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Effectiveness of Virtual Reality–Based Pain Control With Multiple Treatments

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Abstract:

Objective: The current study explored whether immersive virtual reality continues to reduce pain (via distraction) with repeated use.

Setting: The study was conducted in a burn care unit at a regional trauma center.

Patients: Seven patients aged 9–32 years (mean age of 21.9 years; average of 23.7% total body surface area burned [range, 3–60%]) performed range-of-motion exercises of their injured extremity under an occupational therapist's direction on at least 3 separate days each.

Intervention: For each physical therapy session, each patient spent equal amounts of time in virtual reality and in the control condition (no distraction). The mean duration of physical therapy in virtual reality was 3.5, 4.9, and 6.4 minutes for the first, second, and third session, respectively. Condition order was randomized and counterbalanced.

Outcome Measures: For each of the three physical therapy sessions, five visual analog pain scores for each treatment condition served as the dependent variables.

Results: Pain ratings were statistically lower when patients were in virtual reality, and the magnitude of pain reduction did not diminish with repeated use of virtual reality. The results of this study may be examined in more detail at www.vrpain.com.

Conclusions: Although the small sample size limits generalizability, results provide converging preliminary evidence that virtual reality can function as a strong nonpharmacological pain reduction technique for burn patients during physical therapy. Results suggest that virtual reality does not diminish in analgesic effectiveness with three (and possibly more) uses. Virtual reality may also have analgesic potential for other painful procedures or pain populations. Practical implications are discussed.

Key Words: Analgesia—Burn pain—Distraction—Virtual reality.

Successful participation in physical therapy after a severe burn injury is often crucial for minimizing long-term disability. Without physical therapy, the normal healing process in severely burned and grafted skin causes heterotopic scarring and severe contractures.[1] Aggressive physical therapy increases the flexibility and elasticity of healing skin and helps maintain normal range of motion and function.[1] Unfortunately, the pain experienced during therapeutic movement of burned, grafted, and healing extremities can discourage patients from performing their exercises.[2] Patients' nonadherence to such exercises can lead to additional surgery (e.g., more skin grafts) or permanent reduction in limb mobility.[1]

Opioid analgesics have long been considered the "gold standard" of pharmacological analgesics.[3] Although such drugs form the cornerstone for nearly any burn pain management plan,[4,5] side effects (e.g., nausea, vomiting, constipation, sedation, itchiness, urinary retention, cognitive

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impairment, hallucinations, delirium, respiratory depression, tolerance, and risk of physical and psychological dependence[6–8]) limit their use. These side effects can become especially problematic when opioid analgesics are administered over prolonged periods. An additional concern about opioid analgesics is that even though they represent the best approach to treatment of burn pain and are highly effective against background pain, their analgesic efficacy for extreme procedural pain is limited. Patients with severe burns routinely experience severe pain during wound care, despite aggressive pain control with potent opioid analgesics.[9–11] In one study of patients with severe burns, 84% of the patients given a typical dose of morphine still reported severe to excruciating pain during wound care.[9] Two thirds of the burn patients in that study rated their worst pain during wound care as "excruciating."[9]

As a result of the strong psychological component of pain perception, supplemental use of nonpharmacological analgesic techniques (e.g., mental imagery,[12] watching a video,[13] biofeedback,[14] enhanced control,[15] parental participation,[16] and hypnosis[17–19]) can be effective. Cognitive–behavioral strategies have been found to be useful for a wide variety of pain etiologies and to result in significantly reduced pain reports in 85% of 47 studies (meta-analysis[20]). *Distraction* is a cognitive–behavioral intervention particularly useful with burn pain.[5,13] *Immersive virtual reality* is an attention-engaging illusory reality created in the mind of the virtual reality (VR) user (the patient). Researchers argue that VR may be an unusually effective distraction.[21] Performing a VR task draws heavily upon conscious attention,[22,23] leaving less of this cognitive resource to devote to pain perception. With less attention available for evaluating nociceptive input, patients subjectively report less pain.[24] The convergence of multisensory input (sight, sound, and sometimes touch) in the virtual environment creates a sense of "presence" in the environment (i.e., the illusion of entering the computer-generated world).

In this respect, immersive VR differs from more simple forms of distraction (e.g., video movies and interactive video games) in that it increases the amount of the patient's attention drawn into the virtual environment.[25] A second mechanism by which VR may improve analgesia is through the reduction of visual cues associated with the painful procedure. Children often develop strong conditioned anxiety responses to visual cues associated with their wound care or rehabilitation procedure.[26] Anxiety-inducing sights and sounds of the hospital or clinic environment that probably exacerbate patients' pain are blocked out by the VR helmet patients wear during the procedure, thereby limiting the negative cues and aversive conditioning. Although the majority of patients fixate mostly on the wound care during conventional treatment, previous studies suggest that patients are able to shift their attention away from their pain with VR.[21,27]

Researchers measured the pain levels of two pre-adult patients undergoing staple removal from skin grafts who were distracted by VR for 3 minutes and by playing Nintendo 64 (Nintendo, Redmond, WA, U.S.A.) for 3 minutes (order counterbalanced) during a single wound-care session.[21] As predicted, patients' pain levels decreased more with VR than with the video game condition. More recently, researchers conducted a within-subject clinical study with 12 burn patients during physical therapy.[27] All patients reported experiencing less pain in VR than with no distraction during a single physical therapy session, and the magnitude of pain reduction from VR was statistically significant. Patients also reported large reductions in the amount of time they spent thinking about their pain during the 3-minute sessions (e.g., on a 100-mm scale, "time spent thinking about pain" during physical therapy declined from 60 mm with no VR to 14 mm with VR).

A patient with a burn of the average size necessitating hospitalization might require at least 1 week of inpatient care and numerous wound care and exercise sessions. For an extremely severe burn, physical therapy sessions may take place over a period of months and number in the hundreds. In all multiparticipant studies to date, each participant used VR only one time. If the analgesic effects of VR stem primarily from the novelty of this technological approach, pain control would likely become less effective with repeated use. VR pain control would be of limited value if it worked only the first time it was applied. A recent pilot case study of a single burn patient yielded encouraging findings: the amount of VR-associated pain reduction did not diminish with repeated treatments over a 1-week period.[28]

The current study further addresses this issue. Using a within-subjects design, we compared the efficacy of immersive VR with the efficacy of a no-distraction condition (conventional treatment) during at least three separate therapy sessions with multiple patients. We hypothesized that (1) VR would result in less pain and less time thinking about pain than would equivalent periods of physical therapy with a standard protocol (no distraction); and (2) the amount of pain reduction would not decrease with repeated use.

METHODS

Subjects

Seven patients with severe burn injuries participated (age range, 9–32 years [mean, 21.9 years]; mean of

23.7% total body-surface area burned [range, 3–60%]). Patients were all hospitalized at a major regional burn facility, and all reported previous trouble tolerating their pain during physical therapy. Specifically, before recruitment, all patients verbally rated their most severe pain during physical therapy as a score of 5 or higher on a visual analog scale of 0 to 10, where 0 = "no pain at all" and 10 = "worst pain."

Potential patients were recruited by a research nurse who was in contact with occupational therapists about potential enrollees. Six of the patients were male and one was female. Each patient participated in the study as many times as possible before he or she was released from the hospital or underwent surgery. Every patient informed of the study agreed to participate, and after each physical therapy session, each patient agreed to return for more VR treatment the following day. Each patient was treated on at least 3 separate days and used VR only during the physical therapy sessions (none had previous experience with VR). The information presented to patients at time of recruitment is shown in the Appendix.

Standard pharmacological analgesia was administered to patients at the discretion of the physicians and nurses for treatment of pain and was not affected by participation in this study. Some patients' physical therapy sessions were shortly after their daily dressing changes. In these cases, the patients may still have experienced additional pharmacological analgesia from short-acting opioids administered to help reduce procedural pain during their morning dressing/bandage change. Use of a within-subject design insured that drug dosages were the same in the VR and control condition for each patient. The therapist chose the injured extremity that was either the most painful or the most troublesome (with regard to range of motion) for the patient. Each patient spent a predetermined amount of time performing physical therapy in VR and an equal amount of time performing physical therapy with no VR (conventional treatment) during the same session. The same active–assisted range-of-motion exercises were performed during both experimental conditions (e.g., same number of repetitions, same exercises performed in the same plane, and stretch held for the same number of seconds). The duration of exercise treatment was set before the beginning of physical therapy on any given day. 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 for each patient. For instance, if VR was (by chance) first for session 1, "no VR" was first for session 2.

At the end of each treatment period, maximum range of motion of the relevant limb was measured by the occupational therapist with use of a goniometer. Each patient's range of motion was measured only once per condition. Pain, the primary dependent variable, was measured immediately after each experimental treatment, during a brief (approximately 2-minute) pause in therapy. At each pause (once after therapy with VR and once after therapy with no distraction), patients completed five retrospective subjective pain ratings with use of 100-mm visual analog scales.[29,30] With respect to the last 3 minutes of physical therapy during that study condition, patients rated (1) how much time they spent thinking about their pain and/or burn wound (endpoints labeled zero minutes, the entire time), (2) how unpleasant the physical therapy was (not at all unpleasant to the most unpleasant), (3) how much their wound bothered them (not at all bothersome to the most bothersome), (4) their worst pain (no pain to worst pain), and (5) their average pain (no pain to worst pain). The pain experience has at least two components that are separately measurable and sometimes differentially influenced[31,32]: 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 recently reported measure of procedural burn pain.[21]

After filling out their pain ratings after VR, patients were asked for the following ratings based on visual analog scales: (1) To what extent (if at all) did you feel nausea as a result of experiencing VR ("none" to "very much"); (2) While experiencing VR, to what extent did you feel like you went into the virtual world ("I did not feel like I went into the virtual world at all" to "I went completely into the virtual world."); and (3) How real did the objects in the virtual world seem to you ("completely fake" to "indistinguishable from a real object")? Hendrix and Barfield[33] describe several studies showing the reliability of a similar subjective measure of presence.

Procedures

A Silicon Graphics Octane MXE with Octane Channel Option (Silicon Graphics, Mountain View, CA, USA; www.sgi.com) was coupled with a V8 VR helmet (Virtual Research, Aptos, CA, USA; www.virtualresearch.com) to create an immersive, three-dimensional, interactive, computer-simulated environment. Eyepieces on the helmet were circular and had a 60° diagonal field of view per eye. A Polhemus Fastrak motion-sensing system (Polhemus, Colchester, VT, USA; www.Polhemus.com) with 6 degrees-of-freedom sensors was used to measure the position of the user's head. The first patient in the current study explored the virtual environment *SpiderWorld* (see Hoffman et al.[28] for a detailed description), whereas the last six explored *SnowWorld*, a virtual

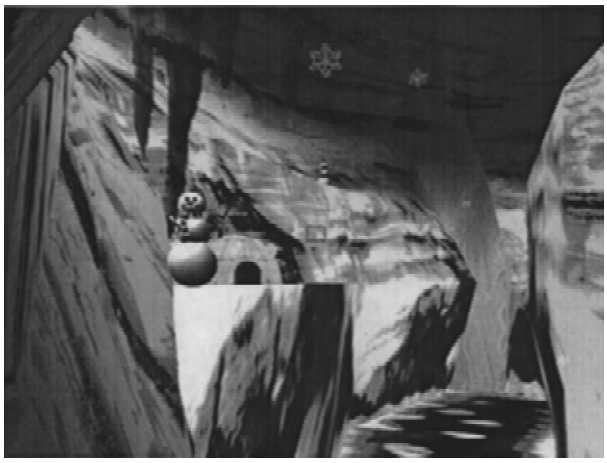

FIG. 1. An image from *SnowWorld*.

environment created with Creator modeling software and VEGA development software from MultiGen-Paradigm, Inc. (San Jose, CA, USA; www.MultiGen.com). *SpiderWorld* was complete with countertops, a window, and three-dimensional cabinets. The patient could "pick up" virtual objects with his or her "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[34,35] if willing, the patient could "eat" a virtual candy bar linked via a position sensor attached to the candy bar's real-world twin. The patient could also "touch" the furry body of a virtual Guyana bird-eating tarantula with wiggling legs. After dropping a virtual spider out of a "spider bucket" with sound effects, the patient could herd the animated spider into a sink, fill the sink with water, and turn on the virtual garbage disposal.

The other six patients in the current study had the illusion of flying through *SnowWorld,* which depicts an icy three-dimensional virtual canyon with a river and waterfalls. Patients shot snowballs at snowmen and igloos by aiming with their gaze and pressing the spacebar on a keyboard. The snowballs exploded with three-dimensional animations and sound effects on impact (Fig. 1). Each patient participated in the VR condition, during which he or she performed active–assisted physical therapy exercises. The occupational therapist held the patient's injured limb (e.g., an arm) and moved it through a predetermined sequence of ranging exercises (e.g., raising the patient's arm as if to ask a question or placing it across the patient's chest) while the patient was in VR. Each patient participated in the control condition, during which he or she performed active–assisted physical therapy exercises with no distraction for the same amount of time spent doing therapy in VR.

TABLE 1.

Day	Mean VAS (mm) No distraction	Mean VAS (mm) VR	t(6) value	*p* value	SE
1	71.94	32.40	11.92	0.000	3.08
2	67.41	30.84	4.53	0.004	8.08
3	77.89	34.41	4.69	0.003	8.07

VAS, visual analog scale; mean VAS, mean of 5 pain ratings given in each session; VR, virtual reality; SE, standard error.

TABLE 2. *Day 1 pain ratings*

Day 1	Mean VAS (mm) No distraction	Mean VAS (mm) VR	t(6) value	*p* value	SE
Time spent thinking about pain	88.71	28.57	7.08	<0.001	8.50
Unpleasant	58.00	31.14	4.65	0.003	5.77
Bothersome	72.43	34.86	2.98	0.025	12.62
Worst pain	76.43	39.14	3.04	0.023	12.25
Average pain	69.00	28.29	t(5) = 3.37	0.020	10.66

VAS, visual analog scale; VR, virtual reality; SE, standard error.

RESULTS

Alpha Values

For each physical therapy session, alpha for *t* tests on the five pain ratings was conservatively set at $p < 0.01$, with use of a Bonferroni correction factor for multiple comparisons[36] to reduce family-wise error (0.05/5 comparisons = 0.01). The number of patients remaining in the study after day 3 fell from 7 to 4, precluding the use of statistics for days 4, 5, 6, or 7. Patients did not lose interest in participating. They either were discharged or required more surgery, precluding additional sessions.

Ratings of Pain Experienced During Treatment

On each day, patients rated pain during physical therapy on five 100-mm visual analog scales for each condition (once after therapy with VR and once after

TABLE 3. *Day 2 pain ratings*

Day 2	Mean VAS (mm) No distraction	Mean VAS (mm) VR	t(6) value	*p* value	SE
Time spent thinking about pain	67.57	23.86	4.25	0.005	10.28
Unpleasant	62.71	30.14	3.39	0.015	9.61
Bothersome	67.43	34.86	2.80	0.031	11.65
Worst pain	80.14	37.43	3.67	0.010	11.63
Average pain	68.40	33.60	t(4) = 4.62	0.010	7.53

VAS, visual analog scale; VR, virtual reality; SE, standard error.

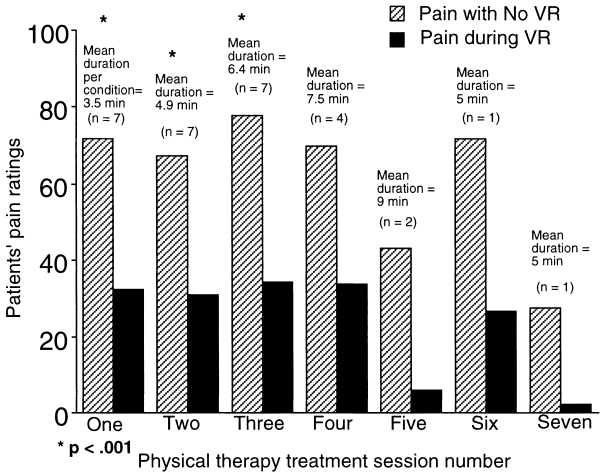

FIG. 2. Visual reality (VR) analgesia remained effective over multiple treatments.

therapy with no VR). As shown in Table 1 and Figure 2, mean visual analog scale pain ratings (time spent thinking about pain + unpleasantness + bothersomeness + worst pain + average pain/5) were significantly higher in the control condition (no distraction) than during VR on each of the first 3 days. A within-subject ANOVA comparing the "no VR–VR" difference in scores from days 1, 2, and 3 showed no difference in the size of the VR analgesic effect, F ($F_{2,8}$ <1; NS). Pain reduction from VR was evident in each of the five pain measures, in each of the sessions (Tables 2–4), and did not diminish with repeated use of VR over the first three sessions. Pain reduction is evident even for patients reporting severe to excruciating pain levels during physical therapy. On the basis of a 0-mm to 100-mm visual analog scale, six of the seven patients in the current study had mean pain ratings of 70 mm (i.e., severe[37,38]) or higher during physical therapy with no distraction. VR analgesia was evident in all patients with (and without) severe pain.

Descriptive statistics for range of motion, duration of physical therapy, nausea, and presence and realism of virtual objects are shown in Table 5. Range of motion was higher with VR than with no VR for all seven sessions, except session 2. In session 2, range of motion was higher with no VR than with VR.

TABLE 4. *Day 3 pain ratings*

Day 3	Mean VAS (mm) No distraction	Mean VAS (mm) VR	t(6) value	p value	SE
Time spent thinking about pain	73.00	23.86	4.54	0.004	10.82
Unpleasant	72.29	29.29	3.30	0.016	13.04
Bothersome	77.71	34.29	4.87	0.003	8.92
Worst pain	78.00	52.43	2.68	0.036	9.53
Average pain	53.50	31.00	t(4) = 4.32	0.012	7.69

VAS, visual analog scale; VR, virtual reality; SE, standard error.

DISCUSSION

Results of the current study show that VR reduced the amount of pain reported on three separate physical therapy sessions. To our knowledge, this is the first multipatient study to test whether VR analgesia remains effective when used more than once.

Before this study, patients participating in studies on VR analgesia had been trying immersive VR for the first time. Patients in all earlier multipatient VR analgesia studies received only one VR treatment, lasting only 3 minutes, per condition (i.e., 3 minutes in VR and 3 minutes with no VR). In the current study, VR was used repeatedly and for more than 6 minutes per condition on day 3, with no decline in analgesic potency. VR reduced patients' pain scores for sensory pain (ratings of worst pain and average pain), as well as affective pain (ratings of unpleasantness and bothersomeness).

Demand Characteristics

Although a standardized treatment protocol was used, the therapist was aware of the treatment condition in the current study, and this knowledge could potentially have influenced the therapist to treat the patient differently. One occupational therapist had used VR a number of times before the study and probably expected it to work,

TABLE 5.

	Day 1 (n = 7)	2 (n = 7)	3 (n = 7)	4 (n = 4)	5 (n = 2)	6 (n = 1)	7 (n = 1)
ROMDIFF (degree)	15.4	–6.67	1.25	2.5	10	10	10
Duration of PT (min)	3.5	4.9	6.4	7.5	9.0	5.0	5.0
Nausea (0 to 100 rating)	2.7	<1	<1	<1	<1	<1	<1
Presence (0 to 100 rating)	59	56	53	49	95	76	86
Realism of virtual objects (0 to 100 rating)	51	66	52	52	94	80	95

ROM, range of motion; VR, virtual reality; ROMDIFF, (ROM without VR) – (ROM with VR); PT, physical therapy.

on the basis of such experience. The other therapist had no experience with VR and probably had no initial predisposition to believe it worked or not. Encouraging in this regard is the finding that the maximum range of limb motion (in arm stretches, for example) was greater with VR than in the no-distraction control condition in six of the seven sessions. This finding suggests that the therapists treated patients the same in both the VR and control conditions (as instructed by the experimenters). The range-of-motion data suggest that therapists did not "let up" in the intensity of exercise during VR.

Although more difficult to implement in a clinical setting, double-blind experiments are needed to further reduce the likelihood of a demand-characteristics explanation of VR analgesia. In a double-blind study, when data are collected, neither the experimenter nor the patient knows what the predicted response is for any given experimental condition. Such studies are needed before VR can become a viable form of nonpharmacological analgesia in everyday medical practice. Patients with severe burns often require dozens of painful physical therapy and wound care procedures lasting approximately 30 to 60 minutes a day during the course of their recovery. Future studies should further increase the frequency and duration of VR treatment, perhaps expanding the number of virtual worlds used by each patient. Such studies should involve larger sample sizes because the small sample size used in the current study limits the generalizability of our findings.

Placebo Effects

Placebo effects can strongly influence pain perception in some patients. Beecher's classic study in 1959 (cited by Melzack[32]) found that about 35% of the patients tested experienced relief from severe pain, such as that following surgery, the first time they received a placebo. Subsequent studies (described by Melzack[32]) have found that sugar placebos became less effective each time they were administered. The fact that only one third of the patients responded in Beecher's study and that the placebo-based analgesia diminished each time dramatically reduces the practical value of using placebos in everyday medical practice. In contrast to what would be expected if VR was operating solely through a placebo mechanism, in the current study the effectiveness of VR analgesia did not diminish with repeated VR treatments, and all seven patients had VR-associated analgesia. Similarly, a recent study[27] found that more than 75% of the burn patients participating had VR-associated analgesia, a percentage much higher than would be expected from a placebo effect. Thus, VR analgesia appears to have properties that could have practical medical value as an adjunctive analgesic. Future research with a double-blind experimental design could greatly reduce the likelihood that a placebo effect is contributing to VR analgesia. Understanding the mechanisms by which VR analgesia is achieved will likely help us build virtual worlds and VR systems that maximize the technique's analgesic effectiveness.

CONCLUSIONS

The use of VR-based pain control need not be limited to burn patients. Burn injuries and their treatment are considered to be among the most painful a person can endure. Therefore, techniques that prove effective with this population will probably prove effective for other painful procedures (e.g., brief cancer procedures, medical procedures requiring the patient to remain conscious or for which repeated sedation is undesirable, and physical therapy for cerebral palsy, stroke, and knee injuries). Indeed, a case study recently showed that VR appears to be effective against dental pain.[39] The utility of this technology for controlling chronic pain has yet to be determined. Because of the potential of VR and the need for new nonpharmacological adjuncts, additional research on the value of VR analgesia during physical therapy is warranted.

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APPENDIX

Information Presented to Patients at Time of Recruitment

"Hi, my name is Gretchen Carrougher, and I am a research nurse here at Harborview in the Burn Center. Your nurse (or doctor) asked you if it was okay for me to talk with you about our research, and I understand that that is okay. There is a research study that you can participate in if you wish—in other words, you don't have to if you don't want too. The study concerns pain control during physical therapy. We are doing a study on the use of virtual reality for pain control during physical therapy. You would perform your physical therapy just like you always do, except you will go into virtual reality for a few minutes while you are doing your physical therapy. Then we will stop and you will answer a few questions about how much pain you experienced. Then we will do more physical therapy for the same amount of time without virtual reality, after which you will give pain ratings again to assess how much pain you experienced. Would you be interested in participating in this study?"