

# SCIENTIFIC AMERICAN™

*Article appeared in [Scientific America.com](http://ScientificAmerica.com), July 2004.*

*by Hunter G. Hoffman*

## Virtual Reality Therapy

In the science-fiction thriller *The Matrix*, the heroes "plugged in" to a virtual world. While their bodies rested in reclining chairs, their minds fought martial-arts battles, dodged bullets and drove motorcycles in an elaborately constructed software program. This cardinal virtue of virtual reality--the ability to give users the sense that they are "somewhere else"--can be of great value in a medical setting. Researchers are finding that some of the best applications of the software focus on therapy rather than entertainment. In essence, virtual reality can ease pain, both physical and psychological.

For the past several years, I have worked with David R. Patterson, a pain expert at the University of Washington School of Medicine, to determine whether severely burned patients, who often face unbearable pain, can relieve their discomfort by engaging in a virtual-reality program during wound treatment. The results have been so promising that a few hospitals are now preparing to explore the use of virtual reality as a tool for pain control. In other projects, my colleagues and I are using virtual-reality applications to help phobic patients overcome their irrational fear of spiders and to treat post-traumatic stress disorder (PTSD) in survivors of terrorist attacks.

At least two software companies are already leasing virtual-reality programs and equipment to psychologists for phobia treatment in their offices. And the Virtual Reality Medical Center, a chain of clinics in California, has used similar programs to successfully treat more than 300 patients suffering from phobias and anxiety disorders. Although researchers must conduct more studies to gauge the effectiveness of these applications, it seems clear that virtual therapy offers some very real benefits.

## SpiderWorld and SnowWorld

Few experiences are more intense than the pain associated with severe burn injuries. After surviving the initial trauma, burn patients must endure a long journey of healing that is often as painful as the original injury itself. Daily wound care--the gentle cleaning and removal of dead tissue to prevent infection--can be so excruciating that even the aggressive use of opioids (morphine-related analgesics) cannot control the pain. The patient's healing skin must be stretched to preserve its elasticity, to reduce muscle atrophy and to prevent the need for further skin grafts. At these times, most patients--and especially children--would love to transport their minds somewhere else while doctors and nurses treat their wounds. Working with the staff at Harborview Burn Center in Seattle, Patterson and I set out in 1996 to determine whether immersive virtual-reality techniques could be used to distract patients from their pain. The team members include Sam R. Sharar, Mark Jensen and Rob Sweet of the University of Washington School of Medicine, Gretchen J. Carrougher of Harborview Burn Center and Thomas Furness of the University of Washington Human Interface Technology Laboratory (HITLab).

Pain has a strong psychological component. The same incoming pain signal can be interpreted as more or less painful depending on what the patient is thinking. In addition to influencing the way patients interpret such signals, psychological factors can even influence the amount of pain signals allowed to enter the brain's cortex. Neurophysiologists Ronald Melzack and Patrick D. Wall developed this "gate control" theory of pain in the 1960s [see "The Tragedy of Needless Pain," by Ronald Melzack; *Scientific American*, February 1990].

Introducing a distraction--for example, by having the patient listen to music--has long been known to help reduce pain for some people. Because virtual reality is a uniquely effective new form of distraction, it makes an ideal candidate for pain control. To test this notion, we studied two teenage boys who had suffered gasoline burns. The first patient had a severe burn on his leg; the second had deep burns covering one third of his body, including his face, neck, back, arms, hands and legs. Both had received skin-graft surgery and staples to hold the grafts in place.

We performed the study during the removal of the staples from the skin grafts. The boys received their usual opioid medication before treatment. In addition, each teenager spent part of the treatment session immersed in a virtual-reality program and an equal amount of time playing a popular Nintendo video game (either Wave Race 64, a jet-ski racing game, or Mario Kart 64, a race-car game). The virtual-reality program, called SpiderWorld, had originally been developed as a tool to overcome spider phobias; we used it for this investigation because it was the most distracting program available at the time and because we knew it would not induce nausea. Wearing a stereoscopic, position-tracked headset that presented three-dimensional computer graphics, the patients experienced the illusion of wandering through a kitchen, complete with countertops, a window and cabinets that could be opened. An image of a tarantula was set inside the virtual kitchen; the illusion was enhanced by suspending a furry spider toy with wiggly legs above the patient's bed so that he could actually feel the virtual spider.

Both teenagers reported severe to excruciating pain while they were playing the Nintendo games but noted large drops in pain while immersed in SpiderWorld. (They rated the pain on a zero to 100 scale immediately after each treatment session.) Although Nintendo can hold a healthy player's attention for a long time, the illusion of going inside the two-dimensional video game was found to be much weaker than the illusion of going into virtual reality. A follow-up study involving 12 patients at Harborview Burn Center confirmed the results: patients using traditional pain control (opioids alone) said the pain was more than twice as severe compared with when they were inside SpiderWorld.

Why is virtual reality so effective in alleviating pain? Human attention has been likened to a spotlight, allowing us to select some information to process and to ignore everything else, because there is a limit to how many sources of information we can handle at one time. While a patient is engaged in a virtual-reality program, the spotlight of his or her attention is no longer focused on the wound and the pain but drawn into the virtual world. Because less attention is available to process incoming pain signals, patients often experience dramatic drops in how much pain they feel and spend much less time thinking about their pain during wound care.

To increase the effectiveness of the virtual therapy, our team created SnowWorld, a program specifically customized for use with burn patients during wound care. Developed with funding from Microsoft co-founder Paul G. Allen and the National Institutes of Health, SnowWorld produces the illusion of flying through an icy canyon with a frigid river and waterfall, as snowflakes drift down [see illustration on pages 58 and 59]. Because patients often report that they are reliving their original burn experience during wound care, we designed a glacial landscape to help put out the fire. As patients glide through the virtual canyon, they can shoot snowballs at snowmen, igloos, robots and penguins standing on narrow ice shelves or floating in the river. When hit by a snowball, the snowmen and igloos disappear in a puff of powder, the penguins flip upside down with a quack, and the robots collapse into a heap of metal.

More recent research has shown that the benefits of virtual-reality therapy are not limited to burn patients. We conducted a study involving 22 healthy volunteers, each of whom had a blood pressure cuff tightly wrapped around one arm for 10 minutes. Every two minutes the subjects rated the pain from the cuff; as expected, the discomfort rose as the session wore on. But during the last two minutes, each of the subjects participated in two brief virtual-reality programs, SpiderWorld and ChocolateWorld. (In ChocolateWorld, users see a virtual chocolate bar that is linked through a position sensor to an actual candy bar; as you eat the real chocolate bar, bite marks appear on the virtual bar as well.) The subjects reported that their pain dropped dramatically during the virtual-reality session.

What is more, improving the quality of the virtual-reality system increases the amount of pain reduction. In another study, 39 healthy volunteers received a thermal pain stimulus--delivered by an electrically heated element applied to the right foot, at a preapproved temperature individually tailored to each participant--for 30 seconds. During this stimulus, 20 of the subjects experienced the fully interactive version of SnowWorld with a high-quality headset, sound effects and head tracking. The other 19 subjects saw a stripped-down program with a low-quality, see-

through helmet, no sound effects, no head tracking and no ability to shoot snowballs. We found a significant positive correlation between the potency of the illusion--how strongly the subjects felt they were immersed in the virtual world--and the alleviation of their pain.

## Seeing Pain in the Brain

Of course, all these studies relied on the subjective evaluation of the pain by the patients. As a stricter test of whether virtual reality reduces pain, I set out with my colleagues at the University of Washington--including Todd L. Richards, Aric R. Bills, Barbara A. Coda and Sam Sharar--to measure pain-related brain activity using functional magnetic resonance imaging (fMRI). Healthy volunteers underwent a brain scan while receiving brief pain stimulation through an electrically heated element applied to the foot. When the volunteers received the thermal stimuli without the distraction of virtual reality, they reported severe pain intensity and unpleasantness and spent most of the time thinking about their pain. And, as expected, their fMRI scans showed a large increase in pain-related activity in five regions of the brain that are known to be involved in the perception of pain: the insula, the thalamus, the primary and secondary somatosensory cortex, and the affective division of the anterior cingulate cortex [see illustration on page 61].

Creating virtual-reality goggles that could be placed inside the fMRI machine was a challenge. We had to develop a fiber-optic headset constructed of nonferrous, nonconducting materials that would not be affected by the powerful magnetic fields inside the fMRI tube. But the payoff was gratifying: we found that when the volunteers engaged in SnowWorld during the thermal stimuli, the pain-related activity in their brains decreased significantly (and they also reported large reductions in subjective pain ratings). The fMRI results suggest that virtual reality is not just changing the way patients interpret incoming pain signals; the programs actually reduce the amount of pain-related brain activity.

Encouraged by our results, two large regional burn centers--the William Randolph Hearst Burn Center at New York Weill Cornell Medical Center and Shriners Hospital for Children in Galveston, Tex.--are both making preparations to explore the use of SnowWorld for pain control during wound care for severe burns. Furthermore, the Hearst Burn Center, directed by Roger W. Yurt, is helping to fund the development of a new upgrade, SuperSnowWorld, which will feature lifelike human avatars that will interact with the patient. SuperSnowWorld will allow two people to enter the same virtual world; for example, a burn patient and his mother would be able to see each other's avatars and work together to defeat monstrous virtual insects and animated sea creatures rising from the icy river. By maximizing the illusion and interactivity, the program will help patients focus their attention on the virtual world during particularly long and painful wound care sessions. Now being built by Ari Hollander, an affiliate of HITLab, SuperSnowWorld will be offered to medical centers free of charge by the Hearst and Harborview burn centers.

Virtual-reality analgesia also has the potential to reduce patient discomfort during other medical procedures. Bruce Thomas and Emily Steele of the University of South Australia have found that virtual reality can alleviate pain in cerebral palsy patients during physical therapy after muscle and tendon surgery. (Aimed at improving the patient's ability to walk, this therapy involves exercises to stretch and strengthen the leg muscles.) Our team at the University of Washington is exploring the clinical use of virtual reality during a painful urological procedure called a rigid cystoscopy. And we have conducted a study showing that virtual reality can even relieve the pain and fear of dental work.

## Fighting Fear

Another therapeutic application of virtual reality is combating phobias by exposing patients to graphic simulations of their greatest fears. This form of therapy was introduced in the 1990s by Barbara O. Rothbaum of Emory University and Larry F. Hodges, now at the University of North Carolina at Charlotte, for treating fear of heights, fear of flying in airplanes, fear of public speaking, and chronic post-traumatic stress disorder in Vietnam War veterans. Like the pain-control programs, exposure therapy helps to change the way people think, behave and interpret information.

Working with Albert Carlin of HITLab and Azucena Garcia-Palacios of Jaume I University in Spain (a HITLab affiliate), our team has shown that virtual-reality exposure therapy is very effective for reducing spider phobia. Our

first spider-phobia patient, nicknamed Miss Muffet, had suffered from this anxiety disorder for nearly 20 years and had acquired a number of obsessive-compulsive behaviors. She routinely fumigated her car with smoke and pesticides to get rid of spiders. Every night she sealed all her bedroom windows with duct tape after scanning the room for spiders. She searched for the arachnids wherever she went and avoided walkways where she might find one. After washing her clothes, she immediately sealed them inside a plastic bag to make sure they remained free of spiders. Over the years her condition grew worse. When her fear made her hesitant to leave home, she finally sought therapy.

Like other kinds of exposure therapy, the virtual-reality treatment involves introducing the phobic person to the feared object or situation a little at a time. Bit by bit the fear decreases, and the patient becomes more comfortable. In our first sessions, the patient sees a virtual tarantula in a virtual kitchen and approaches as close as possible to the arachnid while using a handheld joystick to navigate through the three-dimensional scene. The goal is to come within arm's reach of the virtual spider.

During the following sessions, the participant wears a glove that tracks the position of his or her hand, enabling the software to create an image of a hand--the cyberhand--that can move through the virtual kitchen. The patient maneuvers the cyberhand to touch the virtual spider, which is programmed to respond by making a brief noise and fleeing a few inches. The patient then picks up a virtual vase with the cyberhand; when the patient lets go, the vase remains in midair, but an animated spider with wiggling legs comes out. The spider drifts to the floor of the virtual kitchen, accompanied by a brief sound effect from the classic horror movie *Psycho*. Participants repeat each task until they report little anxiety. Then they move on to the next challenge. The final therapy sessions add tactile feedback to the virtual experience: a toy spider with an electromagnetic position sensor is suspended in front of the patient, allowing him or her to feel the furry object while touching the virtual spider with the cyberhand.

After only 10 one-hour sessions, Miss Muffet's fear of spiders was greatly reduced, and her obsessive-compulsive behaviors also went away. Her success was unusually dramatic: after treatment, she was able to hold a live tarantula (which crawled partway up her arm) for several minutes with little anxiety. In a subsequent controlled study of 23 patients diagnosed with clinical phobia, 83 percent reported a significant decrease in their fear of spiders. Before treatment, these patients could not go within 10 feet of a caged tarantula without high anxiety; after the virtual-reality therapy, most of them could walk right up to the cage and touch its lid with only moderate anxiety. Some patients could even remove the lid.

Similar programs can be incorporated into the treatment of a more serious psychological problem: post-traumatic stress disorder. The symptoms of PTSD include flashbacks of a traumatic event, intense reactions to anything symbolizing or resembling the event, avoidance behaviors, emotional numbing, and irritability. It is a debilitating disorder that affects the patient's social life and job performance and is much more challenging to treat than specific phobias. Cognitive behavioral therapy protocols, such as the prolonged exposure therapy developed by University of Pennsylvania psychologist Edna Foa, have a high success rate for patients with PTSD. The exposure therapy is thought to work by helping patients process and eventually reduce the emotions associated with the memories of the traumatic event. The therapist gradually exposes the patient to stimuli that activate these emotions and teaches the patient how to manage the unwanted responses.

Researchers are now exploring whether virtual-reality programs can be used to standardize the therapy and improve the outcome for patients, especially those who do not respond to traditional methods. JoAnn Difede of Cornell University and I developed a virtual-reality exposure therapy to treat a young woman who was at the World Trade Center during the September 11 attacks and later developed PTSD. During the therapy, the patient put on a virtual-reality helmet that showed virtual jets flying over the towers and crashing into them with animated explosions and sound effects. Although the progress of the therapy was gradual and systematic, the scenes presented by the software in the final sessions were gruesomely realistic, with images of people jumping from the burning buildings and the sounds of sirens and screams. These stimuli can help patients retrieve memories of the event and, with the guidance of a therapist, lower the discomfort of remembering what happened.

Our first patient showed a large and stable reduction in her PTSD symptoms and depression after the virtual-reality sessions. Other patients traumatized by the tower attacks are now being treated with virtual-reality therapy at Weill Cornell Medical College and New York Presbyterian Hospital. I am also collaborating with a team of researchers

led by Patrice L. (Tamar) Weiss of Haifa University in Israel and Garcia-Palacios to create a virtual-reality treatment for survivors of terrorist bombings who develop PTSD.

## Virtual Reality by the Hour

Because dozens of studies have established the efficacy of virtual-reality therapy for treating specific phobias, this is one of the first medical applications to make the leap to widespread clinical use. Virtually Better, a Decatur, Ga.-based company that was co-founded by virtual-reality pioneers Hodges and Rothbaum, has produced programs designed to treat an array of anxiety disorders, including fear of heights, fear of flying and fear of public speaking. The company is leasing its software to psychologists and psychiatrists for \$400 a month, allowing therapists to administer the treatments in their own offices. A Spanish firm called Previ offers similar programs. Instead of reclining on a couch, patients interactively confront their fears by riding in virtual airplanes or by standing in front of virtual audiences.

In contrast, more research is needed to determine whether virtual reality can enhance the treatment of PTSD. Scientists have not yet completed any randomized, controlled studies testing the effectiveness of virtual-reality therapy for treating the disorder. But some of the leading PTSD experts are beginning to explore the virtues of the technology, and the preliminary results are encouraging.

Large clinical trials are also needed to determine the value of virtual-reality analgesia for burn patients. So far the research has shown that the SnowWorld program poses little risk and few side effects. Because the patients use SnowWorld in addition to traditional opioid medication, the subjects who see no benefit from virtual reality are essentially no worse off than if they did not try it. Virtual reality may eventually help to reduce reliance on opioids and allow more aggressive wound care and physical therapy, which would speed up recovery and cut medical costs. The high-quality virtual-reality systems that we recommend for treating extreme pain are very expensive, but we are optimistic that breakthroughs in display technologies over the next few years will lower the cost of the headsets. Furthermore, patients undergoing less painful procedures, such as dental work, can use cheaper, commercially available systems. (Phobia patients can also use the less expensive headsets.)

The illusions produced by these programs are nowhere near as sophisticated as the world portrayed in the Matrix films. Yet virtual reality has matured enough so that it can be used to help people control their pain and overcome their fears and traumatic memories. And as the technology continues to advance, we can expect even more remarkable applications in the years to come.

###

*HUNTER G. HOFFMAN is director of the Virtual Reality Analgesia Research Center at the University of Washington Human Interface Technology Laboratory (HITLab) in Seattle. He is also an affiliate faculty member in the departments of radiology and psychology at the University of Washington School of Medicine. He joined the HITLab in 1993 after earning his Ph.D. in cognitive psychology at the University of Washington. To maximize the effectiveness of virtual reality in reducing physical and psychological suffering, he is exploring ways to enhance the illusion of going inside a computer-generated virtual world.*