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The Effectiveness of Virtual Reality Pain Control With Multiple Treatments of Longer Durations: A Case Study

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Immersive virtual reality (VR) has proved to be potentially valuable as a pain control technique for patients with severe burns undergoing wound care and physical therapy. Recent studies have shown that single, 3-min visits to a virtual world can dramatically reduce the amount of pain experienced during wound care, and the illusion of going inside the computer-generated world helps make VR analgesia unusually effective. This case study explored whether VR continues to reduce pain when the duration and frequency of VR treatments are increased to more practical levels. A patient with deep flash burns covering 42% of his body spent varying amounts of time performing physical therapy with and without virtual reality. Five subjective pain ratings

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for each treatment condition served as the dependent measures. The magnitude of pain reduction with VR, and the patient's illusion of "going into" the virtual world did not diminish with repeated administration and longer treatment durations. Practical implications are discussed. The results of this study may be examined in more detail at www.hitl.washington.edu/projects/burn/.

1. INTRODUCTION

Most of the time, patients with severe burns are resting in their hospital beds. Opioid analgesics (substances related to morphine) are usually effective for controlling such "resting" pain. In contrast, burn patients typically have their bandages changed daily to help prevent infection. The gauze and cotton padding are removed, the burn wound is cleaned with mild soap, dead skin is removed, a medicated ointment or cream is applied, and the wound is rebandaged. Although patients are typically given additional, strong, short-acting opioid pain medication prior to wound care, most patients nevertheless report severe to excruciating pain during such procedures (Perry, Heidrich, & Ramos, 1981). In other words, opioid pharmacologies alone are often inadequate for controlling procedural pain.

Part of the problem is that opioid analgesics have side effects such as nausea, constipation, delirium, reduced respiration, and—in high doses—unconsciousness and sometimes respiratory failure. Founded or not (Melzack, 1990), there are also concerns that burn patients will become addicted to such medications. Also, if the patient is given a high dose of opioids for one wound care session, he or she may be lethargic or very sleepy afterward, interfering with nutritional intake, exercise, and visits with family and friends. For patients with severe burns, pain management requires a long-term strategy.

In addition to daily bandage changes, burn patients undergo daily physical therapy for a number of reasons, including the need to counteract a strong tendency of healing skin to shrink and contract. Aggressive physical therapy for several weeks or months during recovery from a severe burn injury promotes limb mobility and reduces the need for surgical release of contractures. Unfortunately, the pain experienced during physical therapy stretching exercises can be extreme and can discourage patients from complying with their physical therapy (Ehde, Patterson, & Fordyce, 1998).

It is well known that psychological factors play a role in the experience and treatment of pain (Patterson, 1992, 1995; Patterson, Everett, Burns, & Marvin, 1992; Patterson, Ptacek, Carrougher, & Sharar, 1997) and this can be explained within the context of a gate control mechanism. Specifically, an incoming pain signal of a given neurological intensity can be interpreted as more painful or less painful, depending on what the patient is thinking or attending to at the time. Previous experience, expectations, culture, focus of attention, and anxiety are psychological factors that can contribute strongly to the subjective experience of pain (Melzack, 1998; Melzack & Wall, 1965). Such psychological influences are thought to modulate, inhibit, or modify the nociceptive signals at the spinal cord, which serves as a gate to limit or control the intensity of pain signals ever reaching the brain. Psychological treatments are particularly important for physical therapy, because the use of potent opioid analgesics is typically de-emphasized during the late inpatient stage of recovery when physical therapy is most aggressive. In addition to reducing suffering, improved pain management during physical therapy could have important practical implications, because the amount of pain reported during hospitalization has been associated with postdischarge physical and psychologic recovery (Ptacek, Patterson, Montgomery, & Heimbach, 1995).

Distraction with music and videos is one psychological technique that has proved effective for reducing pain (e.g., Miller, Hickman, & Lemasters, 1992; see McCaul & Malott, 1984, for a review and Tan, 1982, for a meta-analysis). This study explored the use of immersive virtual reality (VR) as a new medium of distraction that could be used in addition to traditional pharmacologies. The rationale for using VR or any type of distraction is as follows. Processing pain signals requires conscious attention. An individual has only a finite amount of attention available at any given time and VR competes with pain for this limited cognitive resource. Conscious attention is like a spotlight. Usually it is focused on the pain and wound care. VR presumably lures that spotlight into the virtual world (Hoffman, Prothero, Wells, & Groen, 1998). In addition, if VR analgesia is effective, burn patients undergoing severely painful wound care or physical therapy are likely highly motivated to mentally leave the hospital room and go to the less painful place.

Although case studies should be interpreted cautiously, Hoffman, Doctor, Patterson, Carrougher, and Furness (2000) measured pain levels of two pre-adult patients undergoing staple removal from skin grafts while being distracted by VR for 3 min and by Nintendo64 for 3 min (order counterbalanced) during a single wound care session. Patients showed much lower pain during VR than while playing the Nintendo64 video game. More recently, Hoffman, Patterson, and Carrougher (2000) found a similar pattern of results in a controlled within-subjects clinical study with 12 burn patients. Pain experienced by burn patients during physical therapy dropped when the patients went into VR compared to when patients received no distraction, and the difference was statistically significant. Interestingly, patients performing their physical therapy while in virtual reality also reported large reductions in the amount of time they spent thinking about their pain during the 3-min sessions.

These findings have recently been conceptually replicated in a laboratory analog ischemic pain study involving uninjured volunteers (Hoffman, Garcia-Palacios, Kapa, Beecher, & Patterson, 2002). In an initial attempt to identify the mechanism(s) by which VR analgesia is achieved, Hoffman, Garcia-Palacios, Kapa, et al. (2002) recently measured the pain ratings of 22 healthy, uninjured undergraduate students during a blood pressure cuff ischemia lasting 10 min or less (ischemia is a blockage of blood flow). Pain studies using the tourniquet technique are common, and consistently show a steady increase in pain over a 10-min ischemia (Hamalainen & Kemppainen, 1990; Lorenz & Bromm, 1997; Maixner & Humphrey, 1993; Segerdahl, Ekblom, & Sollevi, 1994). As predicted, Hoffman, Garcia-Palacios, Kapa, et al. (2002) found that pain ratings increased significantly every 2 min during the no distraction phase (0–8 min) and dropped dramatically during the last 2-min period when participants were in VR. All 22 participants reported a drop in pain in VR, and immersive VR analgesia was shown for the first time to also be effective with women. For example, women showed a mean pain rating in the control condition of 56 mm (no distraction during the 6–8 min of the ischemia) versus 23 mm in VR (during the 8–10 min segment of the ischemia). In the same study, on a separate task not involving pain, young adult students in VR showed a significant reduction in performance on an auditory task (monitoring a string of numbers from a tape recorder for three odd numbers in a row) compared to no VR (monitoring numbers while wearing a VR helmet that was turned off). VR distracted attention away from the student's primary task of monitoring the numbers. As predicted, students made significantly more errors in VR. The results of Hoffman, Garcia-Palacios, Kapa, et al. (2002) implicate the contribution of an attentional mechanism for VR analgesia.

Now that there is evidence that single-session VR pain reduction treatments can reduce pain for 3 min, it is important to find out if VR continues to be effective when used more than once, and for longer treatments. If not, then VR analgesia will likely have limited medical value in practice. However, if VR is effective time after time, with longer wound care procedures, it could become a new useful, safe, effective adjunctive pain control technique. This case study explores whether VR continues to reduce pain when the duration and frequency of VR treatments are increased to more practical levels.

2. METHOD

2.1. Participants

The participant was a 32-year-old man. He had deep flash burns on his face, neck, shoulder, chest, and legs sustained from ignited gasoline, covering 42% of his body surface area. Many of his burns required skin grafting. This study was conducted during the patient's hospitalization in a major regional burn center, after he had been moved from intensive care to the acute care burn unit. Although only treated with VR during 5 physical therapy sessions, he received approximately 30 wound care sessions and 60 physical therapy sessions during his 1-month stay at Harborview Medical Center.

2.2. Procedure

Standard pharmacologic analgesia was administered at the discretion of the burn center physicians and staff for treatment of pain and was not affected by participation in this study. The patient received long-acting opioids. The medication, oxycodone hydrochloride controlled-release (OxyContin), was used in dosages titrated to control background pain. He received 1.33 opioid equivalents per 24 hr for the first two sessions and 2.66 opioid equivalents per 24 hr for the third, fourth, and fifth sessions. Use of a within-subjects design (with order of condition counterbalanced) ensured that the level of pharmacological analgesia was the same in the VR and control condition. The patient performed range of motion stretching with his left shoulder under a physical therapist's direction. He had previously reported difficulty tolerating his pain during physical therapy. The study began on his arrival to the acute care burn unit after several weeks in the intensive care unit. The patient spent varying amounts of time (5 min on Day 1, 3 min on Day 2, 5 min on Day 3, 10 min on Day 4, and 15 min on Day 5) performing physical therapy in VR and an equal amount of time in the same session doing physical therapy with no VR. The order in which the treatments were administered was randomized and counterbalanced such that each treatment condition had an equal chance of occurring first or second on each day. Toward the end of each treatment, maximum range of motion of the relevant limb was measured. Pain, the primary dependent variable, was measured immediately after each experimental treatment during a brief pause in physical therapy. At each pause (once after physical therapy with VR, and once after physical therapy with no distraction), the patient completed five retrospective subjective pain ratings using 100-mm Visual Analog Scales (VAS; Gift, 1989; Huskisson, 1974). With respect to the physical therapy session just completed (e.g., "only the last 15 min of physical therapy, which you spent in VR"), the patient rated (a) how much time he spent thinking about his pain or burn wound or both (ranging from *0 min* to *the entire time*), (b) his worst pain (ranging from *no pain* to *worst pain*), (c) his average pain (ranging from *no pain* to *worst pain*), (d) how much his wound bothered him (ranging from *not at all bothersome* to *the most bothersome*), (e) how unpleasant physical therapy was (*not at all unpleasant* to *the most unpleasant*), and (f) his anxiety (*no anxiety* to *highest anxiety*). The pain experience has at least two components that are separately measurable and sometimes differentially influenced (Gracely, McGrath, & Dubner, 1978; Melzack & Wall, 1965): a sensory component (worst pain and average pain in this study) and an affective component (unpleasant and bothersome in this study). Time spent thinking about pain is a new measure of procedural burn pain recently introduced by Hoffman et al. (2000; see also Hoffman, Patterson, & Carrougher, 2000). After physical therapy, in the VR condition the patient was asked to complete the following additional ratings using visual analog scales: (a) To what extent (if at all) did you feel nausea as a result of experiencing VR (ranging from *none* to *very much*)? (b) While experiencing VR, to what extent did you feel like you went into the virtual world (ranging from *I did not feel like I went into the virtual world at all* to *I went completely into the virtual world*)? and (c) How real did the objects in the virtual world seem to you (ranging from *completely fake* to *indistinguishable from a real object*). Hendrix and Barfield (1995) described several studies showing the reliability of a similar subjective measure of presence.

2.3. Experimental Condition

A Silicon Graphics Octane MXE with Octane Channel Option[1] coupled with a Virtual Research V8 VR helmet[2] was used to create an immersive, 3-D, interactive, com-

[1]Silicon Graphics, Inc., 13810 S.E. Eastgate Way, Suite 300, Bellevue WA 98105; http://www.sgi.com/.

[2]Virtual Research Helmets, available at www.Imprintit.com.

puter-simulated environment. A Polhemus Fastrak™ motion sensing system with 6df sensors was used to measure the position of the user's head and hands. The patient experienced SpiderWorld,[3] a modified version of Division Ltd.'s DVS-3.1.2 KitchenWorld[4] complete with countertops, a window, and 3-D cabinets (see Figure 1). The patient could "pick up" virtual objects with his cyberhand. For example, there was a grab bag of more than 20 virtual objects on the counter, which the patient could pull out one by one and identify. Using tactile augmentation (Carlin, Hoffman, & Weghorst, 1997; Hoffman, 1998; Hoffman, Garcia-Palacios, Carlin, Furness, & Botella, 2002; Hoffman, Hollander, Schroder, Rousseau, & Furness, 1998), if willing, the patient could "physically" touch the furry body of a virtual Guyana bird-eating tarantula with wiggling legs, and could physically eat a virtual candy bar linked via a position sensor attached to the candy bar's real-world twin. The patient dropped a virtual spider out of a "spider bucket" with sound effects, and herded the animated spider into a sink, filled the sink with water, and turned on the virtual garbage disposal. The patient also explored a two-story virtual house during the 15-min physical therapy session on Day 5.

2.4. Control Condition

In the control condition, the patient was exercised as usual (no distraction) by the physical therapist.

FIGURE 1 (Left) Example of a burn patient (named Jackie) interacting with a mixed-reality spider during physical therapy for a burn wound (photo copyright Gretchen Carrougher, RN, Harborview. Used with permission). Right, image of what the patient sees in 3-D in the virtual world (image copyright Duff Hendrickson, University of Washington HITLab. Used with permission).

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[3]Created with Ari Hollander at www.imprintit.com, with an animated spider by Duff Hendrikson at www.hitl.washington.edu/people/duff/.

[4]Division Incorporated, 1400 Fashion Island Blvd, Suite 510, San Mateo, CA 94404; http://www.division.com/.

3. RESULTS

Alpha is initially set at .05. A Bonferroni correction factor (dividing alpha by the number of t tests) was used (.05/6 = .008). Therefore, for the following analyses (within-subjects, paired t tests), alpha is set at .008. According to 100-mm VAS subjective pain ratings from the patient, mean pain ratings were higher in the control condition (no VR $M = 66.12$) compared to when the patient was in VR (VR $M = 15.04$), and the difference was statistically significant, $t(4) = 16.90$, $p < .001$, $SE = 3.02$. This pattern of results was also found for each of the five pain ratings analyzed separately. (The raw data used for the following analyses are shown in Table 1.) Time spent thinking about pain (mean pain rating for No VR = 86.6 vs. 13.2 in VR), $t(4) = 14.81$, $p < .001$, $SE = 4.96$; pain unpleasantness (mean pain rating for No VR = 52.0 vs. 14.2 in VR), $t(4) = 5.85$, $p = .004$, $SE = 6.46$; pain bothersomeness (mean pain rating for No VR = 68.8 vs. 14.2 in VR), $t(4) = 9.53$, $p = .001$, $SE = 5.73$; worst pain (mean pain rating for No VR = 71.4 vs. 19.6 in VR), $t(4) = 6.30$, $p = .003$, $SE = 8.22$; and average pain (mean pain rating for No VR = 51.8 vs. 14.0 in VR), $t(4) = 7.04$, $p = .002$, $SE = 5.37$. As shown in Table 1, on each of the 5 days, the maximal range of shoulder motion achieved during VR was greater than or equal to the range achieved in the control condition. According to 100-mm VAS pain ratings (see Figure 2), mean pain ratings were significantly higher in the control condition (no distraction) than during VR for each of the five physical therapy treatments. Anxiety was nearly zero for each treatment condition on each day. As shown in Figure 3, mean nausea ratings in VR were nearly zero (e.g., 1 mm on a 100-mm scale) for each VR treatment. The patient's sense of presence in the virtual world and ratings of realism of the virtual objects was lowest for the first VR treatment, and then increased on subsequent VR treatments (see Figure 3).

4. DISCUSSION

Consistent with previous findings (Hoffman, Patterson, & Carrougher, 2000), in this case study, the patient's pain ratings during physical therapy showed considerable reduction while in VR relative to a conventional treatment (no distraction) con-

Table 1: Raw Pain Scores (in mm) for Each Pain Measure, and Maximum Range of Motion in Degrees on Each of the 5 Treatment Days

	Time Spent		*Unpleasant-ness*		*Bothersome*		*Worst Pain*		*Average Pain*		*Max ROM*	
Day	*No VR*	*VR*	*No VR*	*VR*	*No VR*	*VR*	*No VR*	*VR*	*No VR*	*VR*	*No VR*	*VR*
1	67	10	47	22	94	28	75	11	44	14	170	180
2	91	23	41	17	59	16	53	13	41	5	160	170
3	85	3	67	10	81	12	77	42	64	24	170	180
4	96	20	65	17	60	6	70	28	46	20	180	180
5	94	10	40	5	50	9	82	4	64	7	180	180

Note. ROM = range of motion; VR = virtual reality.

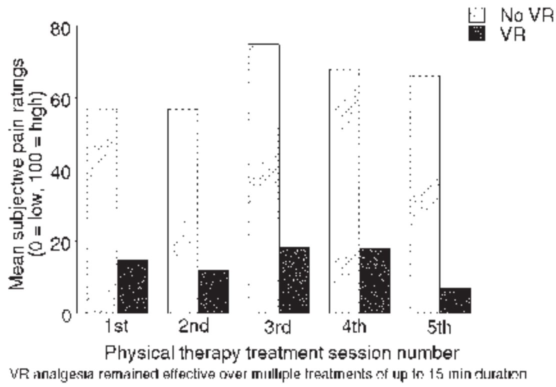

FIGURE 2 Pain ratings for VR and No VR therapy sessions.

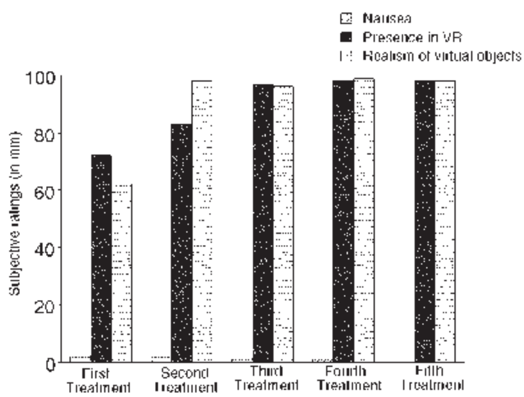

FIGURE 3 Subjective ratings of nausea, presence in VR, and realism of virtual objects over five physical therapy sessions.

trol condition. While in VR, the patient's pain scores decreased dramatically for sensory pain (ratings of worst pain and average pain), affective pain (ratings of unpleasantness and bothersomeness), and he showed a large reduction in the amount of time spent thinking about his pain during wound care. To date, the majority of people participating in these VR studies have been trying immersive VR for the first time. Although preliminary results of other studies have shown large reductions in pain for patients using VR, patients in those studies only received a single VR treatment lasting only 3 min. It could also be the case that VR is only effective the first or second time it is used, and becomes less effective after repeated use, as the novelty wears off. Or, it be may be found that VR can only keep the pain away for a few minutes before pain recaptures the spotlight of the patient's attention. If so, either of these possibilities would greatly diminish the potential medical value of VR for treating patients with severe burns, who often require dozens of painful physical therapy and wound care procedures, sometimes lasting longer than a half-hour, during the course of their recovery. This study extends previous findings by providing encouraging initial support for the notion that VR retains its analgesic properties with multiple treatments and for longer treatment durations. In this study, VR was used repeatedly (on five visits) with no decline in analgesic potency with treatment durations of up to 15 min.

4.1. Placebo Effects

Placebo effects can strongly influence pain perception in some patients. Beecher (as cited in Melzack, 1998) found that about 35% of the patients tested experienced relief from severe pain such as postsurgical pain the first time they received a placebo (i.e., sugar pills). Subsequent studies (described by Melzack, 1998) have found that patients receive less and less pain reduction each time sugar placebos are administered. Unlike placebo effects, in this study the effectiveness of VR analgesia did not diminish with repeated VR treatments. Similarly, in two other studies, the proportions of patients showing VR pain reduction was much higher than would be expected from a placebo effect. Hoffman, Patterson, and Carrougher (2000) found that over 75% of the participants showed VR analgesia, and all 22 of the participants in the study by Hoffman, Garcia-Palacios, Kapa, et al. (2002) showed a reduction in pain during VR compared to no VR.

4.2. Demand Characteristics

Although care was taken in this study to use a standardized treatment protocol, the physical therapist was aware of the treatment condition, and this knowledge could potentially have influenced the therapist to behave differently when the patient was in VR versus no VR. Encouraging in this regard is the finding that the maximum degree of range the patient could stretch his arm was measured to be the same in the VR and the no-distraction control conditions. This is consistent with the notion that the therapist treated the patient the same in the VR and control conditions (as instructed by the experimenters). Anecdotally, the therapist reported that events occurring in the virtual world caused the patient to tense up initially, but that he displayed equal or better range after adjusting to being in VR (consistent with the objective range-of- motion measures).

Although informative, case studies such as this study are by nature scientifically inconclusive (Campbell & Stanley, 1963). Additional empirical studies will be needed to see if the results showing VR analgesia during multiple treatments of longer durations replicate in controlled scientific studies (e.g., with more patients). Although more difficult to implement, future studies should use a double-blind experimental design. In a double-blind design, both the experimenter and participants or patients are kept unaware of what the “correct” answer is for any given condition. This reduces the possibility that demand characteristics influence the patient’s responses. Such studies will help determine whether VR can become a viable form of nonpharmacologic analgesia in everyday medical practice. Considering the difficulties in achieving adequate pain control during wound care procedures with conventional drug therapies, studies on adjunctive pain control techniques that can be used in addition to opioids are needed. The question of whether VR retains its analgesic potency over longer treatment and with repeated administrations is an extremely important issue, especially considering the large number of treatments (wound care and physical therapy sessions) burn patients typically undergo.

New virtual worlds, specifically designed to be attention grabbing (e.g., an immersive fighter jet mission) could be even more effective for pain reduction. For example, SnowWorld, shown in Figure 4, is a new virtual world created using military VR software donated from MultiGen-Paradigm.com. It was evaluated by the patient during a follow-up visit several weeks after his release. The patient flew through an icy 3-D canyon with a river and waterfalls, and shot snowballs at snowmen and igloos. The snowballs exploded with animations and 3-D sound effects on impact. Future VR worlds could help motivate patients to perform beneficial physical therapy exercises, using behavioral reinforcement and other techniques. For example, hands are often burned because people use their hands to put themselves out when they catch on fire. A virtual jet world could be programmed such that the patients run out of jet fuel unless they earn more fuel by performing their hand exercises. Or, the task or game in the virtual world could involve reaching up to grab various targets (and performing stretching exercises at the same time, perhaps without even realizing it). Distraction combined with behavioral reinforcement (cheers from the crowd when they have completed a set of hand stretches) could be used to help motivate the patients to perform their exercises.

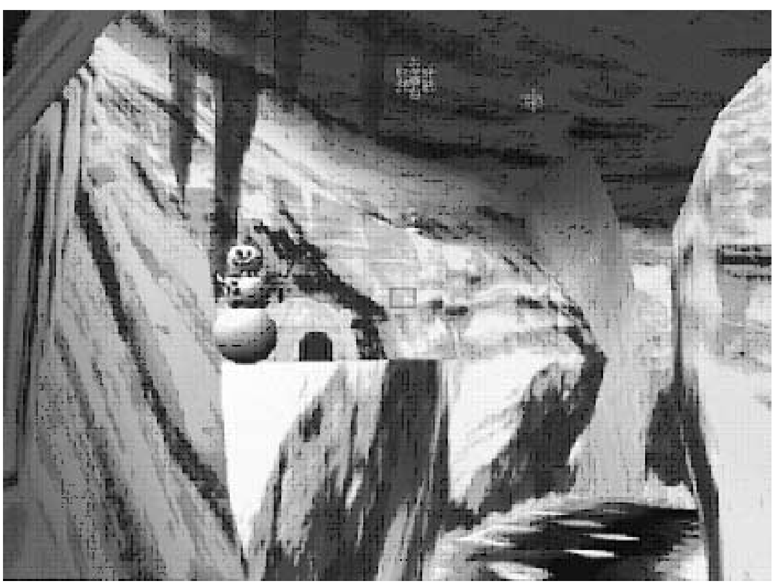

FIGURE 4 An image from SnowWorld.

The potential impact of this new VR pain control technique need not be limited to burn patients. Because burn injuries and their treatment are considered to be among the most painful injuries a person can endure, techniques that prove effective for treating burn pain will likely prove effective for other painful procedures (e.g., dental pain, pain from brief cancer procedures, medical procedures requiring the patient to remain conscious, or for which repeated sedation is undesirable). Additional research on VR analgesia is warranted.

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