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VIRTUAL REALITY IN THE TREATMENT OF PAIN*

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Many medical procedures produce acute pain that in most cases is quite disturbing for the individual. Medication is the treatment of choice for acute pain. However, given the involvement of psychological aspects in the experience of pain, psychological techniques are being used as an effective adjunct to alleviate pain related to medical procedures. In the last years a new technology is demonstrating an enormous potential in this field: Virtual Reality (VR) distraction. In this article we review studies that explore the efficacy of immersive VR distraction in reducing pain related to different medical procedures. We include clinical studies and analogue studies with healthy participants. We discuss the results achieved by these studies and recommend future directions of VR pain control research.

Introduction

Until recently in the history of medicine, pain was understood in terms of a simple connection between a pain stimulus and a hypothetical pain center in the brain. The intensity of pain was thought to be directly related to the magnitude of the tissue damage. The emotional, attentional, behavioral and cognitive aspects were thought to be mere reactions to the pain process.

The theory by Melzack and Wall (1965) constituted a revolution in the understanding of pain. They proposed the concept of modulation. From this perspective, a pain signal does not follow a fixed pathway from the pain receptor (e.g. in the skin) to the brain. The pain signal can be controlled, modified or inhibited on its way to the brain by messages coming from other sources in the brain. Higher order thought processes can change the way incoming pain signals are interpreted as they are processed by the brain, and can even change the intensity of incoming pain signals that make it into the brain (like a gate). According to Melzack and Wall, pain perception involves a balance of activity within the whole system. Pain involves the interaction of several neural networks, including parts of the nervous system involved in the sensory component of pain, but also parts involved in other processes like attention, emotion or memory. Psychological factors such as stress, depression and anxiety can alter the central and autonomic nervous systems and increase the amount of pain experienced. Other psychological factors like relaxation or distraction can diminish the experience of pain.

Melzack and Wall (1965) distinguished three main dimensions related to the experience of pain: a) Sensory-discriminative dimension, related to the mechanism that discriminates the sensory signals of pain; b) Motivational-affective

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dimension, related to the qualitative aspects of the pain experienced like anxiety, depression, suffering, aversiveness, etc., and c) Cognitive-evaluative dimension, related to past experiences related to pain, expectations, beliefs, etc.
In summary, pain is a complex and multidimensional construct that involves sensory, emotional and cognitive processes that can modulate the experience of pain. Melzack and Wall's model widened the understanding of pain, moving the field from a unidimensional view to a multidimensional framework, and opening the doors of pain research and pain management not only to medicine, but to many other disciplines, like psychology (Craig & Rollman, 1999).

From this perspective, psychological techniques like distraction, cognitive reappraisal, preliminary information, behavioral modification, and hypnosis have been used for pain control (Patterson, 1992). Distraction is one of the most commonly used techniques for acute pain control. Its use is based on the assumption that the amount of attention paid to pain stimuli modulates the perception of pain. Attentional resources are limited. If the individual can draw attention away from pain by focusing attention to other stimuli, the perception of pain diminishes. The role of attention in pain is being studied (i.e. Eccleston & Crombez, 1999). The characteristics of a good distractor include multiple sensory modalities, emotional involvement, and participation of the individual (Wismeijer & Vingerhoets, 2005). These features made researchers in the field pay attention to a new technology with a high potential as a good distractor: virtual reality (VR).

Immersive VR gives patients the illusion of "going into" a 3-D computer-generated environment. In this human-computer interaction, the user is no longer just an outsider watching a screen. They become active participants inside a three-dimensional virtual world. A number of factors contribute to the strength of the illusion of presence in a virtual world. The field-of-view or amount of peripheral vision permitted by the VR helmet or HMD and the clarity of what is seen helps, as do stereo visual images. Converging evidence from sounds and sometimes touch and taste, in synchrony with what the users see as they interact with the virtual world also helps strengthen the illusion of presence in the virtual world. Electromagnetic head position tracking can influence presence. When users move their heads up in the real world, what they see in the virtual world changes accordingly. The computer quickly updates the virtual environment presented to the user by changing the viewpoint in VR when the user moves his/her head. VR has the capacity to create many different and dynamic environments in the user's mind, where a very wide pattern of responses can be evoked.

Virtual reality pain control is a new psychological distraction technique that has recently been applied to acute pain. In the next section we summarize the studies exploring the utility of VR for acute pain control.

VR and acute pain control

In this review we will summarize the studies exploring the efficacy of VR for acute pain control in clinical populations. We will also review experimental studies with non-clinical populations. It is not our aim to conduct an exhaustive review. We will focus only in studies using immersive VR and not other similar techniques like non-immersive VR. There are other reviews that we recommend (Wiederhold & Wiederhold, 2007; Wismeijer & Vingerhoets, 2005).
VR for acute pain has been studied mainly in two populations: burn patients and cancer patients. The pioneer work of the use of immersive VR distraction was published by Hoffman, Doctor, Patterson, Carrougher, and Furness, a research group from the University of Washington, in 2000. These authors presented two case reports providing the first evidence of the effectiveness of VR as a powerful adjunctive non-pharmalogical analgesic for acute pain in burn patients. They compared the analgesia of two distraction procedures, playing a video game vs. going into VR. The

patients were two adolescent males. One of them had a severe gasoline burn on 5% of his body and the second patient had deep flash burns on 33.5% of his body surface. They spent 3 minutes in VR and 3 minutes playing a video game while going through wound care. The order of administering the treatments was randomized and counterbalanced. The effectiveness was measured using subjective presence and pain ratings in 100-mm Visual Analogue Scales. Patients were asked to rate their Worst pain, Average pain, Anxiety, Unpleasantness, Bothersomeness, and Time spent thinking about their pain/burn wound during the relevant wound care. They were also asked to rate how much nausea (if any) they experienced while in each condition. They were asked to what extent they felt they went into the computer-generated environment and how real the objects in the virtual world seemed to them. The virtual world used was SpiderWorld. For the video game condition, Wave Race 64 and Mario Kart 64 Nintendo 64 games were used. Results showed that VR was more effective in reducing pain than the video game in both cases and in all measures of pain.

Since the publication of these case reports, the research team led by Drs. Hoffman and Patterson has conducted several studies to explore the efficacy of VR distraction in pain control related to medical procedures like wound care and physical therapy in burn patients. Hoffman, Patterson, and Carrougher (2000) explored the use of VR to distract patients from pain during physical therapy. Twelve patients performed physical therapy with no distraction for three minutes and physical therapy in VR for three minutes. All patients reported statistically significantly lower pain and less time thinking about pain when in VR, compared to no distraction. In these two studies, patients received only a single short VR session. One of the concerns of the researchers was that that the amount of pain reduction may diminish with repeated use of VR. The novelty of the virtual environment would decrease with repeated VR sessions.

In a case study (Hoffman, Patterson, Carrougher, Nakamura, Moore, Garcia-Palacios, & Furness, 2001) and a within subject design study (Hoffman, Patterson, Carrougher, & Sharar, 2001) this group explored whether immersive virtual reality continues to work when used more than once. In the second of these studies seven patients performed physical therapy while being immersed in SnowWorld, a virtual environment that depicts an icy 3-D virtual canyon with a river and waterfalls where the patients can shoot snowballs at snowmen and igloos. Each patient participated in the VR condition on at least three separate days. As before, they received VR for part of their physical therapy, and no distraction during another part. Condition order was randomized and counterbalanced. Pain ratings were statistically lower when patients were in VR, and the magnitude of VR pain reduction did not diminish with repeated use of VR. Although the small sample size is a limitation of this work, the results suggest that VR retains its analgesic properties with multiple treatments. This finding is encouraging for the wound care field, given the fact that burn patients usually need multiple wound care and physical therapy sessions during their recovery. Hoffman and Patterson's team has also designed specific devices for the delivery of VR for specific procedures. They developed a water-friendly HMD in order to apply VR distraction to burn patients who were going through wound care in a water tank (Hoffman, Patterson, & Magula et al., 2004).

Das, Grimmer, Sparnon, McRae, and Thomas (2005) used VR games in children with burn injuries, finding strong support for the use of VR distraction for acute pain in children. A recent paper by Chang, Chung, Wong, Lien and Yang (2007) exploring the use of VR for reducing pain during burn wound care in children in Taiwan found that VR reduced anxiety, suggesting that using VR before the children develop conditioned anxiety regarding pain during wound care would be a useful intervention in this field. In another study van Twillert, Bremer and Faber (2007) comparing VR to no distraction and to other distraction methods like television, did find significant reductions in pain but did not find significant reductions in anxiety ratings. Anticipatory anxiety regarding painful medical procedures is an area of research that could also benefit from VR interventions. More research is needed regarding this issue.

VR pain distraction has been used also in cancer patients in order to reduce pain and distress related to chemotherapy. Gershon, Zimand, Lemos, Rothbaum and Hodges (2003) showed promising findings using immersive VR distraction vs. non-VR distraction vs. no distraction in a 8-year old boy undergoing port access for chemotherapy. They used a virtual environment called Virtual Gorilla. Pain ratings given by the child, his parents and the nurse were lower in the VR condition. His heart rate also decreased in VR. These authors conducted another similar study with a larger sample, 59 cancer patients ranging in age from 7 to 19 years (Gershon, Zimand, Pickering, Rothbaum & Hodges, 2004). They randomly assigned the patients to three conditions, VR distraction, non-VR distraction and no distraction. The results showed lower pain ratings from the children and the nurses and lower pulse rates in the VR distraction condition.

Another interesting study is the one conducted by Schneider, Prince-Paul, Allen, Silverman and Talaba (2004). They randomly assigned 20 women suffering from cancer and going through chemotherapy to VR distraction vs. no distraction. VR significantly reduced chemotherapy symptom distress. Also, both the patients and the nurses were satisfied with VR. In a second study Schneider (2005) evaluated 123 participants in order to explore if the effects of VR lasted for a period of two days. 86% of the participants were satisfied with VR and 82% reported willingness to use it again. An interesting result was that the patients estimated the time of the chemotherapy session to be less than the actual time. However, there were no differences in symptom distress one or two days after the chemotherapy session. VR has also been used in pain control related to dental procedures. Hoffman, Garcia-Palacios, Patterson, Jensen, Furness, and Ammons (2001) reported the results of a study where two patients with periodontitis underwent periodontal scaling and root planing under three conditions: VR distraction, movie distraction, and no distraction. Condition order was randomized and counterbalanced. Both patients reported lower pain ratings in the VR distraction condition; they also reported higher presence in the VR distraction condition than in the movie condition. Wiederhold and Rizzo (2006) recently reported data from a study in which 10 patients undergoing different dental procedures reported less pain and discomfort while being in VR. They also reported physiological correlates of analgesia. As in the Schneider (2005) study, patients estimated the time of the dental procedure to be less than the actual time. Patients and dental staff reported a positive experience using the VR equipment and the use of VR did not cause a significant addition of time or interfere with the dental procedure.

There have been other studies exploring the use of VR distraction in different medical procedures. For example, Steele et al. (2003) applied VR distraction vs. no distraction to a 16-year old patient with cerebral palsy undergoing physical therapy after surgery. Pain ratings were lower in VR. In another study, Wright, Hoffman and Sweet (2005) found support to VR distraction analgesia during transurethral microwave thermotherapy in a case report. Murray et al. (2007) showed preliminary data of the utility of VR for reducing phantom limb pain in three cases. Gold, Kim, Kant, Joseph and Rizzo (2006) found encouraging results in decreasing pain and anxiety in twenty children undergoing IV placement for MRI/CT.

There are two interesting studies combining hypnosis and VR. Patterson, Tininenko, Schmidt, and Sharar (2004) used VR to induce hypnosis in a burn patient, achieving important reductions in pain during burn care. In a more recent study, Patterson, Wiechman, Jensen and Sharar (2006) showed reductions in pain and anxiety in thirteen patients undergoing burn care. These results showed that VR hypnosis could be a promising technique for acute pain control. We have reviewed clinical studies so far. Other works have been conducted with normal samples in order to advance the study of specific aspects of VR analgesia or the mechanism underlying VR analgesia. Hoffman, Garcia-Palacios, Kapa, Beecher and Sharar (2003) replicated VR analgesia in normal participants. Pain was induced via blood pressure cuff ischemia. Using a within subject design, participants reported high levels of analgesia when immersed in VR com-

pared with no distraction. In this same experiment, participants went through a divided attention task while in VR. The results showed a reduction in accuracy in identifying pairs of odd numbers among random numbers when immersed in VR compared to being in the real world. These results support the idea that attentional distraction may be an important mechanism in VR analgesia. Hoffman, Sharar, Coda, Everett, Ciol, Richards, and Patterson (2004) also explored the relationship between VR analgesia and presence. This study found higher analgesia in a highly immersive VR condition compared to a less immersive VR condition (manipulating sound effects, quality of the images, and interaction). The sense of presence and analgesia was higher in the highly immersive VR condition. Magora, Cohen, Shochina and Dayan (2006) found that VR increased ischemic pain tolerance in 20 healthy volunteers. Mühlberger, Wieser, Kenntner-Mabiala, Pauli and Wiederhold (2007) conducted an interesting study exploring the effect of different virtual worlds in pain reduction. They induced pain with cold and warm stimuli and compared the reduction achieved by warm and cold virtual environments.

They also included a control condition in which the participants wore a HMD but they just saw a static picture. They found that VR was superior to the control condition, demonstrating that the distracting value of the VR environments was not achieved only by excluding perception of the real world. They also found that VR analgesia achieved by both virtual environments was similar, that is, the content of the VR environment was not important for reducing pain induced by cold or hot stimuli.

There is an important work in VR distraction literature conducted by Hoffman, Richards, Coda, Bills, Blough, Richards, and Sharar (2004). The study examines brain activity related to VR analgesia. Some of the clinical studies previously mentioned (Gershon et al., 2004; Wiederhold & Rizzo, 2006) found a reduction in physiological measures like pulse rate related to VR analgesia. Hoffman et al. induced pain by thermal stimulation to eight healthy participants and studied brain activity (fMRI) while the participants went through VR distraction vs. no distraction. As in other studies, pain ratings were significantly lower in the VR condition. Also, VR significantly reduced pain-related activity in five brain regions: insula, thalamus, anterior cingulated cortex, and primary and secondary somatosensory cortex.

This is the first study showing the analgesia-related brain activity of VR analgesia. In a recent work Hoffman et al. (2007) explored the efficacy of VR analgesia both alone and combined with opioids using self-report and fMRI. Nine healthy volunteers were randomly assigned to four conditions: control, opioids alone, VR alone, and VR plus opioids. The results indicated that both VR and opioids alone were effective in reducing pain perception and pain-related brain activity. However, the combination of VR and opioids produced the highest reduction in pain ratings. These results, though preliminary, support the idea of the potential of combining pharmacologic and nonpharmacologic procedures for acute pain control. The neurobiology of virtual pain analgesia has been discussed in a recent paper (Gold, Belmont & Thomas, 2007). These authors link the neurobiology of pain to VR pain control and suggest some areas of research to study the mechanisms of VR analgesia like exploring the role of endogenous opiodergic signaling during VR analgesia using an opioid receptor antagonist like naloxone. They also recommend studying different issues to enhance VR analgesia, like customizing the VR environments to match patient characteristics or exploring the role of interaction in the efficacy of VR for pain reduction.

We mentioned a case report using VR hypnosis. Patterson, Hoffman, Garcia-Palacios and Jensen (2006) conducted a study with 103 healthy volunteers to explore the efficacy of VR and hypnosis in acute pain control. Participants were assigned to posthypnotic suggestions vs. no posthypnotic suggestion, then pain was induced using thermal pain stimulation, and then they underwent VR distraction vs. non VR distraction. Results indicated that posthypnotic analge-

sia was mediated by hypnotizability whereas VR distraction was not. The analgesia achieved by hypnosis was specific for highly hypnotizable individuals while VR analgesia was effective independent of hypnotizability. For those with high hypnotizability, the combination of hypnosis and VR was the most effective condition. This study offers support for the possibility of combining different pain control procedures to enhance analgesia.

Conclusions and future directions

All of the studies reviewed in the former section show that VR distraction is a promising technique for acute pain control related to medical procedures. The findings indicated that perception of pain decreases significantly with VR as well as other variables related to pain like unpleasantness, discomfort, distress, or anxiety. It seems that VR distraction can be used in a large number of medical procedures like wound care, physical therapy, chemotherapy, dental procedures, etc. It is important to notice that in the clinical studies, reviewed side effects were not a problem. Most of the studies measured cybersickness and did not report high levels of nausea or other cybersickness symptoms. Also, VR procedures were well-accepted by both the patients and the medical staff.
The studies exploring VR analgesia and brain activity offer preliminary data of reduction in pain-related brain activity. In psychology we have a wide and lasting history of developing and validating subjective measures which are a way to measure treatment efficacy. However, VR analgesia is used mainly in medical settings for pain related to medical procedures. In medicine, the effects of treatments are measured with objective measures. It is important to conduct studies using both subjective and also objective measures for VR analgesia. This will strengthen the efficacy data and the acceptance of this technique by the medical community.

It is important to note the limitations of the research reviewed. Most of the studies conducted so far offer methodological limitations that suggest caution when drawing conclusions. It is necessary to conduct controlled studies with larger clinical samples to strengthen VR pain control research. The results to date are promising and come from different research teams. We have results from subjective and objective measures that show that VR is able to produce analgesia.

Future research should study mechanisms underlying the efficacy of VR. Attention seems to be the cognitive process involved in the efficacy of VR distraction. Experimental research in the role of attention in VR analgesia is needed. Other psychological aspects like individual differences in personality traits or the role of emotions like anxiety in the experience of pain could shed light on the understanding of VR analgesia and the development of VR environments. There are no indications about the features that a virtual environment needs to have to produce analgesia. There are already VR worlds that are demonstrating their efficacy. Studying the features of the VR worlds that already exist and doing research to explore the specific elements that produce analgesia would be helpful to the researchers in this area. Finally, there is an emerging line of research in VR pain control related to using this technology in the treatment of chronic pain. The literature in this field recommends a multidisciplinary and multidimensional approach in the treatment of chronic pain conditions (i.e. Morley, Eccleston & Williams, 1999). VR can help to enhance the efficacy of techniques used in multicomponent programs for chronic pain like relaxation, mindfulness, distraction or cognitive reappraisal. There are some studies supporting the idea that VR can be a useful tool in the management of chronic pain conditions like fibromyalgia (Garcia-Palacios et al., 2006; Wiederhold & Wiederhold, 2007). However, these studies have so far reported only very preliminary data.

VR is a technology with enormous potential in many areas related to mental and physical health. In recent years VR has appeared as a promising distraction technique for acute pain that is producing a growing library of scientific liter-

ature and is contributing to the alleviation of pain in many people who are suffering. In the near future we predict that the VR community will work to develop and test VR procedures for chronic pain, a complex area that constitutes an important and growing health problem which needs better treatments. The birth of *Journal of CyberTherapy & Rehabilitation* will constitute an important source of support for the stimulation and dissemination of this research.

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