Virtual Reality and Interactive Simulation for Pain Distraction

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ABSTRACT

Pain and discomfort are perceptible during many medical procedures. In the past, drugs have been the conventional means to alleviate pain, but in many instances, medications by themselves do not provide optimal results. 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 virtual reality environments and the playing of video games, are being employed to treat pain. In virtual reality 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 virtual environment, 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, leaving little attention left to focus on other things, such as pain. In this way virtual reality 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.

Key Words. Virtual Reality Distraction Intervention; Immersion; Distraction; Visual Analog Scale

Background

Virtual reality (VR) utilizes computer software to display virtual environments. A head-mounted display (HMD) is used to show the image to the user. Head tracking is in effect so that the user can actively view the environment in 360 degrees. Therefore, the images that the user sees can be linked to the user’s head position. Another way VR is reactive is through the manipulation of the environment, usually through a mouse or keyboard. These advanced systems allow users to interact on many levels with the virtual environment, exploiting many of their senses, and encouraging them to become immersed in the world they are experiencing.

Immersion is one of the concepts that allow VR environments to distract patients undergoing various medical procedures in ways that are not possible with other techniques. Immersion relates to how “present” the user feels in the world and how “real” the environment seems. When immersion is high, much of the user’s attention is focused on the virtual environment, leaving little left to focus on other things, such as pain.

Virtual reality (VR) has been effective in reducing reported pain and distress in patients undergoing burn wound care, chemotherapy, dental procedures, venipuncture, and many other painful procedures by drawing attention away from the patients’ mental processing, and thereby decreasing the amount of pain consciously experienced by the patient. Additionally, VR for neurorehabilitation and physical rehabilitation has proven successful, as has VR for other areas, such as prosthetics and orthotics training.

Using VR in clinical practice can have disadvantages such as cost, limited availability, and cybersickness (motion sickness caused by the head tracking technology). With recent advances in technology, however, VR systems are becoming more readily available and less expensive. In addition, improvements in head tracking technology are yielding faster processors, which alleviates the
symptoms of motion sickness that occurred in the past.

**Review of Clinical Studies**

Clinical applications of VR and other technologies, and experimental research on the application of these technologies, have demonstrated an array of success in significantly altering the way we view current methods of treatment for pain and anxiety. Technology has opened up exciting new possibilities in areas of nonpharmacological adjunct pain relief.

In 1984, Seyrek et al. investigated three types of distraction with patients obtaining amalgam restorations in dentistry [1]. The distraction conditions included the following: an audio-comedy program, a video-comedy program, and a video game. Distraction was successfully induced in patients who viewed the video comedy and played the video game during the dental procedure. This finding suggests that an increase in physiologic arousal goes together with effective distraction. These data diverge with earlier reports utilizing relaxation that produced a decrease in physiologic arousal during such dental procedures. In another study on dental treatment, Sullivan et al. discovered that although VR had no significant effect on children’s behavior or anxiety during the dental treatment, VR did considerably lower their pulse rates [2]. Of the 26 children, aged 5–7 years, half experienced VR during their first restorative visit but not the second, while the other half experienced VR during the second restorative visit but not the first. Before and immediately after the restorative visits, the children were instructed to sketch a human figure. To measure anxiety, the Kopppitz method of evaluating drawings was used. To evaluate behavior, the Frankl behavior rating scale was used. Differences (ANOVA) in anxiety ($P = 0.65$) and behavior ($P = 0.50$) were not significant. The overall pulse rate was considerably lower (ANOVA $P \leq 0.001$) when the child was viewing VR while wearing VR glasses.

Oyama et al. demonstrated that the virtual forest system had a considerable effect in the mental support of cancer patients [3]. Twenty-two female cancer patients, aged 33–75 years, were immersed in the virtual forest walk system to investigate the efficacy of VR technology in the psycho-oncological care of patients’ mental health. The patients’ emotional baseline was measured before the VR experience by administering the Hospital Anxiety and Depression Scale. Additionally, the patient’s score on the fatigue scale were evaluated before and after the VR experience. Out of the 22 patients, 4 were very satisfied, 5 were slightly satisfied, 10 were satisfied a little, and 3 were slightly dissatisfied. No patients were very dissatisfied. In regards to fatigue, 16 were not fatigued, 4 were a little fatigued, 1 was fairly fatigued, and 1 did not answer. Seventeen patients wanted a repeat trial while four did not. Schneider and Workman, in 1999, investigated whether VR as a distraction intervention was effective in minimizing chemotherapy-related symptom distress in children (aged 10–17) with cancer in a convenience sample of 11 children receiving outpatient chemotherapy [4]. Patients wore a Virtual IO headset (a lightweight display) during an intravenous chemotherapy treatment while playing one of the following three CD ROM-based scenarios: Magic Carpet, Sherlock Holmes Mystery, and Seventh Guest. To measure symptom distress, the Symptom Distress Scale and the State-Trait Anxiety Inventory for Children-1 were used. Statistical analysis showed that VR intervention was somewhat effective at decreasing the level of symptom distress immediately after the chemotherapy treatment ($P < 0.10$), but it did not have a lasting effect. The high levels of anxiety during the initial chemotherapy treatment showed a decrease during successive treatments.

The analgesic potential of VR as a distraction intervention for patients with cancer was further examined by Sander et al. [5], who showed that VR glasses are a practical, age-appropriate, non-pharmacological addition to standard care in handling the pain associated with lumbar punctures in adolescents. Thirty adolescents with cancer were randomly assigned to either the standard group, which received standard intervention during the lumbar puncture, or the experimental group, which also watched a video while wearing VR glasses. Although there were no statistical differences among the visual analog scale (VAS) pain scores between the two groups ($P = 0.77$), the VR group’s VAS scores tended to be lower (median VAS of 7.0, range 0–48) than the control group’s (median VAS of 9.0, range 0–59). Of the subjects in the experimental group, 77% reported that the VR glasses helped to distract them from the lumbar puncture. Several studies have identified distraction as a coping mechanism used by children with cancer [6]. In Gershon et al.’s study, a VR distraction intervention, a non-VR distraction, or the treatment as usual without any added distraction was randomly assigned to children with can-
cancer, aged 7–19 years [7]. In comparison with the no-distraction condition, diminutions in pain and anxiety were witnessed for children who used the VR distraction. This was evidenced by reports of pain by the nurses, as well as lower pulse rates. Relying on pulse rate, there were no major differences found for the non-VR condition when compared with the no-distraction condition. Implications of these findings are that VR may prove to be a helpful tool for distraction during painful medical procedures; however, additional studies are required to assess potential effectiveness and practicability during other, more distressing medical procedures with larger sample sizes.

Schneider et al. randomly assigned 20 women to receive the VR distraction intervention during a chemotherapy treatment and no-distraction intervention (control) during another chemotherapy treatment [8]. When women used the VR intervention, considerable reductions in symptom distress and fatigue were observed immediately following chemotherapy treatments. The study also suggested that the distraction intervention was well received, reduced symptom distress, and was easy to execute in a clinical setting. The implications for nursing are that VR distraction intervention may control chemotherapy-related symptom distress, boost a patient’s ability to remain on schedule for treatment regimens, and improve a patient’s quality of life. Each of these factors may play a role in increasing the chances for personal survival by decreasing treatment-related symptom distress.

Schneider focused on outpatients receiving chemotherapy to explore whether VR could relieve symptom distress as a distraction intervention [9]. After 48 hours, the posttreatment effect of VR on symptom distress was observed. A crossover design, where 123 participants wore HMDs, was employed to explore whether VR was effective in decreasing chemotherapy-related symptom distress and whether the effects last for a time period of 2 days. In order to measure symptom distress, the Revised Piper Fatigue Scale, the State Anxiety Inventory, and the Adapted Symptom Distress Scale-2 were used. Patients reported they experienced no cybersickness and that the VR was easy to use. A total of 86% of the subjects enjoyed the VR intervention, and 82% would use the VR again. In validation of the distraction capacity of VR, patients conveyed that they experienced an altered perception of time ($P < 0.001$). On the other hand, evaluation of the intervention showed no significant difference in symptom distress 1 or 2 days after the chemotherapy. These findings support the idea that VR can help make chemotherapy treatments more tolerable, but using VR does not improve chemotherapy-related symptoms. Cole et al. concluded from their findings that significant increases in cancer-related self-efficacy and knowledge could be produced through the use of an appealing interactive video game platform [10]. HopeLab created a PC-based game, titled Re-Mission, which consisted of 20 missions within fictional cancer patients’ lives who were undergoing radiation, chemotherapy, and immunotherapy. In this study, 375 cancer patients were randomly assigned to either receive a PC with a popular video game or the same control video game in addition to Re-Mission. In the Re-Mission group, patients’ cancer-related knowledge ($P = 0.04$), ability to manage side effects ($P = 0.04$), self-efficacy to communicate about the cancer ($P = 0.02$), and constipation ($P = 0.007$) increased. On the self-efficacy scale, the overall composite score also increased considerably over time for the Re-Mission group ($P = 0.02$).

Several studies focusing on burn pain, such as Hoffman et al.’s study, have led mental health care to new frontiers as well [11]. Hoffman et al. found that immersive VR decreased the amount of pain reported, in addition to the amount of time burn patients spent thinking about the pain during physical therapy. Each of the 12 patients spent 3 minutes of physical therapy without any distraction, followed by 3 minutes within a virtual world (SpiderWorld). All patients recounted a significant reduction in the magnitude of pain when distracted with VR (60–14 mm on a 100-mm scale), as well as a drop in the amount of time spent thinking about the pain. The data provide preliminary support that VR can act as a strong nonpharmacologic pain reduction method for adult burn patients. Another research study by Wiederhold indicated that VR could effectively reduce levels of pain in participants suffering from a variety of painful stimuli [12]. Six participants were placed inside Icy Cool World, and were first asked to focus on their pain with their eyes closed in order to investigate the efficacy of VR at reducing anxiety and distracting patients from pain. They were then asked to rate their pain during this focus period. Participants were then instructed to open their eyes and begin exploring Icy Cool World. While they navigated the virtual world, their physiological responses were being measured by electrocardiogram sensors. All six participants reported a drop in pain while in the VR environ-
ment, and the magnitude of pain reduction from the VR compared with the pain focus condition was large (75.8%) and significant. All of the participants gave lower pain ratings while engaged in Icy Cool World. Four of the six participants reported a pain rating of 0 for the Icy Cool World condition. A nonparametric Wilcoxon signed rank test indicated that the mean pain rating during the Icy Cool World condition was significantly lower than the session with no distraction (N = 6; P = 0.03). In a separate pilot study, Das et al. investigated seven children with acute burn injuries and found strong support for the use of VR-based games in providing analgesia for children’s acute pain with minimal side effects, reusability, and versatility, as well as little impact on the physical hospital environment [13]. With the use of the Faces Scale, the average pain score for pharmacological analgesia paired with VR was 1.3 (SD 1.8), while the average pain score for pharmacological analgesia by itself was 4.1 (SD 2.9).

The effectiveness of VR as a pain distracter was also examined for patients undergoing venipunctures and wound dressings. Lange et al. investigated whether VR was more effective at decreasing pain and distress in children undergoing minor procedures vs watching an animated movie in 88 subjects requiring venipunctures or wound care procedures [14]. Although there were no significant differences observed between interventions for parent and staff perception or children’s self-reported pain and anxiety, parents perceived that their children had considerably higher anxiety when using VR in contrast to the animated movie (P = 0.02). In actuality, children using VR exhibited significantly lower behavioral distress (P < 0.001). Additionally, children using VR had considerably higher scores of interest/involvement and enjoyment than those watching the movie (P < 0.001). Both parents and staff perceived VR as more effective in distracting (P < 0.001). These findings indicate that VR is at least as effective, and more pleasant, than watching an animated movie.

Tse et al.’s research findings suggest that visual stimuli generated by the eyeglass display are a helpful nonpharmacological adjunct for pain relief in elderly patients receiving wound dressings for leg ulcers [15]. In this study, the analgesic potential of visual stimulation was evaluated in 33 patients with leg ulcers. While receiving wound dressings, the patients alternated between viewing a static blank screen (B-sessions) and wearing an eyeglass display with soundless VCD broadcasts (V-sessions). A considerable decrease in pain scores was observed during the V-sessions (VAS 67.7 ± 28.4 vs 25.6 ± 29.8 when V-sessions vs B-sessions, with P < 0.01). In another study, Reger examined the effectiveness of VR as a pain distracter for 57 children (aged 8–12 years) undergoing a venipuncture [16]. Blood was drawn in one of four conditions: without distraction, cartoon viewing, a VR scenario, and the same VR scenario presented in an HMD. The group that experienced VR through an HMD reported considerably reduced affective pain as compared with children in the other three groups.

By using VR distraction to enhance a patient’s illusion of entering the virtual world, the amount of excessive pain experienced during medical procedures can be reduced. In Hoffman et al.’s study, each subject (aged 18–20 years) received a brief baseline thermal pain stimulus, and the same stimulus again minutes later with either a low-tech or a high-tech VR distraction [17]. Each subject responded with subjective 0–10 ratings of cognitive, sensory, and affective components of pain, as well as a rating of their illusion of entering the virtual world. Subjects in the high-tech VR group reported more pain reduction (reduction of worst pain is 3.1 for high-tech VR vs 0.7 for low-tech VR, P < 0.001) and a stronger illusion of going into the virtual world (VR presence) than subjects in the low-tech VR group (4.2 vs 2.5, respectively, P = 0.009). The amount of pain reduction was positively correlated with VR presence levels reported by subjects (r = 0.48 for “worst pain,” P < 0.005) across the two groups. In another study, the efficacy of VR as a behavioral intervention designed to reduce distress during a port access procedure was studied in 20 pediatric oncology patients [18]. The 7- to 14-year-olds were randomly assigned to participate in either a no-VR control condition or an immersive VR environment. Distress experienced by the children was evaluated both through subjective self-rating and by objective physiological and behavioral ratings. On all measures, VR was effective in decreasing children’s distress.

Hoffman et al. also investigated the neural correlates of VR analgesia [19]. Participants’ pain-related brain activity was measured using functional magnetic resonance imaging (fMRI) during conditions of VR and no VR. VR considerably decreased pain-related brain activity in all five regions of interest, including the anterior cingulate cortex, primary and secondary somatosensory cortex, insula, and thalamus (P < 0.002). This
study shows a direct modulation of brain pain responses by VR distraction. In 2005, Tse et al. conducted a study in which 15 elderly persons were shown affective images and pictures while performing their physiotherapy exercise [20]. A VAS was used to measure pain scores, and the Medical Outcomes Study Short Form 36 (SF-36) was used to measure health-related quality of life. A significant reduction in the VAS was observed from week 1 to week 6 ($t = 3.607; \text{df} = 14; P < 0.05$). Although not statistically relevant, the SF-36 scores during week 6 indicated an increase in health-related quality of life. These data imply that affective images and pictures could be a useful nonpharmacological intervention for pain management of elderly persons.

Our research team recently developed a VR pain distraction system to be used in the dental office [21]. In this study, 10 patients were seen at the Scripps Center for Dental Care in La Jolla. Patients had a variety of dental procedures, including replacement of crowns, fillings, root canals, and cosmetic dental work. During the dental procedures, patients wore the VR head mount and observed a variety of software environments. While the patients were in the virtual environments, noninvasive sensors measured physiological signals including electrocardiogram, skin temperature, skin conductance, and respiratory rate. The length of immersion varied from 20 to 60 minutes. Overall, dental patients reported a reduction in the level of discomfort and pain while exploring the interactive virtual worlds. Another important finding was that perceptions of length of time were altered while in VR. Seven out of 10 patients estimated their time in the virtual environment while undergoing the procedure to be significantly less than the actual time spent under procedure. For example, one patient who had a dental procedure lasting 60 minutes reported a perception of length of time of 20 minutes. Overall, there were no significant reports of cybersickness (motion sickness) or discomfort while wearing the VR system. Cybersickness is commonly experienced among users of VR simulations. In general, over 80% of individuals exposed to VR simulations lasting 20 minutes report increases in sickness symptoms [22]. However, in this particular program, all patients enjoyed interacting with the virtual environments, describing the scenes as both “relaxing” and “pleasant.”

When patients were fully immersed in VR, their skin temperature tended to increase from baseline. In contrast, it is noted that during drill-ing, there was a mild decrease in skin temperature. Most patients were easily able to navigate the virtual environment after a short (less than 2-minute VR orientation and education session) period.

Overall, the dental staff reported a positive experience when using the VR equipment. The HMD did not cause significant issues with access to the mouth for the placement of barriers and other dental equipment. It was necessary, however, to develop a system of disposable cover material for the head mount because there was exposure to bio-spray. The use of the VR system did not cause a significant addition of time spent during the entire dental procedure. This suggests that the use of the VR system would not negatively impact a busy clinical practice.

As is evidenced through a number of studies, and referenced in Table 1, VR can be used to distract patients from pain and anxiety during painful or unpleasant medical procedures. Continuing education and research are now necessary to begin to dissect and analyze the specific brain mechanisms underlying pain distraction with VR.

**Conclusions and Future Directions**

We have presented an overview of research involving the use of VR and other types of interactive simulation tools that demonstrate a capability for reduction in painful or other unpleasant symptoms during medical procedures. There seems to be a correlation between level of interactivity and immersion in the virtual environments and success in relieving distressing symptomatology. In particular, preliminary evidence suggests changes in brain fMRI patterns that seem to correlate with effectiveness of pain relief during VR interactions. Clearly, management and successful intervention for serious pain requires a multidisciplinary team of clinical experts. Successful distraction by using these interactive tools has been shown to be well accepted and often preferred by many patients.

The compilation of heterogeneous results from the studies discussed above is preliminary, and therefore, conclusions regarding the clinical application of this new technology may change in the future. Further elucidation of the mechanisms underlying pain relief should be explored, so that improvements and/or specific creation of environments linked to specific types of pain and disease conditions can be developed. In the future, more studies are needed to examine the efficacy of VR
and other technologies for the relief of other types of pain (e.g., chronic noncancer pain), and to explore the feasibility of porting this technology to a handheld platform. With VR pain distraction software on a cell phone, for example, patients would have access to nonpharmacological pain relief on an “anytime, anywhere” basis. Continued research should involve clinical trials in various hospital settings, taking into account subjective as well as objective measures, so that protocols to be used with specific medical problems can be established.

Table 1  Virtual reality (VR) and pain distraction

<table>
<thead>
<tr>
<th>Year</th>
<th>First Author</th>
<th>No. of Participants</th>
<th>Procedure</th>
<th>Treatment</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>Seyrek [1]</td>
<td>80</td>
<td>Dental procedures</td>
<td>Video game vs comedy, Video vs comedy audio</td>
<td>Video game and comedy video equally distracting</td>
</tr>
<tr>
<td>1999</td>
<td>Oyama [3]</td>
<td>22</td>
<td>Oncology care</td>
<td>One VR session, virtual forest walk</td>
<td>Better mood, less fatigue post VR, forest had significant effect on mental support</td>
</tr>
<tr>
<td>1999</td>
<td>Schneider [4]</td>
<td>22</td>
<td>Chemotherapy</td>
<td>VR during three treatments</td>
<td>Less symptom distress after treatment ($P &lt; 0.10$)</td>
</tr>
<tr>
<td>2000</td>
<td>Sullivan [2]</td>
<td>26</td>
<td>Dental procedures</td>
<td>VR exposure</td>
<td>VR reduced pulse but had no significant effect on behavior or anxiety</td>
</tr>
<tr>
<td>2002</td>
<td>Sander [5]</td>
<td>30</td>
<td>Lumbar puncture</td>
<td>VR glasses/video and standard care vs only standard care</td>
<td>VR helped distract 77% of experimental group</td>
</tr>
<tr>
<td>2003</td>
<td>Reger [16]</td>
<td>57</td>
<td>Venipuncture</td>
<td>Head-mounted display (HMD) VR vs flat-screen VR vs cartoon viewing vs no distraction</td>
<td>Significantly lower affective pain with HMD Reduction in pain for eyeglass display</td>
</tr>
<tr>
<td>2003</td>
<td>Tse [15]</td>
<td>33</td>
<td>Wound dressing</td>
<td>Eyeglass display with soundless video broadcast vs static blank screen</td>
<td>Reduced pain, anxiety, pulse rate</td>
</tr>
<tr>
<td>2004</td>
<td>Gershon [7]</td>
<td>59</td>
<td>Port access (venipuncture)</td>
<td>VR vs non-VR distraction vs no distraction</td>
<td>Significantly reduced pain-related brain activity in anterior cingulate cortex, primary &amp; secondary somatosensory cortex, insula, and thalamus ($P &lt; 0.002$, corrected)</td>
</tr>
<tr>
<td>2004</td>
<td>Hoffman [19]</td>
<td>8</td>
<td>Painful thermal stimuli</td>
<td>Within-subjects design, snow world vs no VR</td>
<td>VR presence significantly, positively correlated with pain reduction</td>
</tr>
<tr>
<td>2004</td>
<td>Hoffman [17]</td>
<td>39</td>
<td>Painful thermal stimuli</td>
<td>VR helmet/headphones/head tracking vs see-through VR glasses</td>
<td>Distraction decreased symptom distress Significant ($P = 0.028$) pain reduction (75%), higher skin temperature</td>
</tr>
<tr>
<td>2004</td>
<td>Schneider [8]</td>
<td>20</td>
<td>Chemotherapy</td>
<td>VR distraction during sessions</td>
<td>Pain score without VR: 4.1; with VR: 1.3</td>
</tr>
<tr>
<td>2004</td>
<td>Wiederhold [12]</td>
<td>6</td>
<td>Chronic pain</td>
<td>South Pole fantasy VR HMD</td>
<td>Pain score without VR: 4.1; with VR: 1.3</td>
</tr>
<tr>
<td>2005</td>
<td>Das [13]</td>
<td>7</td>
<td>Dressing changes</td>
<td>11 trials, within-subjects design, VR and pharmaceutical analgesics vs analgesics only</td>
<td>Altered perception of time ($P &lt; 0.001$), indicating immersion; more than 80% would use VR again</td>
</tr>
<tr>
<td>2005</td>
<td>Schneider [9]</td>
<td>92</td>
<td>Chemotherapy</td>
<td>VR vs no VR</td>
<td>Significantly decreased pain score, NS increase in quality of life</td>
</tr>
<tr>
<td>2005</td>
<td>Tse [20]</td>
<td>15</td>
<td>Physiotherapy</td>
<td>Affective pictures during sessions</td>
<td>Behavioral and physiological measures showed that children using VR experienced significantly less pain and anxiety</td>
</tr>
<tr>
<td>2005</td>
<td>Wolitzky [18]</td>
<td>20</td>
<td>Port access procedure</td>
<td>Gorilla habitat VR HMD vs no VR</td>
<td>Significant ($P &lt; 0.001$) pain reduction (75%), higher skin temperature</td>
</tr>
<tr>
<td>2006</td>
<td>Lange [14]</td>
<td>44</td>
<td>Venipuncture or wound care</td>
<td>Block randomization, VR vs movie</td>
<td>Significant ($P &lt; 0.001$) pain reduction (75%), perceived by parents/staff as more effective ($P &lt; 0.0001$)</td>
</tr>
<tr>
<td>2006</td>
<td>Wiederhold [21]</td>
<td>8</td>
<td>Dental procedures</td>
<td>VR vs no VR</td>
<td>VR was an effective distraction to the dental procedure; effective pain management mechanism; perceived by parents/staff as more effective</td>
</tr>
</tbody>
</table>

NS = nonsignificant; PT = physical therapy; RCT = randomized controlled trial.
References

12 Wiederhold BK. Virtual reality applications for mental health assessment and rehabilitation. Paper presented at the IEEE Virtual Reality Conference, Alexandria Virginia, March 25–29, 2006. The project described was supported by Grant Number HHSN271200477443C/ADB N43DA-4-7744 from the National Institute on Drug Abuse (NIDA). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIDA.