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The Effect of Virtual Reality on Pain and Range of Motion in Adults With Burn Injuries

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Abstract

Few studies have empirically investigated the effects of immersive virtual reality (VR) on postburn physical therapy pain control and range of motion (ROM). We performed a prospective, randomized controlled study of the effects of adding VR to standard therapy in adults receiving active-assisted ROM physical therapy, by assessing pain scores and maximal joint ROM immediately before and after therapy on two consecutive days. Thirty-nine inpatients, aged 21 to 57 years (mean 35 years), with a mean TBSA burn of 18% (range, 3–60%) were studied using a within-subject, crossover design. All patients received their regular pretherapy pharmacologic analgesia regimen. During physical therapy sessions on two consecutive days (VR one day and no VR the other day; order randomized), each patient participated in active-assisted ROM exercises with an occupational or physical therapist. At the conclusion of each session, patients provided 0 to 100 Graphic Rating Scale measurements of pain after each 10-minute treatment condition. On the day with VR, patients wore a head-position-tracked, medical care environment-excluding VR helmet with stereophonic sound and interacted in a virtual environment conducive to burn care. ROM measurements for each joint exercised were recorded before and after each therapy session. Because of nonsignificant carryover and order effects, the data were analyzed using simple paired *t*-tests. VR reduced all Graphic Rating Scale pain scores (worst pain, time spent thinking about the pain, and pain unpleasantness by 27, 37, and 31% respectively), relative to the no VR condition. Average ROM improvement was slightly greater with the VR condition; however, this difference failed to reach clinical or statistical significance ($P = .243$). Ninety-seven percent of patients reported zero to mild nausea after the VR session. Immersive VR effectively reduced pain and did not impair ROM during postburn physical therapy. VR is easily used in the hospital setting and offers a safe, nonpharmacologic adjunctive analgesic treatment.

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Comprehensive rehabilitation therapy is vital to patients with severe burn injuries. Rehabilitation begins shortly after the patient is admitted to the hospital and may include therapeutic positioning, splinting, use of physical agents (eg, hydrotherapy, paraffin, ultrasound, and electrical stimulation), and therapeutic exercise. Therapeutic exercise plays a key role in the prevention of permanent impairments caused by burn scar contractures, which is a recognized complication. Such physical therapy may include active exercise, passive range of motion (ROM) and stretching, and strengthening.¹ Collectively, these interventions help to increase the elasticity of healing skin, help to maintain full joint ROM and function, and can promote endurance, conditioning, and ambulation. Without these interventions, the normal healing process can potentially result in scarring, skin contractures, and limited ROM. Thus, participation in such rehabilitation activities is crucial for minimizing long-term disability.

Unfortunately, patients often experience significant procedural pain during postburn physical therapy. The pain experienced may limit therapy and, consequently, lead to secondary complications.² Because procedural pain often cannot be adequately managed with pharmacologic analgesics alone (eg, opioid analgesics), psychological techniques, such as distraction, have been used. Several investigators have found that cognitive distraction (eg, listening to music, watching a movie, and hypnosis) can lessen the perception of pain.^{3,4}

Immersive virtual reality (VR) is a new form of cognitive distraction and has been found to be an effective adjunctive, nonpharmacologic analgesic for postburn physical therapy.⁵ The underlying premise on why VR is helpful is that individuals have a limited amount of attention that can be divided between incoming stimuli,⁶ and pain requires “attention.” Immersive VR (typically involving a head-mounted display that redirects the user’s view of the real world to a virtual one) gives the individual the illusion of “going into” the 3-dimensional computer-generated environment, as if it were a place in which they are actually physically present.⁷ This illusion is termed “subjective presence” and can be measured using self-reporting Graphic Rating Scales (GRSs). The strength of the presence is thought to reflect the amount of attention that is drawn into the virtual world.^{8,9} Because VR is a highly attention-grabbing experience, it can be an effective psychological pain control technique. Less attention to pain can result in reductions in pain intensity, unpleasantness, and the amount of time patients spend thinking about their pain.⁷

Brain scan studies provide converging objective evidence that VR reduces pain. Neuroimaging studies with healthy volunteers have consistently identified five regions of the brain known to be involved in the perception of pain: the insula, thalamus, primary and secondary somatosensory cortices, and the anterior cingulate cortex.^{10,11} Based on this framework, Hoffman et al¹² measured the patterns of brain activity associated with VR analgesia. In addition to reporting less pain during VR, significant reductions in pain-related brain activity were found in all five of the brain regions noted above, when comparisons were made between a VR and no VR condition. They concluded that VR reduces pain via modulation of both the physiologic and the subjective aspects of pain processing.^{12,13}

To date, two clinical studies have been published exploring the use of immersive VR for pain control during postburn physical therapy. Hoffman et al⁵ studied 12 adult patients (aged 19–47 years) with an average burn size of 21% TBSA during a single physical therapy session. In this study, a within-subjects, within-procedure design was used that limited treatment duration (3 minutes in VR and 3 minutes in no VR). The investigators found that subjective reports of the pain experience were significantly reduced when in VR compared with that in no VR. Ten of 12 patients (83%) demonstrated improved posttreatment ROM during VR compared with the no VR (control) condition. In a second study, Hoffman et al.¹⁴ found a similar pattern of results, again using a within-subjects study design. In that study with 7 patients, aged 9 to 32 years, with an average burn size of nearly 24% TBSA, patients showed clinically meaningful

reductions in pain (ie, greater than 30%) when they performed passive ROM exercises while in VR, even when VR was used on multiple occasions. The treatment durations, on average, were 3.5, 4.9, and 6.4 minutes on the first, second, and third treatment days, respectively. Maximum ROM was measured once at the conclusion of each study condition and compared for differences (no VR vs VR). On average, patients improved their ROM with the VR condition in six of seven study sessions. It is important to note that in both of these studies, pretreatment ROM measurements were not obtained, and the sample sizes were small, thus, limiting generalizability. Therefore, the true impact of VR distraction on joint movement and ROM has yet to be determined.

Given the success of VR analgesia during physical therapy, but noting the aforementioned limitations of previous studies, we sought to determine the impact of immersive VR on subjective pain ratings and on average ROM change in a larger population of adults with burn injuries during longer postburn physical therapy treatment sessions. Specifically, both prephysical and postphysical therapy treatment ROM measurements for all joints exercised were obtained, and the duration of VR treatment was extended in this study.

METHODS

Study patients were recruited and enrolled from a regional Level I burn center for the Pacific Northwest region of the United States, located at Harborview Medical Center in Seattle, Washington. Eligible patients included those older than 20 years who required postburn injury physical therapy, consisting of active-assisted ROM exercises on two consecutive days during their acute hospital stay. Patients were ineligible if they did not speak English, had significant facial, ear or scalp injuries that prevented them from wearing a VR helmet, suffered from a seizure disorder, or had full-joint ROM. Patients were not excluded from participation based on pain levels experienced during physical therapy. Participation was voluntary, and reimbursement for study participation was not provided. Informed written consent was obtained using a protocol reviewed and approved by the University of Washington's Institutional Review Board.

A prospective, within-subjects crossover study design was used. Subjects received standard analgesic medications on both the study days. Typically, this included a long-acting opioid (oral methadone or OxyContin [Purdue Frederick, Co., Norwalk, CT]) and a preprocedural short-acting opioid (oxycodone). Individual medication regimens were determined by the treating physician and were independent of study protocol. Opioid equivalents (OEs), representing the amount of opioids received, were calculated. Specifically, all long-acting opioids administered each morning (typically at 6:00 AM) and all p.r.n. and preprocedural analgesics given 3 hours before each treatment session were recorded. Most study patients received identical analgesics for both the study days, however, some patients did receive different analgesic dosing because of the use of p.r.n. medications. Use of adjunctive anxiolytic medications was also documented. VR distraction was added to one of the study days, with the order of treatment (VR or no VR) randomized such that each patient was equally likely to experience VR on the first or second study day; all subjects received both treatment conditions (VR and no VR; one treatment per study day). The duration of treatment was set before study initiation and was held constant for both the study days. Based on time spent in VR from previous VR studies (typically 3 to 7 minutes), we chose 10 minutes as our standard session time. The treating therapist chose the joints to be exercised based on either the most painful or the most troublesome (with regard to ROM) joints for each patient. The same therapist worked with every patient on both study days, thus, providing the same therapeutic exercises during both study conditions (eg, same number of repetitions and same exercises performed in the same plane for any given patient).

Outcome Measures

Self-reported subjective assessments for pain (worst pain and pain unpleasantness), time spent thinking of pain, nausea (“no nausea at all” to “vomiting”), realness of the virtual environment (“completely fake” to “indistinguishable from a real object”), and sense of presence in the virtual environment (“I did not feel like I went inside at all” to “I went completely into the computer-generated world”) were recorded immediately after each therapy session by a study investigator using 100 mm GRSs (Figure 1). Ratings for nausea, realism, and presence were only collected after the VR treatment session.

Goniometry measurements for joint ROM, taken just before and immediately after each therapy session, were performed by the treating therapist and recorded by a study investigator (Figure 2). Specifically, for each joint measured, a gain or loss of range was determined based on pretherapy to posttherapy measurements. All ROM measurements within a body segment (eg, hand, wrist, forearm, elbow, shoulder, hip, knee, and ankle) were added to provide a composite ROM value. This value was then divided by the total number of joint measurements taken—providing a mean ROM (mROM) change per joint. This mROM change per joint for both treatment conditions was used in the final analysis, concerning the impact of VR on therapeutic exercise.

Immersive Virtual Reality Condition

During the VR condition, patients wore a head-position-tracked, medical care environment-excluding VR helmet with stereophonic sound. The helmet was an Nvis Nvisor (www.nvisinc.com) with 60 degree diagonal field of view and 1280 × 1024 pixels per eye. Patients glided through an icy 3-dimensional canyon with a river and waterfall, as snowflakes drifted down. They interacted with the environment by aiming with their gaze and pressing the spacebar on a keyboard. They could shoot snowballs at snowmen, igloos, and penguins, which were positioned on narrow ice shelves or floating in the river. The snowmen and igloos disappeared in a puff of snow and powder, and the penguins flipped upside down, when hit by a snowball (controlled by the patient). Successful contact between snowball and object also elicited a sound, heard only by the patient. The virtual world was designed by one of the study authors (Figure 3; www.vrpain.com).

Statistical Analysis

The data were analyzed using the Statistical Package for the Social Sciences 11.0 (SPSS, Inc., Chicago, IL) and SAS 9.1 (SAS Institute, Carey, NC). SAS’s Mixed Model analysis procedure was used to identify a significant residual (carryover) effect and a significant treatment (VR vs no VR) effects and to adjust for possible confounding factors in this crossover study design. Likelihood ratio tests from Mixed Model analyses for each subjective pain measure and mROM were used to assess whether there was a significant residual (carryover) effect and whether there was a significant effect due to the order of administration of the treatment. We tested for a significant difference between a number of pain and physical movement assessments, totals and mean scores, also using Mixed Model Likelihood ratio tests. Because both the residual (carryover) effect and the order effect were not statistically significant, we chose to simplify data analysis by performing simple paired Student’s *t*-tests. Statistically significant differences of treatment effects for each of the measurements evaluated in the study were assigned at the $P < .05$ levels.

RESULTS

Forty-one inpatients agreed to participate. Two patients withdrew from participation before study completion. Data analysis were performed on the 39 remaining subjects with complete data. Demographic information is summarized in Table 1.

Patients participated in the study on two consecutive days while hospitalized for treatment of their acute burn injury. The mean duration of treatment was 10 minutes per treatment session (range, 7–15 minutes).

ROM exercises included joints of both the upper and lower extremities. Subjects consistently had one or more body segments exercised on both the study days. On average, subjects had three body segments exercised (range, 1–5), with the upper extremity requiring more therapeutic exercise than the lower extremity. Table 2 provides a breakdown of the number of subjects for each body area measured and the average gain from pretherapy to posttherapy. Participants had on average of 18 (SD = 8) different joints measured (range, 4–30). Using paired sample *t*-tests, there was no significant gain in ROM during the VR treatment session over that in the no VR condition ($P = .243$).

VR reduced GRS scores for worst pain, pain unpleasantness, and time spent thinking about pain, relative to the no VR condition (27, 31, and 37%, respectively). VR object realism, presence, and nausea were each measured only for the VR condition. On average, patients rated the realism of the VR world at 26.1 (SD = 24, range, 0–80). For presence, approximately half of the patients (51.3%) rated their level of presence at greater than 35 mm (0–100mm GRS). Patients experienced little or no nausea during VR. Ninety-seven percent rated their nausea at less than 20 on a 0- to 100-mm GRS (0 = no nausea to 100 = vomiting); 85% experienced no nausea at all. Table 3 provides the mean ratings for each outcome assessed in this study.

OEs, a measure of the analgesics received on each day of the study, were slightly different. Average OEs administered on the VR day were 0.87 (SD = 0.84), whereas on the no VR day, the average OEs were 1.04 (SD = 1.1). This difference was not statistically different ($P = .3$).

In addition to opioid analgesics, 21% of study participants ($n = 8$) received an adjunctive anxiolytic on both the study days. Typically, these patients received lorazepam (1 to 2 mg orally) 30 minutes before wound care.

DISCUSSION

Hospitalized patients reported less pain during postburn physical therapy with the use of immersive VR. Previous studies,^{5,15,16} using the same or a similar version of the software used in this study, have demonstrated the same analgesic effect in both children and adults. Similarly, the reported time spent thinking of pain during physical therapy was also significantly reduced with VR.

The average gain in ROM (pretherapy to posttherapy) was slightly greater in the VR condition, however, this difference failed to reach clinical or statistical ($P = .243$) significance. On average, when in VR, subjects gained 10.2 degree (SD = 5.9) of joint range compared with 9.2 degree (SD = 4.6) with no VR. All subjects had more than one joint and body area exercised and measured. Table 2 provides a breakdown of the number of subjects for each body area measured and the average gain from pretherapy to posttherapy. No patients lost ROM (based on prephysical to postphysical therapy ROM measures) while participating in this study. Therefore, VR did not adversely affect joint ROM outcomes during therapeutic exercise sessions that last for 10 minutes.

The finding that VR decreased reports of pain, but did not result in a significant improvement in ROM, is of clinical interest. It is important to note that pain control and ROM are two different variables and one does not necessarily lead to the other. In this study, the therapist determined the degree of ROM pursued. We have no empirical way of determining whether, just because the patient was experiencing less pain, this had any influence on how far the therapist chose to exercise a joint. If fact, such determinations may have been made independent

of the patients' subjective experience and determined by factors such as contracture rigidity or perceived joint resistance.

Researchers have proposed that just as larger doses of opioids often lead to greater pain reduction, VR may also demonstrate a dose-response relationship. More specifically, VR worlds and systems that are more immersive (through means such as greater visual input size and resolution, sound effects, visual and aural exclusion of real-world environments, and greater user interaction with the virtual world) reduce pain more effectively than worlds of lesser quality.^{8,17} Since this study was completed, new virtual worlds and higher quality VR hardware have been developed. If these newer worlds and hardware provide a stronger "dose" of VR analgesia, greater differences in ROM outcomes may be realized, especially if patients are experiencing excessive pain during physical therapy.

A frequent concern with immersive VR is whether it leads to simulator sickness (ie, nausea), particularly when used in combination with opioid analgesics. Patients in this study experienced little or no nausea during VR. The computer-generated world used in this study was specifically designed for use in a computer that allows for minimal lag—the delay between the time of head movements in the real world and the time it takes the computer to render the changed viewpoint seen in the computer-generated world. The design of the virtual environment was intentionally kept simple, and the subjects' ability to move around the 3D snowy canyon was limited, thus, requiring less head and neck rotation. Perceived speed of movement in the environment was controlled and kept slow within a predefined path. Together, these design features limit the likelihood of one becoming disoriented and nauseated while in VR.

We contend that VR is easily used in the hospital setting and offers a safe nonpharmacologic adjunctive analgesic treatment. It does, however, require the purchase of specialized equipment. Currently, a state-of-the-art VR system (VR helmet and computer) costs approximately \$40,000.00, with the majority of the cost to the helmet. At present, several laboratories are working on the development of lower cost VR helmets. The cost of VR software is not included in this estimate. Immersive VR SnowWorld software is provided to eligible medical centers/burn centers free of charge (www.vrpain.com). Hospital staff must also be available for setup of the system.

Limitations

Several limitations of this study should be noted. Subjects were not blind to the treatment condition (VR vs no VR) and may have been biased in their pain reports because of demand characteristics. Subjects did not wear a helmet or were otherwise distracted on the non-VR (control) days of the study. Similarly, the treating therapist was also aware of treatment conditions and may have created a bias in their behavior (ie, treated patients more gently in one of the treatment conditions). To minimize this confound, the treating therapist remained the same for each subject and was instructed to perform similar ROM exercises on the same joints for both the study days. Given that the objective measure (ie, goniometry measurements) for average ROM was slightly greater in the VR condition (subjects were able to achieve slightly greater stretch), it would appear that the analgesia achieved was not simply because the therapist was "easy" on the patient during VR. However, we still need to acknowledge that the treating therapist was also responsible for the goniometer measurements and, thus, could have been biased. Concerning the assessment for nausea, this outcome was assessed neither in the no VR treatment condition nor before each treatment session (no VR and VR study conditions), thus, we lack the ability to compare the development of nausea without VR (ie, nausea due to opioids alone or other factors) to that experienced with VR.

CONCLUSIONS

This study provides additional support for the use of immersive VR as a nonpharmacologic adjunct to pain control during postburn physical therapy. A particular contribution of this report is that patients were able to remain in the virtual environment for longer durations of time than have been reported in earlier studies that used this modality. Mean active-assisted ROM per joint was not significantly increased following physical therapy during the VR treatment condition (when compared with physical therapy performed without VR). It may have been too optimistic to hypothesize that one 10-minute therapy session would demonstrate a significant difference in ROM outcome (in the face of multiple sessions for every patient over the course of their hospitalization). However, given that the VR group showed a nonsignificant trend towards greater ROM, that no subject lost ROM in the VR condition, and a new VR system and software have recently become available,¹⁷ a new study designed to assess the potential impact of long-term VR use on functional outcomes is warranted.

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Figure 1.
Graphic Rating Scale used to measure worst pain.

Figure 2.
Goniometry measurement of the knee in flexion.

Figure 3.
An image from SnowWorld. Image by Stephen Dagadakis, copyright Hunter Hoffman,
University of Washington, Seattle, WA.

Table 1

Patient demographics (n = 39)

Age (yr)	35 ± 11 (range 21–57)
Gender	
Men, n (%)	35 (89.7)
Ethnicity	
Caucasians, n (%)	35 (89.7)
TBSA burn (%)	18.1 ± 12.7 (range 3–60)
Etiology of injury, n (%)	
Flame/flash	30 (77)
Electrical	2 (5)
Scald	5 (13)
Chemical	2 (5)
Average time from injury to 1st study day (d)	13 ± 13 (range 2–56)
Length of hospitalization (d)	21 ± 16.7 (range 3–72)

Table 2Mean ROM gain/body area* from pretherapy to posttherapy (mean $\pm$ SD)

Body Area	No. Subjects	No. Joints Measured	Movement Measured	No VR	VR	P
Hand	26	15	Flexion; abduction	141.9 $\pm$ 88.9	149.9 $\pm$ 109.9	.685
Wrist	32	4	Flexion; extension	26.6 $\pm$ 13.1	29.2 $\pm$ 18.1	.463
Forearm	20	2	Pronation; supination	13.5 $\pm$ 15.5	10.5 $\pm$ 18.8	.531
Elbow	23	2	Extension	19.8 $\pm$ 15.0	21.0 $\pm$ 14.1	.699
Shoulder	21	5	Flexion	62.2 $\pm$ 37.2	72.1 $\pm$ 35.1	.223
Hip	1	6	Flexion; extension abduction; adduction; internal/external; rotation	0	5.0	—
Knee	3	2	Flexion; extension	11.7 $\pm$ 12.6	30.0 $\pm$ 30.4	.235
Ankle	2	4	Dorsiflexion; plantar flexion; inversion; eversion	11.5 $\pm$ 12.0	13.5 $\pm$ 12.0	.925

ROM, range of motion; VR, virtual reality.

* Presented in degrees of ROM gained; calculated from the difference of pretherapy to posttherapy goniometry measurements.

Table 3Average ratings^{*} for treatment with/without VR analgesia (mean $\pm$ SD)

Outcome Assessed	No VR	VR	P
Worst pain [*]	55 $\pm$ 25	40 $\pm$ 30	.004
Time spent thinking about pain [*]	41 $\pm$ 28	26 $\pm$ 21	.008
Pain unpleasantness [*]	32 $\pm$ 23	22 $\pm$ 22	.031
Average ROM gain/joint [†]	9.2 $\pm$ 4.6	10.2 $\pm$ 5.9	.243
Realism [*]	—	25.6 $\pm$ 23.5	—
Presence [*]	—	35.1 $\pm$ 26.0	—
Nausea [*]	—	3.3 $\pm$ 10.6	—
Opioid equivalents [‡]	1.04 $\pm$ 1.1	0.87 $\pm$.84	.309

^{*} Measured on a 0- to 100-mm scale.

[†] Degrees of ROM gained from pretherapy to posttherapy goniometry measurements.

[‡] One opioid equivalent equals approximately 10 mg morphine sulfate administered intravenously.