with severe electrical and flash burns on his head, shoulders, arms, and feet (36 percent total body surface area (TBSA), 27 percent TBSA were third-degree burns). He spent one 20-minute occupational therapy session with no VR, one with VR on day 2, and a final session with no VR on day 3. His rating of pain intensity during therapy dropped from severely painful during no VR to moderately painful during VR. Pain unpleasantness dropped from moderately unpleasant during no VR to mildly unpleasant during VR. He reported going ''completely inside the computer generated world'', and had more fun during VR. Results are consistent with a growing literature showing reductions in pain during VR. Although case studies are scientifically inconclusive by nature, these preliminary results suggest that the Oculus Rift VR goggles merit more attention as a potential treatment for acute procedural pain of burn patients. Availability of inexpensive but highly immersive VR goggles would significantly improve cost effectiveness and increase dissemination of VR pain distraction, making VR available to many more patients, potentially even at home, for pain control as well as a wide range of other VR therapy applications. This is the first clinical data on PubMed to show the use of Oculus Rift for any medical application.

Introduction

The problem: uncontrolled pain

The current standard of care = pain medications alone. For over 100 years, opioid narcotic pain medication has been the cornerstone of pain control for severe burn patients during wound cleaning. Procedural pain is still managed largely as it has been managed for the past 100 years, pharmacologically, through opioid narcotic analgesics, often in combination with anxiolytics. Analgesics reduce pain by interfering at a neuronal level with the transmission of signals from pain receptors to the brain (e.g., neurotransmission).[1] Although this pharmacologic blocking of physical transmission of pain signals from pain receptors to the brain is the foundation of traditional burn pain control, pharmacologic analgesics alone typically fail to control pain during wound debridement.[1]

When relying on pharmacologies as the primary (and often the only) treatment for pain, most patients with large severe burn wounds report experiencing severe or higher pain during daily wound debridement (worst pain intensity of seven or higher on a 0 to 10 scale).[2] This is even true of soldiers.[3,4] Pain of five or higher is considered uncontrolled pain. Patients with unusually large severe pediatric burn wounds are especially challenging. Typically, the larger the severe burn, the longer the wound cleaning/debridement takes each day, and greater the number of days the patient receives wound care.

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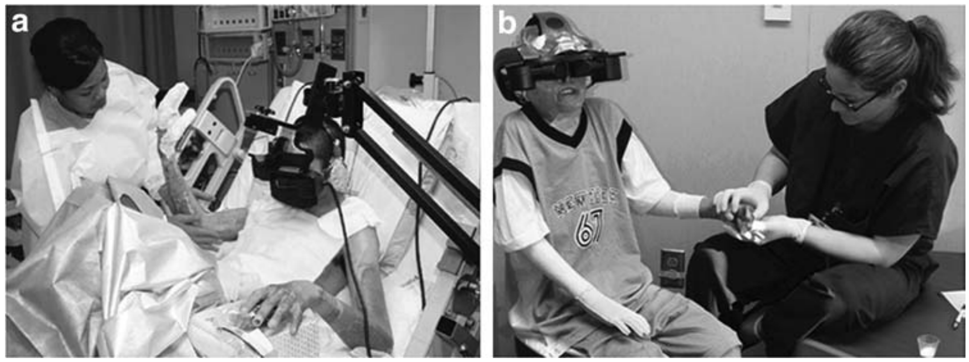

FIG. 1. **(a)** VR during wound cleaning of a soldier. **(b)** VR of pediatric burn patient during passive range of motion exercises. VR, virtual reality. Photo credits and copyright Hunter Hoffman, UW, www.vrpain.com.

Because of the inadequacy of pharmacological interventions alone to control burn pain during wound debridement and during occupational and physical therapy skin stretching exercises, adjunctive nonpharmacological interventions could provide a valuable additional component of a multiprogram burn pain treatment regimen. Psychological interventions can facilitate the effects of standard pharmacologic analgesics.

Immersive virtual reality pain distraction

The goal of immersive virtual reality (VR) is to give patients the illusion of visiting the virtual world, as if it is a place they are visiting, an illusion known as ''presence.'' The rationale of why VR could be valuable for pain control is explained as follows. With burn patients, pain receptors send neural signals/information to the patient's brain that the brain processes, resulting in the patient's conscious experience of pain. This information processing requires attention.[5,6] There is a limit to how much information the brain can process at any given time.[7] Virtual Reality (e.g, SnowWorld) floods the brain with attention grabbing information from multiple senses. SnowWorld is unusually attention grabbing, leaving less attention available for processing pain signals. Patients feel less pain, and spend less time thinking about their pain.[8–12]

SnowWorld was the first virtual reality world specifically designed for treating pain (www.vrpain.com). SnowWorld is custom designed to treat burn patients who are on powerful pain medications, and in pain. During painful wound care procedures, patients interact with snowmen, igloos, penguins, woolly mammoths and flying fish by using a wireless mouse (or sometimes head tracking) to aim and throw snowballs. Snowballs thrown by the patients impact objects in the virtual world with special effects and sound effects. Music by Paul Simon plays in the background, helping to block out anxiety producing sounds from the hospital. Immersive virtual reality visually isolates patients from the ''real world.'' The helmet typically used to deliver VR blocks the patients' view of the hospital room and substitutes computer-generated images via small computer screens and lenses positioned near the patient's eyes.

Research using wide field of view VR goggles and interactive VR worlds

Research using wide field of view VR goggles and interactive virtual reality worlds has shown significant drops in subjective burn pain in both case series as well as randomized controlled trials. VR analgesia has been demonstrated in burn patients during wound debridement (see Figure 1a) and as shown in Figure 1b, during physical/occupational therapy skin stretching exercises.[11,13] In one recent study of soldiers with combat-related burn injuries during wound cleaning, VR distraction with SnowWorld boosted patients ratings of ''fun during wound care'' from ''no fun at all'' (with no VR), to ''pretty fun'' during VR.[4]

A number of laboratory studies have also explored the potential of VR distraction as a non-pharmacologic analgesic. Laboratory studies have explored the relationship between the immersiveness of the VR system and the magnitude of pain reduction during VR distraction.[11,14–17] These studies have

FIG. 2. Pediatric burn patient was the first to try out the Oculus Rift VR goggles for VR pain distraction during physical therapy. Photo credits and copyright Hunter Hoffman, UW, www.vrpain.com.

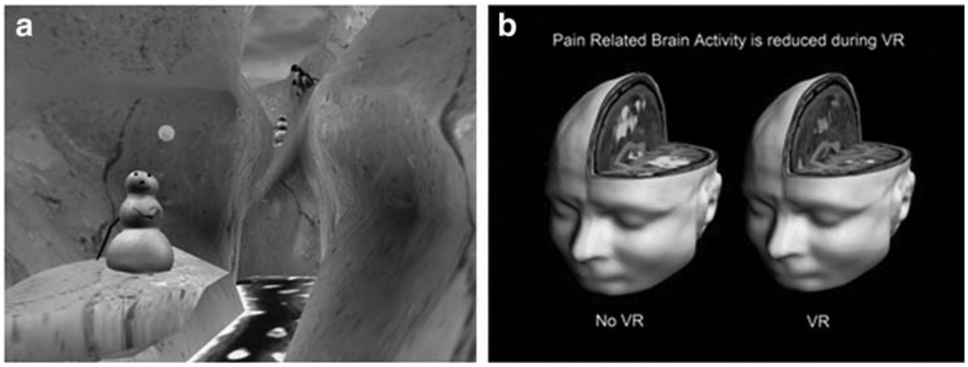

FIG. 3. (**a**) SnowWorld, a VR world designed for distracting patients from acute procedural pain. During wound cleaning and physical therapy, severe burn trauma patients typically report 35–50 percent reductions in worst pain intensity on subjective pain rating scales.[11,13] (**b**) Functional magnetic resonance imaging (fMRI) brain scan studies show large reductions in pain-related brain activity in subjects using SnowWorld.[19,20] SnowWorld still image by Ari Hollander and Howard Rose, copyright Hunter Hoffman, UW, www.vrpain.com. fMRI brain image by Todd Richards and Aric Bills, copyright Hunter Hoffman, UW, www.vrpain.com.

helped researchers design more effective VR systems. For example, in laboratory studies with healthy volunteer participants, allowing patients to interact with the virtual world via throwing snowballs by clicking their computer mouse,[16] and use of wide field of view (large) goggles, have both been shown to significantly boost VR pain reduction compared to less immersive VR.[15]

In addition to reducing the amount of pain reported by participants during brief painful stimuli, studies using functional Magnetic Resonance Imaging (fMRI) have shown large reductions in pain-related brain activity during VR.[19] Healthy volunteers received brief thermal stimuli at painful but tolerable temperatures during brain scans (pain on/off approximately every 30 seconds for approximately six minutes). Half of the stimuli were during no VR, and participants played SnowWorld in the brain scanner during the other three pain stimuli (treatment order randomized). During VR, participants reported large reductions in how much pain they experienced, and their brains showed large reductions in pain-related brain activity in all five brain regions of interest, the thalamus, insula, anterior cingulate cortex, and the primary and secondary somatosensory cortices. A related laboratory pain study showed that the amount of pain reduction from VR was comparable to the amount of pain reduction from a moderate dose of hydromorphone typical of what a burn patient would receive during wound care, and the greatest analgesia was achieved by combining the two treatment modalities (pharmacologic and nonpharmacologic).[20]

Critical Barriers to using immersive VR adjunctively, (i.e., in addition to traditional pain medications), for pediatric patients with large severe burn injuries

Despite the growing evidence that VR is effective during painful medical procedures, VR is not yet widely used clinically during everyday clinical practice. The expense of wide field of view VR systems has limited dissemination. Over the past 20 years, the price of VR computers has dropped from $90,000 to less than $1,500, as graphics processor and CPU speeds have been accelerated and miniaturized for video game consumers. In contrast, during the past 20 years, wide field of view VR goggles have improved in quality, but have remained expensive. However, a similar breakthrough in VR goggle technology is in development, and scheduled for commercial sale in 2014 or 2015: the Oculus Rift, www.oculusvr.com (not available to consumers at the time this was written). The Oculus Rift goggles are wide field of view, roughly similarly in FOV to VR goggles currently being used for VR pain distraction at several regional burn centers, (e.g., the Rockwell Collins SR80 VR goggles, priced at $35,000).[4] The new Oculus Rift goggles are being developed for mass production to be used to play video games and movies. Instead of being built one at a time like the current wide field of view VR goggles, Oculus Rift are mass produced. Fifty thousand Oculus Rift goggles have reportedly already been manufactured and sold to software developers, and when Oculus Rift goes commercial, the goggles are priced to sell to a very large market of PC video game players, a 20 billion dollar a year industry. The estimated selling price of the Oculus Rift goggles is ∼$400. (1/1000th the cost of the Rockwell Collins SR80 used in several key VR analgesia studies). As evidence of the

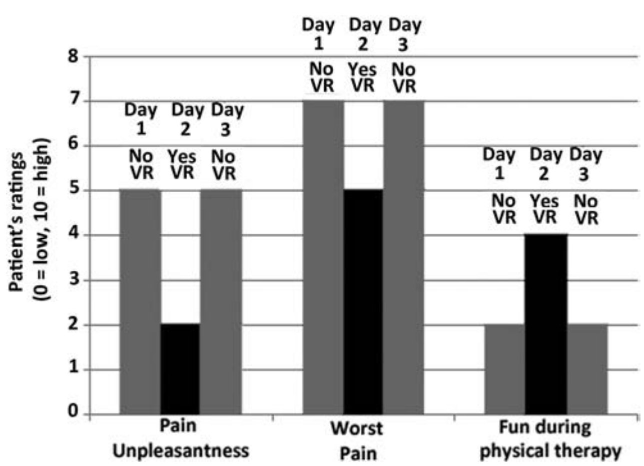

FIG. 4. Pain during passive range of motion exercises during no VR, (gray bars) vs. pain during the same exercises while in VR (black bar).

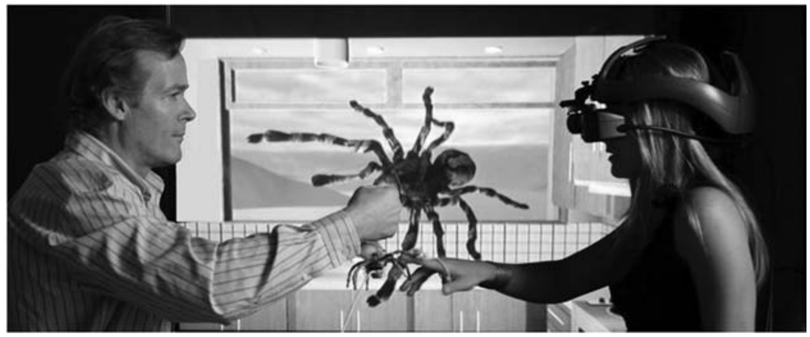

FIG. 5. SpiderWorld VR exposure therapy for phobias.[24] Photo credit Stephen Dagadakis, copyright Hunter Hoffman, www.vrpain.com.

magnitude of this development, Oculus Rift was purchased by Facebook for 2 billion dollars in March 2014.

Materials and Methods

The current case study was conducted as a proof of concept, to explore the feasibility of using the Oculus Rift goggles to distract burn patients during occupational therapy and other painful medical procedures. The patient was an 11-year-old male with severe electrical and flash burns on his head, shoulders, arms, and feet (36 percent TBSA, 27 percent TBSA third-degree burns), from an electrical accident where high voltage electricity passed through his body. Because the patient had severe burn wounds on his head, we mounted our monocular Oculus Rift goggles to a robot-like arm goggle holder.[4] On day 1 (baseline), the patient spent some of his 20 minutes of physical therapy with no VR (standard pain medications alone). On day 2, the patient received the same pain medications, and his occupational therapist conducted the same 20-minute passive range of motion skin stretching exercises while the patient looked into the VR goggles (see Fig. 2) and interacted with the world using a computer mouse (standard pain medications + VR, see Fig. 3a). On day 3, the patient received 20 minutes of physical therapy with no VR, same as day 1.

Results

The GRS ratings[18] of the patient are shown in Figure 4. Pain intensity and pain unpleasantness dropped during VR. The patient reported having more fun during physical therapy with VR than without it. Also, despite the fact that we used a custom robot-like arm mounted oculus rift goggles holder with no head tracking, and a preconsumer software developers prototype version of the helmet with considerably lower quality resolution than the forthcoming consumer version, the patient rated his presence in VR as a 10 (on a graphic rating scale from 0 to 10), reporting that he went ''completely inside the computer generated world as if it was a place he visited.''

Discussion

Results showing reductions in pain intensity and pain unpleasantness, during the 20 minutes of occupational therapy skin stretching exercises, are consistent with a growing literature showing reductions in pain during VR[21,22] but remarkably, in the current study, this was accomplished using a pair of ~$400 VR goggles. Although preliminary, and although case studies are by nature scientifically inconclusive,[23] these results suggest that the Oculus Rift VR goggles merit more attention as a potential treatment for acute procedural pain of burn patients. Randomized controlled studies are warranted. Availability of inexpensive, but highly immersive VR goggles would significantly improve cost effectiveness and increase dissemination of VR pain distraction, making VR distraction available to many more patients, potentially even at home, for pain control, and for a wide range of other VR therapy applications (e.g., VR exposure therapy for phobias,[24] and post-traumatic stress disorder,[25] and beyond; see Figure 5).

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Author Disclosure Statement

No competing financial interests exist.

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Pain Management in Virtual Reality: A Comprehensive Research Chart

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HERE, WE PROVIDE A COMPREHENSIVE LISTING of research done on pain management in virtual reality. MEDLINE was searched in October 2013 for the keywords ''virtual reality and pain.'' Results from that search are presented herein.

Year	*Author*	*Title*	*Publication*	*Topic*
1981	Perry S, Heidrich G, Ramos E	Assessment of pain by burn patients	Journal of Burn Care and Rehabilitation 2:322–327	Burn
1984	Seyrek SK, Corah NL, Pace LF	Comparison of three distraction techniques in reducing stress in dental patients	Journal of the American Dental Association 108:327–329	Dental treatments
1988	Watson D, Clark LA, Tellegen A	Development and validation of brief measures of positive and negative affect: the PANAS scales	Journal of Personality and Social Psychology 54:1063–1070	Affect
1993	Troesch R, Delaney Y	The influence of guided imagery on chemotherapy-related nausea and vomiting	Oncology Nursing Forum 20:1179–1185	Cancer
1994	Regan EC, Price KR	The frequency of occurrence and severity of side-effects of immersion virtual reality	Aviation, Space, and Environmental Medicine 65:527–530	Side effects
1995	Farr C	E-anesthesia: pulp fiction or virtual reality	Dentistry Today 14:70–75	Anesthesia
1996	Eguchi K	Supportive care programs in cancer at the National Cancer Center in Tokyo	Supportive Care in Cancer 4:266–269	Cancer
1996	Ramachandran VS, Rogers-Ramachandran D	Synaesthesia in phantom limbs induced with mirrors	Proceedings of the Royal Society B: Biological Sciences 263:377–386	Phantom limb
1996	Wiederhold MD, Wiederhold BK	From virtual worlds to the therapist's office: are virtual reality techniques useful tools in psychotherapy and diagnosis?	IEEE Engineering in Medicine and Biology 15:44–46	Chronic pain
1997	Carson CL, Grissom NL	Ameliorating adult's acute pain during phlebotomy with a distraction intervention	Applied Nursing Research 10:168–173	Phlebotomy
1997	Cohen LL, Blount RL, Panopoulos G	Nurse coaching and cartoon distraction: an effective and practical intervention to reduce child, parent, and nurse distress during immunizations	Journal of Pediatric Psychology 22:355–370	Immunization

(*continued*)

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Year	*Author*	*Title*	*Publication*	*Topic*
1998	Ohsuga M, Oyama H	Possibility of virtual reality for mental care	Studies in Health Technology and Informatics 58:82–90	Mental care
1998	Ohsuga M, Tatsuno Y, Shimono F, et al.	Bedside wellness—development of a virtual forest rehabilitation system	Studies in Health Technology and Informatics 50: 168–174	Rehabilitation
1998	Ilacqua GE	Migraine headaches: coping efficacy of guided imagery training	Headache 34:99–102	Headache
1999	Oyama H, Ohsuga M, Tatsuno Y, Katsumata N	Evaluation of the psychooncological effectiveness of the bedside wellness system	CyberPsychology and Behavior 2:81–84	Cancer
1999	Schneider SM, Workman ML	Effects of virtual reality on symptom distress in children receiving chemotherapy	CyberPsychology and Behavior 2:125–134	Cancer
2000	Hoffman HG, Patterson DR, Carrougher GJ	Use of virtual reality for adjunctive treatment of adult burn pain during physical therapy: a controlled study	The Clinical Journal of Pain 16:244–250	Burn patient
2000	Hoffman HG, Doctor JN, Patterson DR, et al.	Virtual reality as an adjunctive pain control during burn wound care in adolescent patients	Pain 85:305–309	Burn patient
2000	Sullivan C, Schneider PE, Musselman RJ, et al.	The effect of virtual reality during dental treatment on child anxiety and behavior	ASDC Journal of Dentistry for Children 67:193–196	Dental treatments
2001	Hoffman HG, Garcia-Palacios A, Patterson DR, et al.	The effectiveness of virtual reality for dental pain control: a case study	CyberPsychology and Behavior 4:527–535	Dental procedures
2001	Hoffman HG, Patterson DR, Carrougher GJ, Sharar SR	Effectiveness of virtual reality-based pain control with multiple treatments	Clinical Journal of Pain 17:229–235	Pain control
2001	Anderson PL, Rothbaum BO, Hodges L	Virtual reality: using the virtual world to improve quality of life in the real world	Bulletin of the Menninger Clinic 65:78–91	Improve quality of life
2001	Pennant JH	Anesthesia for laparoscopy in the pediatric patient	Anesthesiology Clinics of North America 19:69–88	Anesthesia
2001	Cupal DD, Brewer BW	Effects of relaxation and guided imagery on knee strength, reinjury anxiety, and pain following anterior cruciate ligament reconstruction	Rehabilitation Psychology 1:28–43	Pain control
2002	Schultheis MT, Himelstein J, Rizzo AA	Virtual reality and neuropsychology: upgrading the current tools	Journal of Head Trauma Rehabilitation 17:378–394	Neuropsychology
2002	Poletto CJ, Van Doren CL	Elevating pain thresholds in humans using depolarizing prepulses	IEEE Transactions on Biomedical Engineering 49:1221–1224	Depolarizing prepulses
2002	Sander Wint S, Eshelman D, Steele J, Guzzetta CE	Effects of distraction using virtual reality glasses during lumbar punctures in adolescents with cancer	Oncology Nursing Forum 29:E8–E15	Cancer
2002	Fors EA, Sexton H, Gotestam G	The effect of guided imagery and amitriptyline on daily fibromyalgia pain: a prospective, randomized, controlled trial	Journal of Psychiatric Research 36:179–187	Fibromyalgia

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Year	Author	Title	Publication	Topic
2003	Gershon J, Zimand E, Lemos R, et al.	Use of virtual reality as a distractor for painful procedures in a patient with pediatric cancer: a case study	CyberPsychology and Behavior 6:657–661	Cancer
2003	Steele E, Grimmer K, Thomas B, et al.	Virtual reality as a pediatric pain modulation technique: a case study	CyberPsychology and Behavior 6:633–638	Pain modulation
2003	Sveistrup H, McComas J, Thornton M, et al.	Experimental studies of virtual reality-delivered compared to conventional exercise programs for rehabilitation	CyberPsychology and Behavior 6:245–249	Rehabilitation
2003	Hoffman HG, Richards T, Coda B, et al.	The illusion of presence in immersive virtual reality during an fMRI brain scan	CyberPsychology and Behavior 6:127–31	Burn patient
2003	Tse MM, Ng JK, Chung JW	Visual stimulation as pain relief for Hong Kong Chinese patients with leg ulcers	CyberPsychology and Behavior 6:315–320	Leg ulcers
2003	Reger GM	Effectiveness of virtual reality for attentional control to reduce children's pain during venipuncture	Proceedings of the 2nd International Workshop in Virtual Rehabilitation, Piscataway, NJ, pp. 62–67	Venipuncture
2003	Schneider SM	Virtual reality for the treatment of breast cancer	San Diego, CA: Interactive Media Institute	Cancer
2003	Schneider SM, Ellis M, Coombs WT, et al.	Virtual reality intervention for older women with breast cancer	CyberPsychology and Behavior 6:301–307	Cancer
2003	Hoffman HG, Coda BA, Sharar SR, et al.	Virtual reality analgesia during thermal and electrical pain for longer durations, and multiple treatments	San Diego, CA: Interactive Media Institute	Analgesia
2004	Gershon J, Zimand E, Pickering M, et al.	A pilot and feasibility study of virtual reality as a distraction for children with cancer	Journal of the American Academy of Child & Adolescent Psychiatry 43:1243–1249	Cancer
2004	Hoffman HG, Sharar SR, Coda B, et al.	Manipulating presence influences the magnitude of virtual reality analgesia	Pain 111:162–168	Analgesia
2004	Hoffman HG	Virtual-reality therapy	Scientific American 291: 58–65	Burn patient
2004	Patterson DR, Tininenko JR, Schmidt AE, Sharar SR	Virtual reality hypnosis: a case report	International Journal of Clinical and Experimental Hypnosis 52:27–38	Burn patient
2004	Hoffman HG, Patterson DR, Magula J, et al.	Water-friendly virtual reality pain control during wound care	Journal of Clinical Psychology 60:189–195	Burn patient
2004	Schneider SM, Prince-Paul M, Allen MJ, et al.	Virtual reality as a distraction intervention for women receiving chemotherapy	Oncology Nursing Forum 31:81–88	Cancer
2004	Simmons D, Chabal C, Griffith J, et al.	A clinical trial of distraction techniques for pain and anxiety control during cataract surgery	Insight 29:13–16	Cataract surgery
2005	Wright JL, Hoffman HG, Sweet RM	Virtual reality as an adjunctive pain control during transurethral microwave thermotherapy	Urology 66:1320	Pain control
2005	Wismeijer AA, Vingerhoets AJ	The use of virtual reality and audiovisual eyeglass systems as adjunct analgesic techniques: a review of the literature	Annals of Behavioral Medicine 30:268–278	Analgesia

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Year	*Author*	*Title*	*Publication*	*Topic*
2005	Pesudovs K	The development of a symptom questionnaire for assessing virtual reality viewing using a head-mounted display	Optometry & Vision Science 82:571; author reply 571–572	Questionnaire
2005	Ames SL, Wolffsohn JS, McBrien NA	The development of a symptom questionnaire for assessing virtual reality viewing using a head-mounted display	Optometry & Vision Science 82:168–176	Questionnaire
2005	Das DA, Grimmer KA, Sparnon AL, et al.	The efficacy of playing a virtual reality game in modulating pain for children with acute burn injuries: a randomized controlled trial	BMC Pediatrics 5:1	Burn patients
2005	Sherstyuk A, Aschwanden C, Saiki S	Affordable virtual environments: building a virtual beach for clinical use	Studies in Health Technology and Informatics 111: 465–467	Pain treatment
2005	Hoffman HG, Richards TL, Coda B, et al.	Modulation of thermal pain-related brain activity with virtual reality: evidence from fMRI	Neuroreport 15:1245–1248	Analgesia
2005	Schneider SM	Virtual reality intervention for chemotherapy symptoms	Orlando, FL: Oncology Nursing Society	Cancer
2005	Wolitzkya K, Fivushb R, Zimand E, et al.	Effectiveness of virtual reality distraction during a painful medical procedure in pediatric oncology patients	Psychology & Health 20: 817–824	Cancer
2005	Tse MM, Pun SP, Benzie IF	Affective images: relieving chronic pain and enhancing quality of life for older persons	CyberPsychology and Behavior 8:571–579	Chronic pain
2005	Wiederhold BK	Advances in the clinical delivery of virtual reality	American Psychological Association Annual Convention, Washington, DC, August 18–21, 2005	Pain control
2005	deCharms R, Maeda F, Glover GH, Ludlow d	Control over brain activation and pain learned by using real-time functional MRI	St. Louis, MO: Washington University School of Medicine	Pain learned, fMRI
2006	Patterson DR, Hoffman HG, Palacios AG, Jensen MJ	Analgesic effects of posthypnotic suggestions and virtual reality distraction on thermal pain	Journal of Abnormal Psychology 115:834–841	Thermal pain
2006	Hoffman HG, Seibel EJ, Richards TL, et al.	Virtual reality helmet display quality influences the magnitude of virtual reality analgesia	Journal of Pain 7:843–850	Analgesia
2006	Magora F, Cohen S, Shochina M, Dayan E	Virtual reality immersion method of distraction to control experimental ischemic pain	Israel Medical Association Journal 8:261–265	Ischemic pain
2006	Gold JI, Kim SH, Kant AJ, et al.	Effectiveness of virtual reality for pediatric pain distraction during i.v. placement	CyberPsychology and Behavior 9:207–212	I.V. placement
2006	Murray CD, Patchick E, Pettifer S, et al.	Immersive virtual reality as a rehabilitative technology for phantom limb experience: a protocol	CyberPsychology and Behavior 9:167–170	Phantom limb
2006	Patterson DR, Wiechman SA, Jensen M, Sharar SR	Hypnosis delivered through immersive virtual reality for burn pain: a clinical case series	International Journal of Clinical and Experimental Hypnosis 54:130–142	Burn patients
2006	Haik J, Tessone A, Nota A, et al.	The use of video capture virtual reality in burn rehabilitation: the possibilities	Journal of Burn Care & Research 27:195–197	Burn patients

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Year	*Author*	*Title*	*Publication*	*Topic*
2006	Murray CD, Patchick EL, Caillette F, et al.	Can immersive virtual reality reduce phantom limb pain?	Studies in Health Technology and Informatics 119: 407–412	Phantom limb
2006	Hoffman HG, Richards TL, Bills AR, et al.	Using FMRI to study the neural correlates of virtual reality analgesia	CNS Spectrums 11:45–51	Analgesia
2006	Cole SW, Kato PM, Marin-Bowling VM, et al.	Clinical trial of re-mission: a video game for young people with cancer	CyberTherapy 11, Conference, Gatineau, Canada, June 12–15	Cancer
2006	Wiederhold BK	Virtual Reality applications for mental assessment and rehabilitation	Virtual Reality Conference, Alexandria, Virginia, March 25–29	Rehabilitation
2006	Lange B, Wiliams M, Fulton I, Craigie M	Virtual Reality distraction for children receiving minor medical procedures	CyberTherapy 11, Conference, Gatineau, Canada, June 12–15	Minor medical procedures
2007	Vazquez JLM, Santander A, Gao K, et al.	Using cybertherapy to reduce postoperative anxiety in cardiac recovery intensive care units	Journal of Anesthesia and Clinical Research 4:363	Surgical anxiety
2007	Hoffman HG, Richards TL, Van Oostrom T, et al.	The analgesic effects of opioids and immersive virtual reality distraction: evidence from subjective and functional brain imaging assessments	Anesthesia & Analgesia 105:1776–1783	Analgesic, opioids
2007	Dahlquist LM, McKenna KD, Jones KK, et al.	Active and passive distraction using a head-mounted display helmet: effects on cold pressor pain in children	Health Psychology 26: 794–801	Cold pressor pain
2007	Li S, Kay S, Hardicker NR	Virtual reality: towards a novel treatment environment for ankylosing spondylitis	Studies in Health Technology and Informatics 127: 190–196	Ankylosing spondilitis
2007	Gold JI, Belmont KA, Thomas DA	The neurobiology of virtual reality pain attenuation	CyberPsychology and Behavior 10:536–544	Pain reduction
2007	Wiederhold MD, Wiederhold BK	Virtual reality and interactive simulation for pain distraction	Pain Medicine 8:S182–S188	Pain distraction
2007	Mühlberger A, Wieser MJ, Kenntner-Mabiala R, et al.	Pain modulation during drives through cold and hot virtual environments	CyberPsychology, Behavior, and Social Networking 10:516–522	Pain modulation
2007	van Twillert B, Bremer M, Faber AW	Computer-generated virtual reality to control pain and anxiety in pediatric and adult burn patients during wound dressing changes	Journal of Burn Care & Research 28:694–702	Burn patients
2007	Chan EA, Chung JW, Wong TK, et al.	Application of a virtual reality prototype for pain relief of pediatric burn in Taiwan	Journal of Clinical Nursing 16:786–793	Burn patients
2007	Mosso JL, Rizzo S, Wiederhold B, et al.	Cybertherapy—new applications for discomfort reductions. Surgical care unit of heart, neonatology care unit, transplant kidney care unit, delivery room-cesarean surgery and ambulatory surgery, 27 case reports	Studies in Health Technology and Informatics 125: 334–336	Discomfort reduction
2007	Windich-Biermeier A, Sjoberg I, Dale JC, et al.	Effects of distraction on pain, fear, and distress during venous port access and venipuncture in children and adolescents with cancer	Journal of Pediatric Oncology Nursing 24:8–19	Cancer

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Year	*Author*	*Title*	*Publication*	*Topic*
2008	Gregoretti C, Decaroli D, Piacevoli Q, et al.	Analgo-sedation of patients with burns outside the operating room	Drugs 68:2427–2443	Burn patients
2008	Sharar SR, Miller W, Teeley A, et al.	Applications of virtual reality for pain management in burn-injured patients	Expert Review of Neurotherapeutics 8:1667–1674	Burn patients
2008	Oneal BJ, Patterson DR, Soltani M, et al.	Virtual reality hypnosis in the treatment of chronic neuropathic pain: a case report	International Journal of Clinical and Experimental Hypnosis 56:451–462	Chronic neuropathic pain
2008	Hoffman HG, Patterson DR, Seibel E, et al.	Virtual reality pain control during burn wound debridement in the hydrotank	Clinical Journal of Pain 24:299–304	Burn patients
2008	Dahlquist LM, Weiss KE, Clendaniel LD, et al.	Effects of videogame distraction using a virtual reality type head-mounted display helmet on cold pressor pain in children	Journal of Pediatric Psychology 34:574–584	Cold pressor pain
2008	Mott J, Bucolo S, Cuttle L, et al.	The efficacy of an augmented virtual reality system to alleviate pain in children undergoing burns dressing changes: a randomised controlled trial	Burns 34:803–808	Burn patients
2008	Sharar SR, Carrougher GJ, Nakamura D, et al.	Factors influencing the efficacy of virtual reality distraction analgesia during postburn physical therapy: preliminary results from 3 ongoing studies	Archives of Physical Medicine and Rehabilitation 88:S43–S49	Postburn physical therapy
2008	Maani C, Hoffman HG, Desocio PA, et al.	Pain control during wound care for combat-related burn injuries using custom articulated arm mounted virtual reality goggles	Journal of Cybertherapy and Rehabilitation 1:193–198	Wound care
2008	Wiederhold MD, Wiederhold BK	Pain management with cell phone technology	CyberTherapy 13: Changing the Face of Healthcare, June 23–25, 2008, San Diego, CA	Cell phone pain management
2009	Furman E, Jasinevicius TR, Bissada NF, et al.	Virtual reality distraction for pain control during periodontal scaling and root planning procedures	The Journal of the American Dental Association 140:1508–1516	Dental treatments
2009	Miller K, Rodger S, Bucolo S, et al.	Multi-modal distraction. Using technology to combat pain in young children with burn injuries	Burns 36:647–658	Burn patients
2009	Cheetham M, Pedroni AF, Antley A, et al.	Virtual milgram: empathic concern or personal distress? Evidence from functional MRI and dispositional measures.	Frontiers in Human Neuroscience 3:29	Empathy
2009	Morris LD, Louw QA, Grimmer-Somers K	The effectiveness of virtual reality on reducing pain and anxiety in burn injury patients: a systematic review	Clinical Journal of Pain 25:815–826	Burn patients
2009	Casale R, Damiani C, Rosati V	Mirror therapy in the rehabilitation of lower-limb amputation: are there any contraindications	American Journal of Physical Medicine & Rehabilitation 88:837–842	Amputation
2009	Leibovici V, Magora F, Cohen S, Ingber A	Effects of virtual reality immersion and audiovisual distraction techniques for patients with pruritus	Pain Research & Management 14:283–286	Pruritus
2009	Carrougher GJ, Hoffman HG, Nakamura D, et al.	The effect of virtual reality on pain and range of motion in adults with burn injuries	Journal of Burn Care & Research 30:785–791	Burn patients

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Year	Author	Title	Publication	Topic
2009	Powell W, Stevens B, Simmonds M	Treadmill interface for virtual reality vs. overground walking: a comparison of gait in individuals with and without pain	Studies in Health Technology and Informatics 144: 198–203	Pain reduction
2009	Shahrbanian S, Ma X, Korner-Bitensky N, Simmonds MJ	Scientific evidence for the effectiveness of virtual reality for pain reduction in adults with acute or chronic pain	Studies in Health Technology and Informatics 144:40–43	Acute/chronic pain
2009	Markus LA, Willems KE, Maruna CC, et al.	Virtual reality: feasibility of implementation in a regional burn center	Burns 35:967–969	Burn patients
2009	Sarig-Bahat H, Weiss PL, Laufer Y	Cervical motion assessment using virtual reality	Spine (Phila Pa 1976) 34:1018–1024	Cervical motion
2009	Mosso JL, Gorini A, De La Cerda G, et al.	Virtual reality on mobile phones to reduce anxiety in outpatient surgery	Studies in Health Technology and Informatics 142: 195–200	Surgery
2009	Mahrer NE, Gold JI	The use of virtual reality for pain control: a review	Current Pain and Headache Reports 13:100–109	Pain control
2009	Askay SW, Patterson DR, Sharar SR	Virtual reality hypnosis	Contemporary Hypnosis 26:40–47	Hypnosis
2009	Rutter CE, Dahlquist LM, Weiss KE	Sustained efficacy of virtual reality distraction	Journal of Pain 10:391–397	Cold pressor pain
2009	Nilsson S, Finnström B, Kokinsky E, Enskär K	The use of virtual reality for needle-related procedural pain and distress in children and adolescents in a paediatric oncology unit	European Journal of Oncology Nursing 13:102–109	Cancer
2009	Cole J, Crowle S, Austwick G, Slater DH	Exploratory findings with virtual reality for phantom limb pain; from stump motion to agency and analgesia	Disability and Rehabilitation 31:846–854	Phantom limb
2009	Meng FG, Wu CY, Liu YG, Liu L	Virtual reality imaging technique in percutaneous radiofrequency rhizotomy for intractable trigeminal neuralgia	Journal of Clinical Neuroscience 16:449–451	Neuralgia
2009	Konstantatos AH, Angliss M, Costello V, et al.	Predicting the effectiveness of virtual reality relaxation on pain and anxiety when added to PCA morphine in patients having burns dressings changes	Burns 35:491–499	Burn patients
2009	Hoffman HG, Patterson DR, Soltani M, et al.	Virtual reality pain control during physical therapy range of motion exercises for a patient with multiple blunt force trauma injuries	CyberPsychology and Behavior 12:47–49	Motion exercises, trauma
2009	O'Dell MW, Lin CC, Harrison V	Stroke rehabilitation: strategies to enhance motor recovery	Annual Review of Medicine 60:55–68	Rehabilitation
2009	Wood DP, Webb-Murphy J, Center K, et al.	Combat-related post-traumatic stress disorder: a case report using virtual reality graded exposure therapy with physiological monitoring with a female Seabee	Military Medicine 174: 1215–1222	Post-traumatic stress disorder (PTSD)
2009	Wood DP, Murphy J, McLay R, et al.	Cost effectiveness of virtual reality graded exposure therapy with physiological monitoring for the treatment of combat related post traumatic stress disorder	Studies in Health Technology and Informatics 144: 223–229	PTSD

(*continued*)

Year	Author	Title	Publication	Topic
2009	Walker ML, Ringleb SI, Maihafer GC, et al.	Virtual reality-enhanced partial body weight-supported treadmill training poststroke: feasibility and effectiveness in 6 subjects	Archives of Physical Medicine and Rehabilitation 91:115–122	Stroke
2009	Kott K, De Leo G, Lesher K, et al.	Virtual reality gaming for treadmill training: improved functional ambulation in children with cerebral palsy	Journal of CyberTherapy and Rehabilitation 2:35–42	Cerebral palsy
2010	Sarig Bahat H, Weiss PL, Laufer Y	The effect of neck pain on cervical kinematics, as assessed in a virtual environment	Archives of Physical Medicine and Rehabilitation 91:1884–1890	Neck pain
2010	Bayat A, Ramaiah R, Bhananker SM	Analgesia and sedation for children undergoing burn wound care	Expert Review of Neurotherapeutics 10:1747–1759	Burn patients
2010	Dahlquist LM, Herbert LJ, Weiss KE, Jimeno M	Virtual-reality distraction and cold-pressor pain tolerance: does avatar point of view matter?	CyberPsychology, Behavior, and Social Networking 13:587–591	Cold pressor pain
2010	Huang SW	Comments on ''Feasibility and potential effect of a low-cost virtual reality system on reducing pain and anxiety in adult burn injury patients during physiotherapy in a developing country.''	Burns 37:354; author reply 354–355	Burn patients
2010	Zschaler S	Increased pain through psychological therapy? Combination of PCA morphine therapy with virtual reality by awake dressing change: paradoxical effects	Schmerz 24:629–630	Morphine vs. virtual reality
2010	Ramachandran VS, Seckel EL	Using mirror visual feedback and virtual reality to treat fibromyalgia	Medical Hypotheses 75: 495–496	Fibromyalgia
2010	Malloy KM, Milling LS	The effectiveness of virtual reality distraction for pain reduction: a systematic review	Clinical Psychology Review 30:1011–1018	Pain reduction
2010	Gaggioli A, Amoresano A, Gruppioni E, et al.	A myoelectric-controlled virtual hand for the assessment and treatment of phantom limb pain in trans-radial upper extremity amputees: a research protocol	Studies in Health Technology and Informatics 154: 220–222	Phantom limb
2010	Gutierrez-Maldonado J, Gutierrez-Martinez O, Loreto D, et al.	Presence, involvement and efficacy of a virtual reality intervention on pain	Studies in Health Technology and Informatics 154: 97–101	Pain control
2010	Patterson DR, Jensen MP, Wiechman SA, Sharar SR	Virtual reality hypnosis for pain associated with recovery from physical trauma	International Journal of Clinical and Experimental Hypnosis 58:288–300	Physical trauma
2010	Sato K, Fukumori S, Matsusaki T, et al.	Nonimmersive virtual reality mirror visual feedback therapy and its application for the treatment of complex regional pain syndrome: an open-label pilot study	Pain Medicine 11:622–629	Chronic pain
2010	Sarig-Bahat H, Weiss PL, Laufer Y	Neck pain assessment in a virtual environment	Spine (Phila Pa 1976) 35:E105–E112	Neck pain

(*continued*)

Year	*Author*	*Title*	*Publication*	*Topic*
2010	Morris LD, Louw QA, Crous LC	Feasibility and potential effect of a low-cost virtual reality system on reducing pain and anxiety in adult burn injury patients during physiotherapy in a developing country	Burns 36:659–664	Burn patients
2010	Kwekkeboom KL, Cherwin CH, Lee JW, Wanta B	Mind-body treatments for the pain-fatigue-sleep disturbance symptom cluster in persons with cancer	Journal of Pain and Symptom Management 39:126–138	Cancer
2010	Dahlquist LM, Weiss KE, Law EF, et al.	Effects of videogame distraction and a virtual reality type head-mounted display helmet on cold pressor pain in young elementary school-aged children	Journal of Pediatric Psychology 35:617–625	Cold pressor pain
2010	Wiederhold MD, Wiederhold BK	Virtual reality and interactive simulation for pain distraction: an overview	CyberTherapy & Rehabilitation 3:14–19	Pain distraction
2010	Wood DP, Wiederhold BK, Spira J	Lessons learned from 350 virtual-reality sessions with warriors diagnosed with combat-related posttraumatic stress disorder	CyberPsychology, Behavior, and Social Networking 13:3–11	PTSD
2011	Lamont K, Chin M, Kogan M	Mirror box therapy: seeing is believing	Explore (NY) 7:369–372	Phantom limb
2011	Maani CV, Hoffman HG, Morrow M, et al.	Virtual reality pain control during burn wound debridement of combat-related burn injuries using robot-like arm mounted VR goggles	Journal of Trauma 71: S125–S130	Burn patients
2011	Li A, Montaño Z, Chen VJ, Gold JI	Virtual reality and pain management: current trends and future directions	Pain Management 1:147–157	Current trends
2011	Gutiérrez-Martínez O, Gutiérrez-Maldonado J, Loreto-Quijada D	Control over the virtual environment influences the presence and efficacy of a virtual reality intervention on pain	Studies in Health Technology and Informatics 167: 111–115	Cold pressor pain
2011	Gutierrez-Maldonado J, Gutierrez-Martinez O, Cabas-Hoyos K	Interactive and passive virtual reality distraction: effects on presence and pain intensity	Studies in Health Technology and Informatics 167:69–73	Cold pressor pain
2011	Alvarez AG, Dal Sasso GT	Virtual learning object for the simulated evaluation of acute pain in nursing students	Revista Latino-Americana de Enfermagem 19:229–237	Acute pain
2011	Hänsel A, Lenggenhager B, von Känel R, et al.	Seeing and identifying with a virtual body decreases pain perception	European Journal of Pain 15:874–879	Decrease pain perception
2011	Morris LD, Grimmer-Somers KA, Spottiswoode B, Louw QA	Virtual reality exposure therapy as treatment for pain catastrophizing in fibromyalgia patients: proof-of-concept study (study protocol)	BMC Musculoskeletal Disorders 12:85	Fibromyalgia
2011	Maani CV, Hoffman HG, Fowler M, et al.	Combining ketamine and virtual reality pain control during severe burn wound care: one military and one civilian patient	Pain Medicine 12:673–678	Burn patients
2011	Hoffman HG, Chambers GT, Meyer WJ 3rd, et al.	Virtual reality as an adjunctive non-pharmacologic analgesic for acute burn pain during medical procedures	Annals of Behavioral Medicine 41:183–191	Parkinson

(*continued*)

Year	*Author*	*Title*	*Publication*	*Topic*
2011	Griffin HJ, Greenlaw R, Limousin P, et al.	The effect of real and virtual visual cues on walking in Parkinson's disease	Journal of Neurology 258:991–1000	Gluteal hidradenitis
2011	Danilov AB, Gak SV	[Virtual reality in treatment of pain syndromes]	Zhurnal Nevrologii I Psikhiatrii Imeni S.S. Korsakova 111:81–85	Pain syndromes
2011	Schmitt YS, Hoffman HG, Blough DK, et al.	A randomized, controlled trial of immersive virtual reality analgesia, during physical therapy for pediatric burns	Burns 37:61–68	Burn patients
2011	Law EF, Dahlquist LM, Sil S, et al.	Videogame distraction using virtual reality technology for children experiencing cold pressor pain: the role of cognitive processing	Journal of Pediatric Psychology 36:84–94	Cold pressor pain
2011	Bell KM, Bechara BP, Hartman RA, et al.	Influence of number of operated levels and postoperative time on active range of motion following anterior cervical decompression and fusion procedures	Spine (Phila Pa 1976) 36:263–268	Cervical motion
2011	Zeher MJ, Armiger RS, Burck JM, et al.	Using a virtual integration environment in treating phantom limb pain	Studies in Health Technology and Informatics 163: 730–736	Phantom limb
2011	Wood DP, Webb-Murphy J, McLay RN, et al.	Reality graded exposure therapy with physiological monitoring for the treatment of combat related post traumatic stress disorder: a pilot study	Studies in Health Technology and Informatics 163: 696–702	PTSD
2011	McLay RN, Wood DP, Webb-Murphy JA, et al.	A randomized, controlled trial of virtual reality-graded exposure therapy for post-traumatic stress disorder in active duty service members with combat-related post-traumatic stress disorder	CyberPsychology, Behavior, and Social Networking 14:223–229	PTSD
2012	Spyridonis F, Gronli TM, Hansen J, Ghinea G	Evaluating the usability of a virtual reality-based Android application in managing the pain experience of wheelchair users	Conference Proceedings of the IEEE Engineering in Medicine & Biology Society 2012:2460–2463	Wheelchair users
2012	Seifert AR	Absence of verbal recall or memory for symptom acquisition in fear and trauma exposure: a conceptual case for fear conditioning and learned nonuse in assessment and treatment	Journal of Rehabilitation Research & Development 49:1209–1220	Avoidance learning
2012	Asl Aminabadi N, Erfanparast L, Sohrabi A, et al.	The impact of virtual reality distraction on pain and anxiety during dental treatment in 4–6 year-old children: a randomized controlled clinical trial	Journal of Dental Research, Dental Clinics, Dental Prospects 6:117–124	Dental treatments
2012	Brown NJ, Rodger S, Ware RS, et al.	Efficacy of a children's procedural preparation and distraction device on healing in acute burn wound care procedures: study protocol for a randomized controlled trial	Trials 13:238	Burn patients
2012	Chang CM, Chang YC, Chang HY, Chou LW	An interactive game-based shoulder wheel system for rehabilitation	Journal of Patient Preference and Adherence 6:821–828	Rehabilitation

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Year	*Author*	*Title*	*Publication*	*Topic*
2012	Llobera J, González-Franco M, Perez-Marcos D, et al.	Virtual reality for assessment of patients suffering chronic pain: a case study	Experimental Brain Research 225:105–117	Chronic pain
2012	Sil S, Dahlquist LM, Thompson C, et al.	The effects of coping style on virtual reality enhanced videogame distraction in children undergoing cold pressorpain	J Behav Med [Epub ahead of print]	Cold pressor pain
2012	Michiels S, De Hertogh W, Truijen S, et al.	The assessment of cervical sensory motor control: a systematic review focusing on measuring methods and their clinimetric characteristics	Gait & Posture 38:1–7	Neck pain
2012	Gutiérrez-Maldonado J, Gutiérrez-Martínez O, Loreto-Quijada D, Nieto-Luna R	The use of virtual reality for coping with pain with healthy participants	Psicothema 24:516–522	Cold pressor pain
2012	Won AS, Collins TA	Non-immersive, virtual reality mirror visual feedback for treatment of persistent idiopathic facial pain	Pain Medicine 13:1257–1258	Facial pain
2012	Keefe FJ, Huling DA, Coggins MJ, et al.	Virtual reality for persistent pain: a new direction for behavioral pain management	Pain 153:2163–2166	Persistent pain
2012	Teeley AM, Soltani M, Wiechman SA, et al.	Virtual reality hypnosis pain control in the treatment of multiple fractures: a case series	American Journal of Clinical Hypnosis 54:184–194	Multiple fractures
2012	Kipping B, Rodger S, Miller K, Kimble RM	Virtual reality for acute pain reduction in adolescents undergoing burn wound care: a prospective randomized controlled trial	Burns 38:650–657	Burn patients
2012	Flor H	New developments in the understanding and management of persistent pain	Current Opinion in Psychiatry 25:109–113	Persistent pain
2012	Louw Q, Grimmer-Somers K, Schrikk A	Measuring children's distress during burns dressing changes: literature search for measures appropriate for indigenous children in South Africa	Journal of Pain Research 4:263–277	Burn patients
2012	Kho ME, Damluji A, Zanni JM, Needham DM	Feasibility and observed safety of interactive video games for physical rehabilitation in the intensive care unit: a case series	Journal of Critical Care 27:219.e1–e6	Rehabilitation
2012	Humphries C	The mystery behind anesthesia: technology review published by MIT	The Wall Street Journal, pp. D1, D2	Chronic pain
2012	Wiederhold BK, Wiederhold M	Managing pain in military populations with virtual reality	NATO Science for Peace and Security Series—E: Human and Societal Dynamics	Military population
2012	Alphonso AL, Monson BT, Zeher MJ, et al.	Use of a virtual integrated environment in prosthetic limb development and phantom limb pain	Studies in Health Technology and Informatics 181: 305–309	Phantom limb
2012	Stetz MC, Brown KS, Folen RA, et al.	Comparing distraction/relaxation modalities with chronic pain patients	NATO Science for Peace and Security Series—E: Human and Societal Dynamics	Chronic pain

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Year	Author	Title	Publication	Topic
2013	Faber AW, Patterson DR, Bremer M	Repeated use of immersive virtual reality therapy to control pain during wound dressing changes in pediatric and adult burn patients	Journal of Burn Care & Research 34:563–568	Burn patients
2013	Cacau Lde A, Oliveira GU, Maynard LG, et al.	The use of the virtual reality as intervention tool in the postoperative of cardiac surgery	The Revista Brasileira de Cirurgia Cardiovascular 28:281–289	Rehabilitation
2013	Martini M, Perez-Marcos D, Sanchez-Vives MV	What color is my arm? Changes in skin color of an embodied virtual arm modulates pain threshold	Frontiers in Human Neuroscience 7:438	Pain perception
2013	Giggins OM, Persson UM, Caulfield B	Biofeedback in rehabilitation	Journal of NeuroEngineering and Rehabilitation 10:60	Rehabilitation
2013	Villiger M, Bohli D, Kiper D, et al.	Virtual reality-augmented neurorehabilitation improves motor function and reduces neuropathic pain in patients with incomplete spinal cord injury	Neurorehabilitation & Neural Repair 27:675–683	Neurorehabilitation
2013	Shiri S, Feintuch U, Weiss N, et al.	A virtual reality system combined with biofeedback for treating pediatric chronic headache—a pilot study	Pain Medicine 14:621–627	Pediatric headache
2013	Diers M, Flor H	[Phantom limb pain. Psychological treatment strategies]	Schmerz 27:205–211; quiz 212–213	Phantom limb
2013	Loreto-Quijada D, Gutiérrez-Maldonado J, Gutiérrez-Martínez O, Nieto R	Testing a virtual reality intervention for pain control	European Journal of Pain 17:1403–1410	Pain control
2013	Botella C, Garcia-Palacios A, Vizcaíno Y, et al.	Virtual reality in the treatment of fibromyalgia: a pilot study	CyberPsychology, Behavior, and Social Networking 16:215–223	Fibromyalgia
2013	Crews RT, Yalla SV, Fleischer AE, Wu SC	A growing troubling triad: diabetes, aging, and falls	Journal of Aging Research 2013:342650	Diabetes, falls
2013	de Tommaso M, Ricci K, Laneve L, et al.	Virtual visual effect of hospital waiting room on pain modulation in healthy subjects and patients with chronic migraine	Pain Research and Treatment 2013:515730	Chronic migraine
2013	Bouchard S, Bernier F, Boivin É, et al.	Empathy toward virtual humans depicting a known or unknown person expressing pain	CyberPsychology, Behavior, and Social Networking 16:61–71	Empathy
2013	Baas JM	Individual differences in predicting aversive events and modulating contextual anxiety in a context and cue conditioning paradigm	Biological Psychology 92: 17–25	Anxiety

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Closing Editorial

Future Directions: Advances and Implications of Virtual Environments Designed for Pain Management

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Abstract

Pain symptoms have been addressed with a variety of therapeutic measures in the past, but as we look to the future, we begin encountering new options for patient care and individual health and well-being. Recent studies indicate that computer-generated graphic environments—virtual reality (VR)—can offer effective cognitive distractions for individuals suffering from pain arising from a variety of physical and psychological illnesses. Studies also indicate the effectiveness of VR for both chronic and acute pain conditions. Future possibilities for VR to address pain-related concerns include such diverse groups as military personnel, space exploration teams, the general labor force, and our ever increasing elderly population. VR also shows promise to help in such areas as drug abuse, at-home treatments, and athletic injuries.

Background

According to the International Association of Pain, pain is an unpleasant sensory and emotional experience associated with actual or potential tissue damage. It is a ubiquitous symptom underlying most illnesses, and it diverges into two unique forms: acute and chronic. Acute pain serves a biological purpose, as it usually occurs at the onset of painful incidents such as procedural operations, recovery and rehabilitation, childbirth, dental work, burns, fractures, and so on. If acute pain is not treated properly, it can become chronic.[1] Chronic pain is characterized by pain that outlasts normal time of healing, or pain that is associated with a disease or injury. If chronic pain is not treated properly, it can worsen over time and lead to a reduction in quality of life.[2] Pain of any sort is generally associated with psychophysiological factors because emotional and behavioral responses have the ability to influence the development of illness and the outcome of treatment, and vice versa.[3] Psychological models are incorporated into pain therapy, since they provide a better understanding of the cognitive, emotional, and behavioral manifestations of pain.[4] In extreme cases, pharmacological and interventional therapies can be leveraged to manage much more persistent and detrimental pain symptoms.

Pain requires cognitive attention.[5] Since humans have a limited attentional capability,[6] a computer-generated simulation of three-dimensional environments that can be interacted with in a seemingly realistic manner—virtual reality (VR)—is capable of transporting an individual into an alternate reality without physically leaving their current environment.[7] VR has been found to reduce performance on divided attention tasks,[8] and patients have less attentional capacity to focus on incoming signals from pain receptors as they shift their focus to interaction with the virtual environment (VE).

VEs can also be used to train patients on preventative and rehabilitative procedures.[9] When used in combination with electrophysiological state-sensing devices such as electroencephalograph (EEG), electrocardiograph (ECG), electromyogram (EMG), and other technology, rich patient biofeedback data can be observed. Commercially available handheld devices and peripheral gaming accessories such as Razer Hydra, Leap Motion 3D controller, Myo armband, and the Virtuix Omni treadmill (to name a few) can be used to incorporate dynamic control mechanisms into VR simulations. The release of the Oculus Rift Developer's Kit (costing

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approximately US$275) head-mounted display (HMD) in 2013 shed light on a new era of inexpensive VR visualization systems. Because of the game-like scenarios that can be programmed, several studies have reported that patients actually have ''fun'' during treatment with VR.[10,11]

Costing up to US$635 billion each year in medical treatment costs and lost productivity in the United States,[12] US$417 billion in Europe,[13] (chronic) pain management is not as ''fun'' an issue for policy makers. The World Health Organization (WHO) estimates that 22% of the global population has some degree of chronic pain.[14] Though an increased understanding of biological mechanisms underlying pain symptoms, diagnostic procedures, and therapeutic applications have been explored, current treatments for pain often do not result in the complete alleviation of symptoms.[15]

General Overview of Pain Management Therapies

Pain management can be divided into four categories (see Fig. 1).

1. Physiotherapy (physical therapy). The practice of using acupuncture, thermal agents, light therapy, electrotherapy, therapeutic exercise, and some behavior therapy all fall under the category of physiotherapy, which is the treatment of pain by promotion of mobility, functional ability, and routine physical intervention.

2. Psychotherapy (psychological therapy). Problems addressed by psychotherapy are centered on the mental well-being of patients. Techniques involve exploration of thoughts, feelings, and behavior for the purpose of achieving higher levels of functionality and quality of life. Cognitive Behavior Therapy (CBT) teaches patients to analyze and restructure their thought processes while becoming more aware and in control of physiological factors that correlate with mental state—factors such as heart rate, respiration, and so on.

3. Pharmacotherapy (pharmacological therapy). The oral administration of medicinal drugs to relieve pain symptoms is known as pharmacotherapy. WHO guidelines elicit a ''pain ladder'' for the consumption of pharmacological analgesics for patients experiencing severe pain that cannot be addressed solely with nonmedicinal therapy.[16] The ladder starts with nonopioid drugs such as cannabinoids, paracetamol, dipyrone, nonsteroidal anti-inflammatory drugs (NSAIDs), or COX-2 inhibitors. If pain is not considerably addressed using nonopioids, further progression could require consumption of a mild opioid such as codeine phosphate, dextroproxyphene, or tramadol in conjunction with nonopioids. If pain persists, or the patient is experiencing onset of sudden severe pain symptoms, strong opioids such as morphine, diamorphine, fentanyl, buprenorphine, oxymorphine, oxycodone, or hydromorphone can be issued in conjunction with nonopioids. In patients experiencing neuropathic pain, tricylic antidepressants, class I antiarrhythmics, and anticonvulants are commonly issued to relieve pain symptoms.

4. Intervention therapy. The use of interventional applications to diagnose or locate the patient's source of pain or provide relief is known as intervention therapy. Treatments include injection therapy, surgical intervention, nerve blocks, neuroaugmentation, implantable devices or drug delivery systems, and direct brain stimulation (to name a few). Interventional procedures are most commonly used in combination with standard analgesic methods to reduce opioid side effects and to achieve a better analgesic efficiency.

Room for Improvement

In a general Western healthcare model, patients who experience symptoms of pain must consult a primary care specialist with the hope of obtaining a diagnosis and curative treatment. When such a treatment is unavailable, these

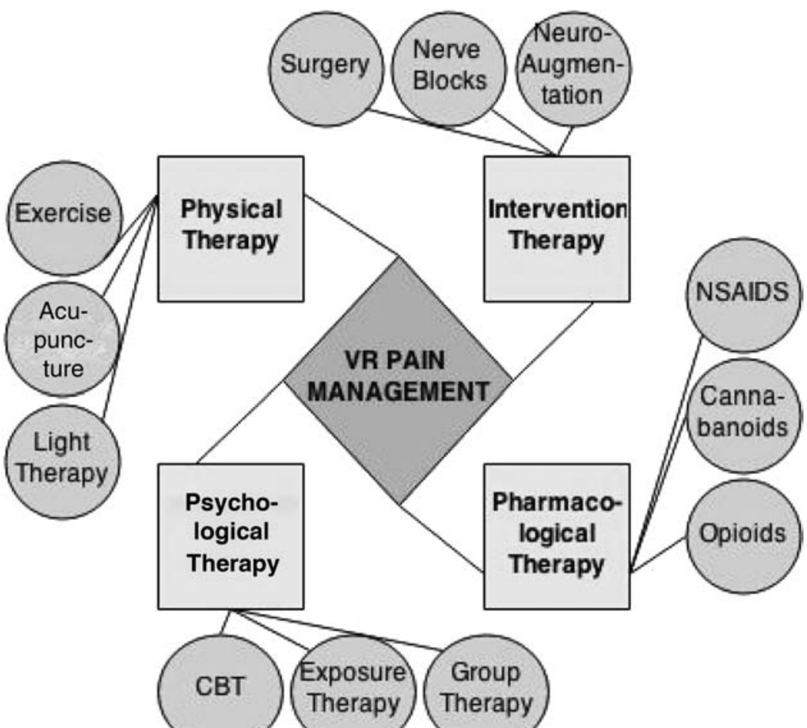

FIG. 1. Virtual reality (VR) pain management is an interdisciplinary to therapy designed to attack pain symptoms with an omnidirectional approach.

patients ''expect'' a prescription for analgesic medication to relieve their symptoms. Some of these medications might relieve acute pain in the short term, but their utility for treating long-term chronic pain can be controversial. Studies suggest only 32% of patients placed on long-term opioids[17] and 50% placed on antidepressants[18] experience a pain reduction. In addition to an ambiguous success rate, a sample of orally consumed pharmacological drugs can produce a substance dependency in patients.[19] A 2010 U.S. Department of Health and Human Services Nation Survey on Drug Use and Health (NSDUH) reported that approximately 1.7 million people had a pain reliever dependency.[20] Side effects such as mental illness or even noneffectiveness increase pain management opportunity costs and likelihood of unwanted results. Extreme caution must be taken when issuing stronger medicinal drugs, since they oft come with side effects that can impede patient progress if appropriate considerations are not acknowledged.

In 2011, the Health Ministry of New South Wales, Australia, reported the following issues associated with the current model of care for pain management: an overdependence on pharmacotherapy, lack of services approaching pain problems using biopsychosocial approaches, lack of timely access to existing services, an increasing demand for pain management particularly in populations suffering chronic pains as a result of surviving conditions that are associated with or lead to persistent pain, and a lack of targeted services for clients experiencing pain who have differing needs.[21] Having taken these issues into consideration, we observe how VR therapy can be utilized as a low-cost intervention for a variety of pain-related symptoms.

VR Intervention as a Pain Management Technique

VR is a technology that has emerged as an affordable solution for pain management therapy, proven effective in helping patients cope with pain arising from numerous ailments, being acute or chronic. Table 1 displays a number of recent (2012–2014) publications that show the efficacy of VR in the treatment of a variety of pain symptoms.

VR exposes patients to computer-generated sights and sounds, creating visual and auditory stimulus that would otherwise be presented through the physical environment. This method of intervention provides either distraction or training to patients suffering pain symptoms. Distraction therapy has been applied in clinical practice for decades; the foundation of logic backing the technique is based on the assumption that there exist psychological elements in the perception of pain. It is thought that the more attention someone pays to harmful stimulus, the more intense the realization of the pain. Thus, VEs are used to distract patients from ongoing treatments in a seamless fashion, so as to cause minimal amount of actual pain. Just like many other intervention therapies, VR intervention is being used in combination with other analgesic strategies such as training to attack pain symptoms with an omnidirectional approach (Fig. 1).

VR and physiotherapy

Wii Fit from Nintendo® (and other videogames) has shown that peripheral devices can be used to interact with games with new meaning. Game players balance themselves on the Wii Fit™ board, and sensor data are used as a control mechanism in the game environment. One study showed significant improvements in dynamic balance, functional mobility, and a reduced risk for falling in elderly patients when playing Wii Fit™.[22] Another study, focused on the link between elderly diabetic patients and injuries due to falling, concluded that VR has the potential to train patients in balance, strength, and gait so as to reduce the risk of falling.[23] For additional analysis on performance, neuromuscular movements can be monitored using electromyography (EMG). Several studies have shown that when this biofeedback is delivered through a display, sound, or haptic signal, it can serve as a correctional mechanism for the patient and as a monitoring mechanism for the therapist.[24] VR displays can integrate biofeedback notifications into simulations just as games might use status bars, numerical displays, and written or spoken notifications. Quite like videogames, in fact, VEs are interacted with through a variety of human–computer interaction (HCI) factors, which gives therapists the option of incorporating environment control mechanisms that rely on handheld and peripheral gaming accessories requiring mobility. An example of such a mechanism was used earlier, when we mentioned the Wii Fit board. Another example is the Virtuix Omni (omnidirectional) treadmill, which allows users to ''walk in all directions, while standing in one spot,'' and enables researchers/therapists to expose patients to VEs that must be navigated through by walking. Numerous studies have shown the effect of treadmill training on rehabilitative populations.[25] It is only recently that interdisciplinary researchers/therapists have affordable, commercially available tools to utilize to create more engaging and motivating physical therapy environments.

VR represents an opportunity to both enrich and intensify the experience patients have when receiving physiotherapy. The dramatically interactive nature of VR requires patients to become more involved in the therapy process and can significantly improve both compliance and therapeutic results. During physiotherapy, the main impediment to progress is often pain. VR can help overcome this pain so patients may more rapidly proceed through the therapeutic hierarchy.

VR and psychotherapy

A 17-country study examined the incidence of mental disorders among people with comorbid single or multiple pain conditions. Results indicated that mental disorders followed a linear pattern, with the lowest rates found among individuals with no pain, intermediate rates among those with one pain symptom, and highest rates among those experiencing multiple pain symptoms.[26] Psychological factors are highly correlated with pain; depression, anxiety, and posttraumatic stress disorder (PTSD) are frequent byproducts of traumatic physical injury and chronic pain.[27] VR used within a CBT model can train patients on shifting attention away from pain or stress-inducing thoughts.[28] Self-management (SM) is an action taken by the patient to manage or minimize the impact of pain.[29] Along with guided in-clinic therapy, patients have the opportunity to heal with at-home mobile interfaces like those that have been used in numerous studies to monitor and assist patients in SM over long periods of time.[30] VR can provide a mobile experience that is programmable and useful for targeting patients with special needs.[31]

Table 1. Recent Studies that Show the Efficiency of Virtual Reality (VR) in the Treatment of a Variety of Pain Symptoms

Study	*Pain/discomfort studied*	*Treatment*	N	*Findings*
Ortiz-Catalan et al. (2014)	Phantom limb pain—chronic	Phantom movements were predicted using myoelectric pattern recognition and then used as input for VR and AR environments, including a racing game	1 chronic PLP patient who had shown resistance to a variety of treatments for 48 years	A reduction of time at higher pain intensity levels, as well as the appearance of periods of lower or absent pain within 18 weeks
Loreto-Quijada et al. (2013)	General pain/discomfort	Figures that represented pain were displayed to subjects, who were asked to evaluate in terms of arousal and valence; pain figure was then paired with shock, and nonpain figure was paired with no shock	64 undergraduate students asked to evaluate arousal and valence in response to a figure representing pain	Interaction with VR led to significant increases in pain threshold and tolerance, as well as significantly greater underestimation of time
Bidarra et al. (2013)	Dental treatment pain—acute	VR gaming distraction	—	Preliminary evaluation of dentist and game design domains that influence prototype development for an at-the-dentist VR distraction system
Botella et al. (2013)	Fibromyalgia (FM)—chronic, neuropathic	10 sessions of 2 hours group cognitive behavioral treatment for FM supported by VR	6 women diagnosed with FM, with a mean age of 55 years old (range = 47–65; SD = 7.6) and a mean duration of diagnosis of 11 years	Results indicate high levels of satisfaction of VR use by 6 patients and reduction in impairment caused by FM symptoms
Kipping et al. (2012)	Pediatric burn wounds—acute	VR exposure, prospective randomized controlled trial using nonpharmacological methods,	41 adolescents aged between 11 and 17 years	Statistically significant reduction in pain scores during dressing removal, and significantly less doses of Entonix given to those receiving VR exposure
Villiger et al. (2013)	Neuropathic pain in patients with incomplete spinal cord injury (iSCI)—chronic	VR training, uncontrolled	14 iSCI patients were treated over 4 weeks in 16 to20 sessions of 45 minutes	Positive changes reported by patients, improvements in lower limb function, reduced intensity and unpleasantness score on Neuropathic Pain Scale (NPS), and stability of finding even after 12 to 16 weeks of training termination
Cacau Lde et al. (2013)	Cardiac rehabilitation postoperatively—acute	VR cardiac rehabilitation vs. traditional cardiac rehabilitation	30 patients exposed to VR, 30 patients not exposed to VR assessed through functional independence measure (FIM), 6-minute walk test (6MWT), and Nottingham Health Profile (NHP)	VR group shows lower reduction in functional performance on first day after surgery as compared to control group, no significant difference in performance on discharge day, a significant decrease in pain score at the third assessment, higher energy level in first evaluation, no statistical significance for emotional reactions, physical ability, or social interaction, shorter length of stay, and higher 6MWD
Giggins et al. (2013)	Pediatric headache—chronic	VR biofeedback pain management	10 adolescents attending an outpatient pediatric neurology clinic were treated by a system which combined VR and biofeedback	Ratings of pain, daily functioning, and quality of life improved significantly at 1 and 3 months post-treatment
Wiederhold et al. (2012)	Pain in military populations	Review	—	Funded by NATO, United States Army, Defense Ministry of Austria, and Defense Ministry of Croatia
Stetz et al. (2012)	Pain in military populations	CBT to manage pain	42 chronic pain patients from the Tripler Army Medical Center, older than 17 years of age, intact sensory deficits, and cognitively enabled to follow directions	Statistically significant drop in pain rating in technology-assisted sessions than during standard modality

VR exposure therapy targets anxiety disorders in patients with pain symptoms by exposing them to stimuli that trigger unwanted psychophysiological behaviors and training them to condition their psychophysiological responses accordingly. Low-cost EEG systems can be used to monitor real-time brain activity during mobile and immobile tasks in VR.[32] This adds another dimension of analysis for monitoring patients with psychological problems because emotional correlates can be drawn from reading spatio-temporal source dynamics and event potentials during different tasks.[33]

VR and pharmacotherapy

Patients can use VR as an adjunct to pharmaceutical drugs for an increased analgesic efficiency. A study, focused on burn pain reduction in adolescent populations undergoing wound dressing, found that patients experienced a significant reduction in pain scores and dosage of Entonix with VR as opposed to otherwise.[34] The combined usage of VR and pharmaceutical drugs has also been utilized in treating by-products of trauma, such as PTSD, with no recorded evidence of negative side effects in the well-being of the patient.[35] The ingestion of pharmaceutical drugs can activate primary physiological systems. VR treatment acknowledges these changes and offers methods for promoting activation of systems otherwise unacknowledged by drug treatment.

VR and other interventional therapies

Attention to acute pain during interventional treatments can be repressed with the use of VR devices.[36,37] A pilot study conducted on VR distraction at the dentist found that when designing these interfaces, special attention had to be paid for different patient and therapist domains. For example, devices interfering with the work of the dentist could cause a disturbance during the procedure, and devices that were not engaging enough could fail to distract patients.[38]

Future Implications

Approximately US$14.6 billion over the next 10 years has been allocated by the 2014 U.S. Executive Budget to ‘‘implement innovative policies to train new health care providers and ensure that the future health care workforce is prepared to deliver high-quality and efficient health care services.’’[39]

Below, we explore areas and populations that may benefit from the incorporation of VR into existing training and treatment protocols (Fig. 2).

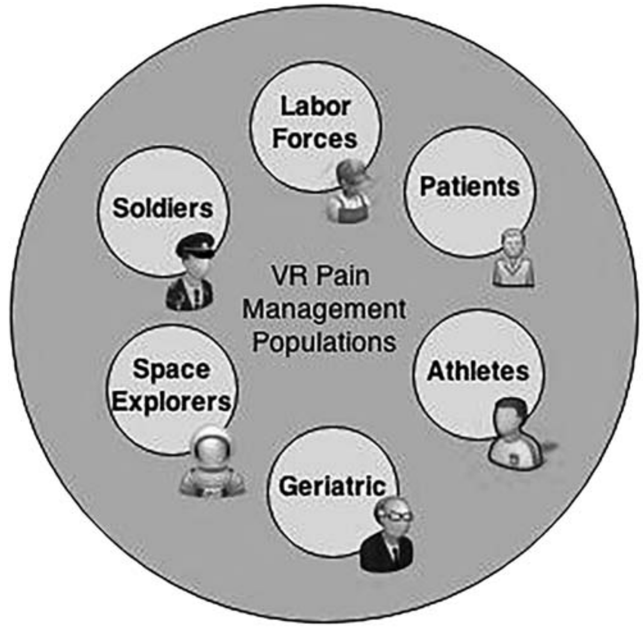

FIG. 2. Areas and populations that could benefit with interdisciplinary incorporation of VR.

Military populations

Military personnel exposed to traumatic incidents have a high risk for developing PTSD. Incidents may result in injuries such as severed limbs, traumatic brain injury (TBI), and other acute and chronic pain conditions. Treatment typically requires administration of opioid drugs. Studies have shown that these drugs may induce a high dependency in patients, thus the need to investigate new methods for providing efficient pain relief to veterans.[28] One area of investigation is phantom limb pain, and VR applications are being studied to investigate advancing treatments for this syndrome further.[40] There has been a significant amount of work in applying VR therapies to wounded warriors,[28,41–44] and room for improvement still remains. The U.S. Department of Veteran’s Affairs was provided $56 billion (from the 2014 Executive Budget) for war veteran healthcare services, which ‘‘include innovative programs to educate and support veterans’ caregivers, enhance veteran’s access to care through telehealth technologies, and support equitable, high-quality care for women veterans in an appropriate and safe environment.’’[45]

Space exploration

Difficulties associated with illness and injury have accounted for more space exploration failures than any other technical or environment reason.[46] There is room for incorporating VR into space exploration as a countermeasure to deal with the threat of traumatic incidences occurring during extravehicular activity, onset of neuropathic pain during missions, and other pain-inducing incidents. Low back pain in microgravity is one of the most common problems experienced by astronauts.[47] A portable wireless VR solution for back pain telemonitoring has been previously explored to meet similar application requirements.[48] Opportunities such as these provide reason for the two interdisciplinary fields to marry so they can potentially produce a synergy.

Geriatric populations

Injury prevention in elderly populations continues to be an issue, as one out of three adults aged 65 or older falls each year. Falls are the leading cause of both fatal and nonfatal injuries. Arthritis is another big issue among geriatric populations, costing the United States up to US$128 billion per year in medical costs and lost productivity.[48,49] Approximately 50 million adults are affected with some form of arthritis. The U.S. Center for Disease Control and Prevention was provided approximately US$14 million from the president’s 2014 Executive Budget to expand and disseminate evidence-based programs for the treatment of arthritis.[50] The European Commission also adopted the European Innovative

Table 2. Global Funding for Advancing Pain Management Techniques and Research

Agency	*Location*	*Goals*	*Additional Information*
American Fibromyalgia Syndrome Association, Inc.	United States	Researching treatment, cause, and cure for fibromyalgia syndrome	www.afsafund.org
American Pain Society	United States	Providing grants to investigate pain	www.americanpainsociety.org
British Pain Society	United Kingdom	Providing grants to investigate pain	www.britishpainsociety.org
Canadian Pain Society	Canada	Providing grants to investigate pain	www.canadianpainsociety.ca
Defense Advanced Research Programs Agency	United States	Development of innovative military technology	www.darpa.mil
Department of Defense	United States	Involved in funding defense medical research	www.defense.gov
European Innovative Partnership	European Union	Commercially feasible innovative concepts	www.ec.europa.eu/research/innovation-union
Horizon 2020	European Union	Increasing Europe's global competitiveness by driving innovative research	ec.europa.eu/programmes/horizon2020/
Mayday Fund	United States/Canada	Clinical interventions, pediatric pain, pain in non-verbal populations, emergency treatments	www.maydayfund.org
NASA Innovative Advanced Concepts	United States and some international opportunity	Innovative, interdisciplinary space exploration concepts	www.nasa.gov/directorates/spacetech/niac
National Institute of Arthritis and Musculoskeletal and Skin Diseases	United States	Issues related to arthritis, musculoskeletal and skin disorders	www.niams.nih.gov
National Institute on Aging	United States	Issues related to aging	www.nia.nih.gov
National Institute of Health Pain Consortium	United States	Advancing pain treatment, medication, and research for pain-related diseases	www.painconsortium.nih.gov
National Science Foundation	United States	Funding various project related to pain and disease	www.nsf.gov
National Sleep Foundation	United States	Pain and sleep	www.sleepfoundation.org
Solving Kids Cancer Therapeutic Development Initiative	International	Pediatric cancer	http://solvingkidscancer.org
Thrasher Research Fund	International	Prevention, diagnosis and treatment of children's diseases	www.thrasherresearch.org
Department of Veteran's Affairs	United States	War veterans	www.va.gov
William T. Grant Foundation	United States	Illness affecting youth aged 5–25 years in the United States	www.wtgrantfoundation.org

Partnership on Active and Healthy Ageing initiative with the goal to add 2 years to the average healthy lifespan of Europeans by 2020.[51] With resources such as these, we expect to see significant advances in the implementation of VR devices with geriatric populations experiencing pain symptoms in the future.

Pain due to cancer and other chronic injuries

VR has been used in the treatment of illnesses that often result in chronic pain. Yet there remains a need for further exploration of VR treatment methods used in conjunction with traditional analgesics to relieve pain symptoms in these populations. Because pain is not monomorphic, patients can develop intolerance to treatments. This ushers in the use of VR where medication cannot go. VR simulations can be programmed to change in response to patient pain, dialing up the ''dosage'' as more relief is needed, and dialing down the ''dosage'' as less is necessary. This ability to control the CyberDose© may prove useful as more self-care is administered by patients in their home environment.

Occupational injuries

On average, up to 12 people die every day due to occupational injury and illness. In 2012, out of 3,945 U.S. worker fatalities in the private industry, 775 (19.6%) were in construction. Leading causes for worker deaths on construction sites were falls, followed by object impalement, and electrocution.[52] VR techniques can be implemented to train labor force on preventative techniques to reduce the number of fatalities and injuries in the workspace. In addition, the millions of injuries that occur each year in the workplace can be effectively treated using VR to guide both cognitive and physical rehabilitation.

Drug abuse

The National Institute for Drug Abuse has begun a research program to examine the intersection of pain treatment with the abuse of and addiction to opioid medications. Goals are centered on developing alternative pain management solutions (such as VR) with reduced addiction potential, and elucidating risk or protective factors associated with opioid abuse and addiction.

Safe at-home treatments

The National Institute for Health's 8th Pain Symposium in 2012 was primarily focused on exploring self-management techniques for pain management.[53] VR applications are promising for the advancement of at-home medical services because they enable mobility, remote patient monitoring, and treatment specialization capabilities. Much work still needs to be done to quantify the benefits of using topical agents and other safe self-applied techniques such as VR for at-home pain management purposes.

Athletic injuries

Accidents that occur during athletic activity can cause injuries in the form of sprains, knee injuries, swollen muscles, fractures, dislocations, and more. According to the U.S. Consumer Product Safety Commission's National Electronic Injury Surveillance System, more than 1.9 million individuals were treated for a sports-related injury in an emergency medical facility.[54] VR can be incorporated during athletic conditioning to prevent injury, and during rehabilitation as a vehicle on the road to recovery.

Conclusions

The use of VR to treat pain and manage patients with a variety of medical conditions has been well established. VR distraction is effective during medical and surgical procedures, acute pain, chronic pain, pain with rehabilitation, chronic pain of cancer, diabetic neuropathic pain, and related conditions such as pruritus. The technique is safe and effective and has been used on patients with migraine headaches. The often relaxing and stress-reducing capabilities of virtual environments demonstrate wide applicability in behavioral medicine and patients with psychophysiological disorders. These disorders, such as functional abdominal pain, muscle sprain, fibromyalgia and neuropathic pain, and postherpetic neuralgia, are very common in primary care practices. There is significant national and international attention focused on pain management in the occupational and clinical settings.

Table 2 describes some of the funding mechanisms available and those funding agencies that have made pain research one of their priorities. We encourage readers to take advantage of these and other funding resources to continue research on more effective and innovative pain reduction strategies.

Author Disclosure Statement

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CyberSightings

CYBERSIGHTINGS IS A regular feature in CYBER that covers the news relevant to the Cyberpsychology community, including scientific breakthroughs, latest devices, conferences, book reviews, and general announcements of interest to researchers and clinicians. We welcome input for inclusion in this column, and relevant information and suggestions can be sent andrea.gaggioli@unicatt.it.

In the Spotlight

Is the metaverse still alive? In the last decade, online virtual worlds such as Second Life and the like have become enormously popular. Since their appearance on the technology landscape, many analysts have regarded shared 3D virtual spaces as a disruptive innovation, which would have rendered the Web itself obsolete. This high expectation attracted significant investment from large corporations such as IBM, which started building their virtual spaces and offices in the metaverse. Then, when it became clear that these promises would not be kept, disillusionment set in, and virtual worlds started losing their edge. However, this is not a new phenomenon in high tech, happening over and over again. The U.S. consulting company Gartner has developed a very popular model to describe this effect, called the ''Hype Cycle.'' The Hype Cycle provides a graphic representation of the maturity and adoption of technologies and applications. It consists of five phases, which show how emerging technologies will evolve. In the first, *technology trigger* phase, a new technology is launched, which attracts the interest of media. This is followed by the *peak of inflated expectations*, characterized by a proliferation of positive articles and comments, which generate overexpectations among users and stakeholders. In the next *trough of disillusionment* phase, these exaggerated expectations are not fulfilled, resulting in a growing number of negative comments generally followed by a progressive indifference. In the *slope of enlightenment*, the potential of the technology for further applications becomes more broadly understood, and an increasing number of companies start using it. In the final *plateau of productivity* stage, the emerging technology establishes itself as an effective tool, and mainstream adoption takes off.

So at what stage in the Hype Cycle are virtual worlds now? After the 2006–2007 peak, metaverses entered the downward phase of the Hype Cycle, progressively losing media interest, investments, and users. Many high tech analysts still consider this decline an irreversible process. However, the negative outlook that headed shared virtual worlds into the *trough of disillusionment* may soon be reversed. This is thanks to the new interest in virtual reality raised by the Oculus Rift (recently acquired by Facebook for $2 billion), Sony's Project Morpheus, and similar immersive displays, which are still at the take-off stage in the Hype Cycle. Oculus Rift's chief scientist Michael Abrash makes no mystery of the fact that his main ambition has always been to build a metaverse such as the one described in Neal Stephenson's (1992) cyberpunk novel *Snow Crash*. As he writes on the Oculus blog (www.oculusvr.com/blog/introducing-michael-abrash-oculus-chief-scientist/), ''Sometime in 1993 or 1994, I read *Snow Crash* and for the first time thought something like the Metaverse might be possible in my lifetime.'' Furthermore, despite the negative comments and deluded expectations, the metaverse keeps attracting new users: on its 10th anniversary on June 23, 2013, an infographic reported that Second Life had more than one million users visit around the world monthly, more than 400,000 new accounts per month, and 36 million registered users. So will Michael Abrash's metaverse dream come true? Even if one looks into the crystal ball of the Hype Cycle, the answer is not easily found.

Upcoming Meetings

22nd International Conference on User Modeling, Adaptation, and Personalization
Aalborg, Denmark
July 7–11, 2014
www.um.org/umap2014/

6th International Conference on Intelligent Technologies for Interactive Entertainment
Chicago, Illinois
July 9–11, 2014
www.intetain.org/2014/show/home/

8th IADIS International Conference on Interfaces and Human–Computer Interaction
Lisbon, Portugal
July 15–17, 2014
www.hcii2014.org/

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CyberEurope

In this feature, we will try to describe the characteristics of current cyberpsychology research in Europe. In particular, CyberEurope aims at describing the leading research groups and projects running on the other side of the Ocean.

Horizon 2020 Cross-Cutting Issues (I)

Horizon 2020 is the European Framework Programme for research and innovation. It is subsequent to FP7 and covers the period 2014–2020. Horizon 2020 supports research and innovation projects and programs in ground-breaking basic research, strategic and applied research, demonstration projects, and close-to-market activities.

The Horizon 2020 Work Programme 2014–2015, published in December 2013 (http://ec.europa.eu/research/participants/portal/desktop/en/home.html), sets out the funding opportunities under the different parts of the program. Each part describes the overall objectives, the respective calls, and the topics within each call.

As discussed in the previous issues, Horizon 2020 consists of three pillars: (a) excellence in the science base, (b) industrial leadership, and (c) societal challenges. However, it also includes seven cross-cutting issues that have been mainstreamed in the different parts of the Work Programme, ensuring a more integrated approach. We will discuss the first four in this issue.

Innovation

Substantial support will be provided for innovation through activities such as prototyping, testing, demonstrating, piloting, large-scale product validation, and market replication. Significant support to demand side approaches will be another important feature, notably precommercial and first commercial public procurement of innovation, as well as regulation to foster innovation and standard setting. There will also be the piloting of new forms and sources of innovation, including public sector and social innovation, as well as pilots on private sector services and products.

Spreading excellence and widening participation

The existence of internal disparities in research and innovation performance within the EU hinders some Member States from meeting their full potential. Low performance is also reflected in the participation patterns of some Member States in framework programs, with limiting factors such as a low level of national investment in research and innovation and reduced access to research networks. The first calls will include offers of funding of a total of €50 million targeting those Member States through measures such as teaming, twinning, and ERA chairs.

Information and communications technology

The information and communications technology (ICT) sector represents 4.8% of the EU economy and accounts for 25% of total business expenditure in research and development. The transformative power of ICT can also help address many of Europe's most pressing societal challenges in areas such as health, the environment, and fostering secure and inclusive societies. In Horizon 2020, the EU is investing at least 25% more in ICT research than in previous research programs. This will support the full range, from high risk, ground-breaking research to innovation that can deliver revolutionary business breakthroughs, often on the basis of emerging technologies. Around €1.2 billion of funding for ICT is available through the first Horizon 2020 calls.

The ICT part of the first Horizon 2020 Work Programme focuses on the development of a new generation of components and systems, including micro- and nano-electronics and photonics technologies, next generation computing, infrastructures, technologies and services for the future Internet, content technologies, and advanced interfaces and robotics.

Social sciences and humanities

Social sciences and humanities (SSH) research is fully integrated into each of the pillars of Horizon 2020 and each of the specific objectives. It is a key objective that SSH will contribute to the evidence base for policy making at international, EU, national, and regional levels. In addition, SSH is at the heart of the societal challenge ''Europe in a changing world: Inclusive, innovative and reflective societies'' (part 13 of the Work Programme).

Almost 200 topics in the programmed parts of Horizon 2020 are relevant to SSH. This represents around 35% of the total topics in the Work Programme. All these are flagged by the system designed for searching the Work Programme. The estimated budget for SSH related topics is more than €400 million (in addition to funding available through the ERC and the MSCA).

A detailed overview of all the steps for funding can be found in the Horizon 2020 online manual (http://ec.europa.eu/research/participants/portal/desktop/en/funding/guide.html).

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Cyberpsychology, Behavior, and Social Networking

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