Treating Psychological and Physical Disorders with VR

Larry F. Hodges
Georgia Institute of Technology

Page Anderson
Virtually Better

Grigore C. Burdea
Rutgers University

Hunter G. Hoffman
University of Washington

Barbara O. Rothbaum
Emory University School of Medicine

Clinical virtual reality uses VR in the treatment of psychological and physical disorders. Here we present some applications that therapists have used with patients.

In his 1999 survey of the current state of virtual reality applications, Fred Brooks could find only seven categories of verifiable production applications of VR:[1]

- Vehicle simulation
- Entertainment
- Vehicle design
- Architectural design and spatial arrangement
- Training (only at NASA)
- Psychological treatment
- Probe microscopy

If we examine these VR application domains today, a clear commonality is that most are expensive, large-scale applications that a few rich customers buy and use. Currently, there's no such thing as a VR mass market. Successful commercial VR is based on selling expensive pieces of hardware and software to a few clients who have the financial, spatial, and human resources to purchase, house, and maintain them. The one exception has been using virtual environments (VEs) to treat psychological disorders. The typical customer for these systems isn't a large government agency or international company but usually a clinician in a hospital or an independent clinic. As a result, VR therapy systems have had to be inexpensive, be easy to use and maintain, and fit into existing space in a clinician's office (see Figure 1).

1 Typical office setup for virtual reality therapy.

© 2000 Virtually Better

Treating psychological disorders is one aspect of a larger application area of VR that we refer to as *clinical virtual reality*—the direct use of VR as a tool in treating or assessing psychological and physical disorders. Examples of clinical applications that use VR include treatment of phobias, post-traumatic stress disorder in Vietnam War veterans, eating disorders, pain distraction, and physical (stroke and orthopedic) rehabilitation. This article offers some general ideas on how clinical VR applications fundamentally differ from many other VR applications and presents three detailed examples of current clinical VR applications that have moved from the demonstration phase to actual use with patients in a clinical setting.

Potential market

Clinical VR is one of the most promising areas for new VR applications that have the potential for a large user base. For example, an estimated 10 to 11 percent of the US population experiences a phobia at some point in their lives.[2] Unfortunately, about 60 to 85 percent of those suffering from specific phobias never seek professional treatment for their problem.[3] One likely reason is that they're too afraid of confronting the feared object or situation to seek therapy. Although traditional cognitive-behavioral therapists and researchers have developed and tested effective ways of treating phobias, we need new approaches (such as new variations on the techniques) to encourage phobia sufferers to seek treatment.

As a second example, we can look at the approximately 40 million disabled Americans.[4] This number includes people with restricted mobility, reduced sensory motor capabilities, and communication and intellectual deficiencies. Aging of the disabled has compounded the effects of disability on our society, resulting in a cost to society of $300 billion.[5] The lead-

0272-1716/01/$10.00 © 2001 IEEE

ing cause of activity limitations for Americans are orthopedic conditions,[4] with ankle and leg injuries accounting for a portion of these conditions, which can affect people of all ages.

The potential market for clinical VR use in physical rehabilitation is equally large. If we only consider ankle problems, each year in the US there are 1.2 million visits to physicians' offices for ankle sprains and 675,000 visits for ankle fractures according to the American Academy of Orthopedic Surgeons (http://orthoinfo.aaos.org). Since ankle impairments affect walking, many patients have difficulty traveling to clinics for treatment. In many parts of the US, such as rural areas, no clinics exist to serve such patients. The lack of timely therapeutic intervention can lead to permanent disability in otherwise reversible conditions. Other possible applications for clinical VEs include substance abuse, pain distraction, cognitive rehabilitation, social skills training, conflict management training, and diversity training.

Matching applications to the medium

With the exception of entertainment, most current VR applications are intended to interact with humans' cognitive and physical (manipulation) aspects. The VR systems for these applications aim to accurately represent spatial data that's perceived through the visual, and sometimes haptic or auditory senses, so that users can understand a design or task.

Few applications except entertainment engage the emotional, social, or spiritual aspects of our being. Most clinical VR applications, however, aim to engage or elicit a reaction from one of these human aspects. The engagement might depend on pure entertainment to make a repetitive rehabilitation task more palatable, or it may be designed to deliberately elicit anxiety related to a specific experience or belief. In each case, the environments are designed with an understanding that when we enter a VE we bring with us our beliefs, experiences, fears, and expectations. Our experience of a virtual space is a combination of what the programmer puts there and our reasonable reactions to them. Since VR is still a long way from reproducing environments that are indistinguishable from real environments, we achieve these goals by creating effective abstractions of reality.

Part of the job of virtual world builders is to understand and capture the essence of the environment they want to represent in those abstractions. As Susumu Tachi described in his introductory comments at the IEEE VR 2001 conference in Yokohama, Japan, "The science of virtual reality tries to elucidate what is the essence of reality. The engineering of virtual reality tries to realize that essence through technological means." VR application development should try to match that essence to the application's goals.

Successful clinical VR applications

Several clinical VR applications have moved from the demonstration stage to either the pilot production (has real users but remains in the developer's hands, under test) or full production stage (has real users doing real work, with the system in the user's hands) of application maturity. The diversity of these applications is astounding. They all have interdisciplinary development teams consisting of both clinicians and computer experts, and the imagination to match the limited capabilities of current VR technology to the existing needs of clinical practice. This article gives a brief survey of three clinical VR applications: treatment of anxiety disorders, pain distraction, and ankle rehabilitation. Each survey presents a brief summary of the problem being addressed, the advantages of using VR, and current results and successes.

Anxiety disorders

To conquer our fears, we must face them. A psychological model called *emotional processing theory* elucidates this idea.[6] This theory purports that fears are coded as memories and include information about stimuli (what types of things elicit the fear), responses (how we feel and what we do when confronted with the feared situation), and meaning (how we interpret the situation). Therapy attempts to change the fear structure. For it to be effective, therapy must satisfy two conditions. First, it must activate the fear memory. Second, while the fear structure is activated, it must provide information that's incompatible with the fear memory to form a new memory.[6]

Psychologists have used exposure therapy to treat anxiety. Exposure therapy typically consists of confronting the feared situation in imagination (imaginal exposure) or in real life (in vivo exposure). Then, information incompatible with the fear is provided and experienced during therapy. Any method capable of activating the fear memory structure and modifying it would be predicted to improve symptoms of anxiety. Thus, VR is a potential tool for treating anxiety disorders. If an individual becomes immersed in a feared VE, activation and modification of the fear structure is possible. Furthermore, VR offers some advantages in conducting exposure therapy. The ideal is that exposure therapy should be repeated (the individual should be able to confront the fear numerous times), gradual (the individual should confront the fear in steps, beginning with the least fear-provoking situation), and prolonged (the individual should be able to stay in the feared situation until anxiety subsides). VR gives the therapist greater control over the feared situation, thus allowing for a maximally effective exposure. For example, in treating the fear of flying using VR, the therapist can control the weather, which isn't possible in the real world.

Most of the work to date has focused on treating specific phobias. Individuals with specific phobias have an excessive, persistent, and irrational fear of a specific situation to the extent that it impacts the quality of their life.[2] For example, someone with a phobia of flying might decline a job promotion because it involves airplane travel.

Several case studies support the use of VR in treating specific phobias, including fear of heights,[7] fear of flying,[8] specific phobia of spiders,[9] and claustrophobia.[10] Case studies are important first steps for determining a treatment's effectiveness, but they're vulnerable to a host of methodological flaws that could contaminate the results. Controlled studies in which therapists assess and treat study participants independently according to a standardized treatment protocol provide more compelling data that a treatment will be useful. To date, researchers have done controlled studies examining VR for treating two types of specific phobia—fear of heights and flying.

Acrophobia. VR was used for exposure therapy in treating the fear of heights (acrophobia) in the first controlled study applying VR to a psychological disorder.[7] Participants were repeatedly exposed to virtual footbridges, outdoor balconies, and a glass elevator. VR exposure (VRE) therapy was effective in significantly reducing the fear of heights and improving attitudes toward heights, whereas no change was noted in the control group. Anxiety, avoidance, distress, and fearful attitudes toward heights decreased significantly for the VRE group but not for the wait-list control group.

The results of this study provided preliminary evidence that VEs could satisfy the two conditions necessary for treating anxiety effectively. First, individuals' fears were activated within the VE. Many participants spontaneously reported physical sensations associated with anxiety while in the VEs, including sweating, butterflies, and weak knees.[11] In addition to activating the fear, individuals were able to recover from the fear while in the VE, as shown by decreases in anxiety over the course of therapy. Finally, the study suggested that facing a fear in a virtual world helped people face their fear in the real world. In fact, 7 of the 10 VRE treatment completers exposed themselves to real-life height situations by the end of treatment without being instructed to do so.

Fear of flying. To further challenge the potential of using VR to treat anxiety, researchers compared the efficacy of VRE to in vivo standard exposure therapy (SE), the current standard of care in treating specific phobias.[12] Random assignment of participants, standardized treatment delivery, homogeneous *Diagnostic and Statistical Manual of Mental Disorders* (DSM) inclusion criteria,[2] and blind independent assessment assured a methodologically rigorous study.

Treatment consisted of eight individual therapy sessions. The researchers taught anxiety management skills to all participants during sessions 1 through 4. Exposure was conducted in sessions 5 through 8, either in a VRE by sitting in an airplane for take-offs, smooth flight, turbulent flight, and landings or in an SE by participating in airport preboarding activities and sitting in a stationary airplane.

A post-treatment flight on a commercial airline measured participants' willingness to fly and anxiety during flight. The results indicated that VRE and SE were both superior to a wait-list control group that received no treatment, with no differences between VRE and SE. The researcher showed that VRE was effective by

- decreases in self-reported anxiety on standardized questionnaires,
- the number of participants willing to fly following treatment,
- anxiety ratings during the actual flight, and
- self-ratings of improvement.

The gains observed in treatment were maintained at a six- and 12-month follow-up.[13] One year after they completed treatment, more than 93 percent of participants in both treatment groups reported continuing to fly after the graduation flight and evaluated themselves as "much improved" after treatment.

This study's results suggest that VR is equally effective as a tool for exposure therapy and as the current standard of care for treating some phobias. Another interesting finding is that anxious individuals seem to prefer VRE therapy more than SE therapy. In the fear of flying study, individuals in the wait-list condition were allowed to choose the type of therapy after the waiting period ended, and 14 of the 15 chose VRE therapy. Thus, not only does VR appear to be effective, but it also appears to be palatable to the people who need treatment.

This conclusion is supported by a recent study in which Garcia-Palacios et al.[14] surveyed 777 undergraduate students. Students filled out a fear of spiders questionnaire. They then read a brief, general description of how exposure therapy works and gave ratings about their willingness to get involved in two different ways of applying the therapy to spider phobia—in vivo exposure or VRE. People who had a high fear of spiders (over one standard deviation above the sample mean on a fear of spiders questionnaire) strongly preferred VRE treatment (81 percent in study 1 and 89 percent in study 2) compared to in vivo exposure therapy. Furthermore, in study 2, only 8 percent of fearful students said they would "absolutely not" be willing to come in for three, one-hour VRE therapy sessions, whereas 34 percent of fearful students said "absolutely not" to one three-hour in vivo therapy session.

Post-traumatic stress disorder. Specific phobias are among the most treatable of psychological disorders. A more severe test of VR therapy's efficacy has been in treating combat-related post-traumatic stress disorder (PTSD) among Vietnam veterans. PTSD is a debilitating disorder that can develop after the experience of a traumatic event such as combat, sexual assault, or a motorvehicle accident. The disorder is characterized by

- reexperiencing the trauma through memories, flashbacks, or nightmares;
- avoidance of thoughts, feelings, and memories of things associated with the trauma; and
- hyperarousal, such as sleep difficulties and irritability.

Combat-related PTSD is estimated to affect 830,000 veterans and can be a devastating disorder that's difficult to treat.[15] Although no therapeutic intervention has proven to be consistently effective in treating combat-related PTSD, behavioral therapies with an exposure component have been more effective than most other types of treatment.[16] Unfortunately, a significant number of veterans don't seem to benefit from exposure therapy, perhaps because of difficulties imagining, visualizing, or describing their trauma experiences.

© 2000 Virtually Better

2 **Landing zone in Virtual Vietnam.**

© 2000 Virtually Better

3 **Small group audience in VR.**

Thus, VR offers the possibility of assisting veterans in facing their traumatic memories (see Figure 2).

An uncontrolled treatment study of VR therapy was conducted in conjunction with the Atlanta Veteran's Administration Medical Center (VAMC) and sponsored by the National Institutes of Mental Health. Ten Vietnam veterans completed the treatment.[17]

Six months after treatment, the average reduction in PTSD symptoms ranged from 15 to 67 percent. Six of 8 patients reported improvement, and clinicians rated that 7 of 8 patients were improved. From pre- to post-treatment, veterans' PTSD symptoms decreased from severe to moderate and from moderately to mildly depressed. Thus, participants experienced a modest amount of relief from the treatment, although most participants were still suffering from some PTSD symptoms. The results from this study showed that VR could be effectively used within a comprehensive treatment program to treat a complicated and debilitating psychological disorder.

Social anxiety. One of our current projects continues to push the envelope by examining the use of VR for exposure therapy in treating social anxiety. To date, VR has been successfully used to treat anxiety in situations with powerful physical cues (such as distance cues for heights and flying and gunfire for PTSD). However, social anxiety's hallmark is the fear of negative evaluation from other people. We don't know whether VR can elicit an essentially interpersonal fear, such as feeling judged, evaluated, pitied, or criticized. However, if effective, VR has the potential to help many individuals overcome their fear of public speaking, which is the most commonly feared social situation affecting up to 57 percent of the general population.[18] It's associated with lower income, decreased likelihood of achieving postsecondary education, and increased likelihood of unemployment.[19]

Data from two case studies using a virtual small group audience for exposure are promising (see Figure 3).[20] Results showed that at pretreatment, the participants in these two case studies seemed to be impaired by their public speaking anxiety as measured by DSM-IV criteria for social phobia and previous therapy for public speaking anxiety. After treatment, both patients reported dramatic decreases on self-report measures of public speaking anxiety and reported levels comparable to typical public speaking fears in the general population[21,22] Importantly, the participants rated themselves as "very much improved" and gave a graduation speech to a group of people. Finally, in response to an eight-month follow-up questionnaire, one of the participants indicated that she accepted an executive position in a volunteer organization, had delivered a prepared speech "more than 50 times," and had spoken extemporaneously between "40 and 50 times" since completing treatment. These preliminary findings show that therapists can use VR to help people with social anxiety, but clearly, we need a larger scale study.

Lessons learned. This research program shows that VR can be an effective tool for exposure therapy in treating anxiety disorders. Each study increasingly challenged the technology's limits. Results show that

- anxious individuals can feel nervous in a virtual world,
- confronting a fear in a virtual world generalizes to facing the fear in the real world,
- VR can be effectively used to treat relatively simple anxiety disorders such as specific phobias and more complex anxiety disorders such as PTSD and social anxiety, and
- VR can generate powerful interpersonal and physical cues.

We've learned many lessons over the past nine years while conducting this research. First, a relatively low level of computer graphics sophistication is effective in treating anxiety, especially when augmented by inexpensive multisensory cues. For example, vibrations from speakers mounted under the chairs likely contributed to the effectiveness of the fear of flying treatments,[7] and tactile cues from furry toy spiders has doubled the clinical effectiveness of VR exposure therapy for spider phobia.[23] Furthermore, it's preferable to have a general environment, because it lets an anxious individual "fill in the blanks" with personal experience. Finally, it's imperative to have a multidisciplinary treatment team to create effective VEs, with experts in computer and behavioral sciences. Often, psychologists aren't comfortable with technology and computer scientists aren't comfortable with the idea of psychotherapy, so building such teams can take time and attention.

Pain distraction

Many frequent medical procedures performed in US hospitals cause patients excessive pain, which may be associated with a lengthened hospital stay, longer recovery time, and poorer patient outcomes, all of which have health-care quality and cost implications. VR computer technology may soon be used as a novel technique for reducing excessive pain.

Wound care of severe burns is one of the most painful procedures in medicine. Morphine-related analgesics (that is, opioids) are the standard for treating severe burn pain and are typically the primary analgesia in severe burn pain management plans.[24] Yet opioids have side effects that limit dosage size and frequency (such as tolerance, nausea, delirium, constipation, sleepiness, and risks for physical and psychological dependence). While opioids work well for treating pain while patients are resting, most severe burn patients (about 84 percent,[25]) still report severe to excruciating pain during wound care. Unfortunately, patients often endure daily bandage changes to prevent infection and frequent painful physical therapy sessions to stretch their newly healing skin. The problem of excessive pain is particularly disturbing because a large proportion of severe burn patients are young. For example, more than 40 percent of the more than 400 annual patients with severe burns staying at Harborview Burn Center in Seattle are 22 years old or younger.

As a result of the strong psychological component to pain perception, psychological techniques such as distraction, mental imagery, biofeedback, enhanced control, parental participation, and hypnosis have been shown to reduce pain when used in addition to morphine-related analgesics (see Hoffman et al.[26]). Distraction is particularly useful for burn pain,[27] and immersive VR is unusually attention-grabbing. Patients using VR have the sensation of going inside the 3D computer-generated environment, luring their attention away from their wound. This leaves less attention available to devote to pain perception and patients subjectively experience less pain.

Researchers recently treated two pre-adult patients during wound care involving the removal of staples from healing burn skin grafts (see Figure 4). Each patient had half of their staples removed while playing Nintendo and half removed while in VR (order counterbalanced). Both patients showed large drops in subjective pain ratings while in VR compared to playing Nintendo.[28] Pain during physical therapy sessions also decreased markedly when patients were in VR.[29] Interestingly, the amount of time patients even thought about their pain dropped almost in half.

Because patients commonly endure 20 to 40 painful procedures during their hospital stay, VR pain control would be of little value in practice if it only worked once. Preliminary results suggest that the amount of VR pain reduction achieved doesn't diminish with repeated treatment.[26]

Presence, the sense of going inside the computer-generated environment, is the essence of immersive VR. Hoffman et al.[30] recently explored whether manipulating how present people felt in VR affected analgesic effectiveness. Thirty-eight healthy undergraduate student volunteers participated in a safe ischemic pain laboratory analog study (approved by the University of Washington ethics committee). Subjects were randomly assigned to either a high-tech VR group or a low-tech VR group for a two-minute distraction. The high-tech VR distraction group flew a virtual fighter jet through an icy 3D virtual canyon and shot snowballs at snowmen and igloos. The computer kept track of changes in head position (subjects saw the virtual river when they looked down, a canyon wall when they looked to the right, and so on). They could shoot snowballs with animated explosions and 3D sound effects, and they saw an animated river with waterfall and texture-mapped icy canyon walls. Subjects wore a Virtual Research VR helmet with a 60-degree diagonal field of view (allowing some peripheral vision of the virtual world), and the helmet completely blocked the subjects' view of the real world.

4 **Staple removal from a skin graft. Copyright 2000 to Gretchen Carrougher, RN, Harborview. Copyright 2000 for background image (the jets) goes to Multi-Gen-Paradigm. Graphics artwork on that image by Chris Chambers.**

In contrast, students in the low-tech distraction group also followed a spline path through an icy 3D virtual canyon, but the computer didn't track head position. Subjects didn't shoot snowballs, had no sound effects, no texture maps on the canyon walls, no animations, and they wore much cheaper ViO glasses with a smaller field of view. Subjects in the low-tech group could see the real world (that is, their lap and the laboratory floor) if they glanced down. Both groups also received a two-minute no distraction control condition, during which they didn't wear the VR helmets.

Five visual analog pain scores and an anxiety measure for each treatment condition served as the primary dependent variables. On average, the low-tech VR group showed low presence, little pain reduction, and no drop in anxiety in VR whereas subjects in the high-tech VR group experienced high presence and significant reductions in both pain and anxiety during VR. Collapsing across groups, the researchers positively correlated the amount of pain and anxiety reduction with presence levels reported by subjects (people reporting higher illusion of presence also tended to report more reduction in pain while in VR). Both groups were under similar contextual demand characteristics (for example, subjects from both groups likely figured out that researchers were studying whether pain would be reduced by VR) but were kept unaware of the existence of the other VR treatment group (subject-blind design). Despite similar demand characteristics, subjects in the high-tech group showed more pain reduction compared to subjects in the low-tech group. Thus, like the clinical studies, preliminary laboratory results implicate the contribution of an attentional mechanism for how VR analgesia works.

Because severe burn pain is among the most painful injuries, burn pain serves as a paradigm for other types of procedural pain. Interventions that help severe burn pain during wound care are likely to help with other painful medical procedures. Among other adjunctive psychological remedies, VR pain control may eventually supplement pharmacologies for thousands of patients during cancer treatments, childbirth, dental and gum disease treatment, physical therapy after knee surgery, and other procedural pain. The encouraging preliminary results suggest that the topic of VR pain control warrants further research.

Ankle rehabilitation

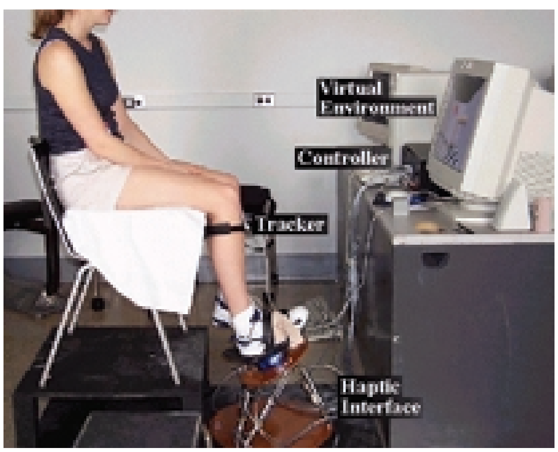
Foot and ankle injuries can occur from trauma,[31] sports injuries,[32] dance,[33] as well as from falls[34] and osteoporosis in the elderly.[35] According to the American Academy of Orthopedic Surgeons, each day 25,000 individuals sprain their ankle in the US alone. Therefore, individuals of all ages can experience lower extremity trauma that will interfere with functional mobility. The incidence of leg and ankle injuries has reportedly increased in recent years.[36] There's also the concern that individuals who are injured don't fully regain function and are prone to reinjury.[37]

Current ankle rehabilitation devices have certain drawbacks. The simple mechanical systems for at-home use aren't sensorized nor networked. Therefore, there's no remote monitoring or reevaluation of patient progress. Patients thus need to travel repeatedly to clinics to be reevaluated, which is difficult for patients with ankle injuries. Furthermore, those clinic and home exercises aren't interactive and can be repetitive and boring. The patient, therefore, may not be as motivated to do the exercises prescribed, and the lack of timely therapy aggravates the patient's medical condition. Changes in the health-care system have shortened the length of hospital stays and the time spent on intensive rehabilitation. In addition, timeliness and duration of rehabilitative therapy have been reported as problems for orthopedic patients in remote rural locations such as Montana or Alaska.[38] These pressures serve as an impetus for developing effective and efficient therapeutic interventions. Using VR technology may solve the challenges of effective and efficient therapy that's timely and accessible.

Girone and colleagues at the Center for Advanced Information Processing (Rutgers University), working in collaboration with the University of Medicine and Dentistry of New Jersey, have developed the Rutgers Ankle as a high-technology rehabilitation interface.[39] As Figure 5 shows, the system consists of a Stewart-platform type robot that exercises the patient's foot under control of a PC running a VR simulation. The platform sensors allow real-time sampling of foot position/orientation and forces/torques applied by the patient.

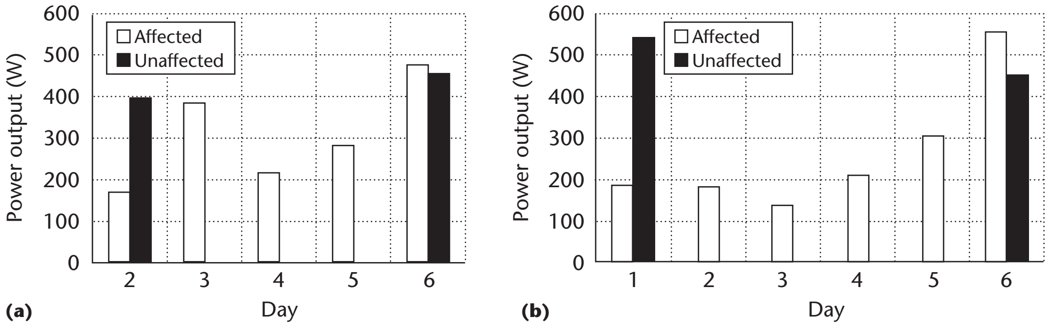
A study done on four patients in 1999 aimed to determine the Rutgers Ankle efficacy as an evaluation tool. The patients ranged in age from 26 to 81 years with general conditions varying from an injured athlete to an elderly person regaining the ability to walk. The therapist compared the performance of the injured to the noninjured ankle when using the Rutgers Ankle and was able to characterize a patient's movement dysfunction by identifying the deficits in range of motion, strength, and coordination. All patients responded favorably to the experience.

In a later study, the Rutgers Ankle efficacy as a rehabilitation device was tested on patients attending an outpatient rehabilitation clinic in New Jersey. Patients had to repeatedly perform a VR exercise consisting of piloting an airplane using their injured ankle. As Figure 6 shows, patients had to pilot the virtual plane through many 3D loops while exercising against the resistance provided by the platform.[40] The therapist changed the exercise difficulty by changing the loops' location, airplane speed, or platform resistance levels. Three orthopedic patients and one stroke patient participated in this study, in six rehabilitation sessions over two weeks.



5 The Rutgers Ankle System.[39]

6 Ankle rehabilitation exercise in VR.[40]



7 **Peak values for ankle mechanical power over the duration of the rehabilitation intervention: (a) an orthopedic patient and (b) a stroke patient.[40,42](Figure 7a ©2000 Rutgers University. Figure 7b © 2001 MIT Press. Reprinted by permission.)**

The objective performance measures obtained by the VR system showed significant improvement in the patients' condition. For example, Figure 7 illustrates the increase in ankle mechanical power (work against platform resistance over time) for an orthopedic patient and a stroke patient. Ankle mechanical power is an important variable affecting equilibrium, and an increase in power correlates with a reduction in the risk of reinjury of the affected ankle. The orthopedic patient had a 67 percent increase in his affected ankle power, and the stroke patient improved by 205 percent. At the end of therapy, both patients had more power in their affected ankle than in the healthy one. Improvements were also experienced by all patients in range of motion and torque capability, and these measures correlated well with standard clinical examinations. Remarkably, the stroke patient improved on his stair climbing ability, but there were no stair climbing exercises in his therapy during the study. It appears that training to ameliorate critical impairments (torque increases and ankle endurance) may have transferred to function.[41]

Conclusion

Although less than 10 years old as a discipline, clinical VR has rapidly progressed from an academic exercise to a robust area of VR practice. Outside of entertainment, there's currently no other application of VR that is as successful in terms of actual use beyond research demonstrations as clinical VR. VEs are routinely used for treating anxiety disorders at numerous clinics in the US and in Canada, Israel, Australia, Korea, Italy, Spain, and Argentina.

Several studies have shown that using VR for pain distraction and rehabilitation, while not yet widely available to clinicians, is clinically viable. Apart from being entertaining (almost video game-like), these applications are often patient-based and track patient performance. Rehabilitation procedures must be flexible enough to address the particular conditions of a given patient and vary certain simulation parameters, such as difficulty index. By tracking patient performance, the simulation changes slightly every time it's started, based on what the patient did in the previous rehabilitation session.

Another characteristic of clinical VR is its dual use in assessment and rehabilitation. The same simulation may be used both as an assessment tool of a patient condition, and (later) as a rehabilitation tool. The online nature of VR rehabilitation allows transparent data collection, producing much richer clinical data than classical means. This data can then be made available remotely, through what has been recently termed telerehabilitation.[43]

Finally, in an area full of subjectivism, clinical VR—through its scientific data sampling—may introduce objective measures of a patient's rehabilitation. The application developer then must match VR-specific variables obtained from the simulation with clinical evaluations done preexposure and postexposure to VR.

In addition to the work we've presented, researchers are rapidly envisioning and exploring new areas of clinical VR. We're aware of a number of new projects investigating low-cost VEs for such diverse applications as the rehabilitation of balance disorders[44] assessment and rehabilitation of attention deficits,[45] and assessment of visuospatial[46] and driving skills.[47] In all these areas it's possible that relatively low-cost VR technology, at its present state of development, can produce more improved clinical results than current approaches. The major obstacle to even faster development in this area has been the need to develop new applications in the content of multidisciplinary teams. Close cooperation and communication among engineers, computer scientists, and clinicians is imperative if we are to create effective new VR therapy applications. ■

Acknowledgments

An early draft of this article was first presented as the keynote address at IEEE Virtual Reality 2001 in Yokohama, Japan. The Office of Naval Research provided travel support to Larry Hodges for developing the ideas in that talk and this article.

Barbara Rothbaum and Larry Hodges receive research funding and are entitled to royalty sales from Virtually Better, which is developing products related to the research described in this article. In addition, the investigators serve as consultants to and own equity in Virtually Better. Emory University and Georgia Institute of Technology have reviewed and approved the terms of this arrangement in accordance with their conflict of interest policies.

Grigore Burdea received research funding from the National Science Foundation.

References

1. F.P. Brooks, Jr., "What's Real About Virtual Reality?," *IEEE Computer Graphics and Applications*, vol. 19, no. 6, Nov./Dec. 1999, pp. 16-27.
2. American Psychiatric Assoc., *Diagnostic and Statistical Manual of Mental Disorders*, fourth ed., APA, Washington, D.C., 1994.
3. W.J. Magee, "Agoraphobia, Simple Phobia, and Social Phobia in the National Comorbidity Survey," *Archives of General Psychiatry*, no. 53, 1996, pp. 159-168.
4. *Research Plan for the National Center for Medical Rehabilitation Research*, Nat'l Insts. of Health publication no. 93-3509, Nat'l Center for Medical Rehabilitation Research, Washington, D.C., 1993.
5. E. Brandt and A. Pope, eds., *Enabling America—Assessing the Role of Rehabilitation Science and Engineering*, Nat'l Academy Press, Washington, D.C., 1997.
6. E.B. Foa and M.J. Kozak, "Emotional Processing of Fear: Exposure to Corrective Information," *Psychological Bull.*, vol. 99, 1986, pp. 20-35.
7. B.O. Rothbaum et al., "Effectiveness of Virtual Reality Graded Exposure in the Treatment of Acrophobia," *Am. J. Psychiatry*, vol. 152, 1995, pp. 626-628.
8. B.O. Rothbaum et al., "Virtual Reality Exposure Therapy in the Treatment of Fear of Flying: A Case Report," *Behaviour Research and Therapy*, vol. 34, no. 5/6, 1996, pp. 477-481.
9. A.S. Carlin, H.G. Hoffman, and S. Weghorst, "Virtual Reality and Tactile Augmentation in the Treatment of Spider Phobia: A Case Report," *Behaviour Research and Therapy*, vol. 35, no. 2, Feb. 1997, pp. 153-158.
10. C. Botella et al., "Virtual Reality Treatment of Claustrophobia: A Case Report," *Behaviour Research and Therapy*, vol. 36, no. 2, Feb. 1998, pp. 239-246.
11. L.F. Hodges et al., "Virtual Environments for Treating the Fear of Heights," *Computer*, vol. 28, no. 7, July 1995, pp. 27-32.
12. B.O. Rothbaum, "A Controlled Study of Virtual Reality Exposure Therapy for the Fear of Flying," *J. Consulting and Clinical Psychology*, vol. 68, no. 6, 2000, pp. 1020-1026.
13. B.O. Rothbaum et al., "12-month Follow-Up of Virtual Reality and Standard Exposure Therapies for the Fear of Flying," to be published in *J. Consulting and Clinical Psychology*.
14. A. Garcia-Palacios et al., "Redefining Therapeutic Success with VR Exposure Therapy," to be published in *Cyberpsychology & Behavior*.
15. D.R. Weiss et al., "The Prevalence of Lifetime and Partial Post-Traumatic Stress Disorder in Vietnam Veterans," *J. Traumatic Stress*, vol. 5, 1992, pp. 365-376.
16. M. van Etten and S. Taylor, "Comparative Efficacy of Treatments for Posttraumatic Stress Disorder: A Meta-Analysis," *Clinical Psychology and Psychotherapy*, vol. 5, 1998, pp. 126-145.
17. B.O. Rothbaum et al., "Virtual Reality Exposure Therapy for Vietnam Veterans with Posttraumatic Stress Disorder," to be published in *J. Traumatic Stress*.
18. F.L. Schneier et al., "Functional Impairment in Social Phobia," *J. Clinical Psychology*, vol. 55, 1994, pp. 322-331.
19. M.B. Stein, J.R. Walker, and D.R. Forde, "Public-Speaking Fears in a Community Sample," *Archives of General Psychiatry*, vol. 53, 1994, pp. 169-174.
20. P. Anderson, B.O. Rothbaum, and L. Hodges, "Virtual Reality Exposure Therapy for the Fear of Public Speaking: A Case Study," presented at the Ann. Meeting of the American Psychological Association, Washington, D.C., 2000.
21. S.G. Hofmann and P.M. DiBartolo, "An Instrument to Assess Self-Statements during Public Speaking: Scale Development and Preliminary Psychometric Properties," *Behavior Therapy*, vol. 31, 2000, pp. 499-515.
22. R. Klorman et al., "Psychometric Description of Some Specific-Fear Questionnaires," *Behavior Therapy*, no. 5, 1974, pp. 401-409.
23. H.G. Hoffman et al., "Interfaces that Heal: Coupling Real and Virtual Objects to Treat Spider Phobia," to be published in *Int'l J. Human–Computer Interaction*.
24. D.R. Patterson, "Practical Applications of Psychological Techniques in Controlling Burn Pain," *J. Burn Care Rehabilitation*, vol. 13, no. 1, 1992, pp. 13-18.
25. S. Perry, G. Heidrich, and E. Ramos, "Assessment of Pain by Burn Patients," *J. Burn Care Rehabilitation*, vol. 2, 1981, pp. 322-327.
26. H.G. Hoffman et al., "The Effectiveness of Virtual Reality Based Pain Control with Multiple Treatments," *Clinical Journal of Pain*, vol. 17, no. 3, Sept. 2001, pp. 229-235.
27. A.C. Miller, L.C. Hickman, and G.K. Lemasters, "A Distraction Technique for Control of Burn Pain," *J. Burn Care Rehabilitation*, vol. 13, no. 5, Sept./Oct. 1992, pp. 576-580.
28. H.G. Hoffman et al., "Use of Virtual Reality for Adjunctive Treatment of Adolescent Burn Pain During Wound Care: A Case Report," *Pain*, vol. 85, no. 1-2, March 2000, pp. 305-309.
29. H.G. Hoffman, D.R. Patterson, and G.J. Carrougher, "Use of Virtual Reality for Adjunctive Treatment of Adult Burn Pain During Physical Therapy: A Controlled Study," *Clinical J. Pain*, vol. 16, no. 3, Sept. 2000, pp. 244-250.
30. H.G. Hoffman et al., "The Influence of Manipulating Presence on the Magnitude of Virtual Reality Analgesia," submitted for publication.
31. C.S. Parenteau et al., "Foot-Ankle Injuries: Influence of Crash Location, Seating Position and Age," *Accident Analysis & Prevention*, vol. 28, no. 5, 1996, pp. 607-17.
32. D. Hopper, B. Elliott, and J. Lalor, "A Descriptive Epidemiology of Netball Injuries during Competition: A Five Year Study," *British J. Sports Medicine*, vol. 29, no. 4, 1995, pp. 223-228.
33. J. Macintyre, "Foot and Ankle Injuries in Dance," *Clinics in Sports Medicine*, vol. 19, no. 2, 2000, pp. 351-368.
34. S.L. Jensen, "Epidemiology of Ankle Fractures: A Prospective Population-Based Study of 212 Cases in Aalborg, Denmark," *Acta Orthopaedica Scandinavica*, vol. 69, no. 1, 1998, pp. 48-50.
35. P. Kannus et al., "Epidemiology of Osteoporotic Ankle Fractures in Elderly Persons in Finland," *Annals of Internal Medicine*, vol. 125, no. 12, 1996, pp. 975-978.
36. C.M. Court-Brown, J. McBirnie, and G. Wilson, "Adult Ankle Fractures—An Increasing Problem?," *Acta Orthopaedica Scandinavica*, vol. 69, no. 1, 1998, pp. 43-47.
37. J.P. Gerber et al., "Persistent Disability Associated with Ankle

Sprains: A Prospective Examination of an Athletic Population," *Foot & Ankle Int'l*, vol. 19, no. 10, 1998 pp. 653-60.
38. Center for Telemedicine Law, *Telemedicine Reimbursement Source Book*, CTL, Washington, D.C., July 2000.
39. M.J. Girone et al., "Othopedic Rehabilitation Using the 'Rutgers Ankle' Interface," *Proc. Medicine Meets Virtual Reality 2000*, IOS Press, Amsterdam, The Netherlands, 2000, pp. 89-95.
40. J. Deutsch et al., "Rehabilitation of Musculoskeletal Injuries Using the Rutgers Ankle Haptic Interface: Three Case Reports," *Proc. Eurohaptics 2001*, Univ. of Birmingham, Birmingham, UK, 2001, pp. 11-16.
41. M. Schenkman et al., "Multisystem Model for Management of Neurologically Impaired Adults—An Update and Illustrative Case," *Neurology Report*, vol. 24, no. 4, 1999, pp. 145-157.
42. J. Deutsch et al., "Post-Stroke Rehabilitation with the Rutgers Ankle System—A Case Study," *Presence*, MIT Press, vol. 10, no. 4, 2001, pp. 420-435.
43. M. Rosen, "Telerehabilitation," *NeuroRehabilitation*, vol. L, no. 12, 1999, pp. 11-26.
44. J. Jacobson et al., "Balance NAVE: A Virtual Reality Facility for Research and Rehabilitation of Balance Disorders," to be published in *Proc. ACM Virtual Reality Systems and Technology*, ACM Press, New York, 2001.
45. A.A. Rizzo et al., "The Virtual Classroom: A Virtual Reality Environment for the Assessment and Rehabilitation of Attention Deficits," *CyberPsychology & Behavior*, vol. 3, no. 3, 2000, pp. 483-501.
46. J.S. McGee et al., "Issues for the Assessment of Visuospatial Skills in Older Adults Using Virtual Environment Technology," *CyberPsychology & Behavior*, vol. 3, no. 3, 2000, pp. 469-483.
47. M. Schultheis et al., "Virtual Reality and Driving: The Road to Better Assessment for Cognitively Impaired Populations," to be published in *Presence: Teleoperators and Virtual Environments* (special issue on virtual environments and neuropsychology).

Larry F. Hodges *is an associate professor in the College of Computing and the head of the Virtual Environments Group in the Graphics, Visualization, and Usability Center at the Georgia Institute of Technology. He is also cofounder of Virtually Better, a company that specializes in creating virtual environments for treating anxiety disorders. His research interests include all aspects of virtual reality and 3D human–computer interaction. He received his PhD from North Carolina State University in computer engineering in 1988. He is a senior editor of* Presence: Teleoperators and Virtual Environments *and is a member of the steering committee for the annual IEEE Virtual Reality conference.*

Page Anderson *is director of clinical services at Virtually Better, a clinic specializing in the treatment of anxiety. She conducts federally funded clinical trials testing the effectiveness of VR in the treatment of anxiety and is interested in applying VR technology to self-help programs for anxiety. She earned a PhD at the University of Georgia in clinical psychology and completed a postdoctoral fellowship at Emory University School of Medicine.*

Grigore Burdea *is an associate professor in the Electrical and Computer Engineering Department at Rutgers University and the director of the Human–Machine Interface Laboratory. He obtained his PhD from New York University in 1987. He wrote* Virtual Reality Technology *and* Force and Touch Feedback for Virtual Reality *(both by John Wiley & Sons, New York) and served as the general chair of the IEEE Virtual Reality 2000 conference.*

Hunter Hoffman *manages the Paul Allen/NIH VR burn pain reduction project at the Human Interface Technology Laboratory (the HITLab) at the University of Washington in Seattle. He is an affiliate associate professor of psychology at the University of Washington. He spent a year at Princeton University, did his graduate research on human memory and attention with Elizabeth Loftus at the University of Washington, and then began studying attention and immersive virtual reality at the HITLab in 1993. He and Dave Patterson have been collaborating on VR pain control since 1996.*

Barbara O. Rothbaum *is an associate professor in psychiatry at the Emory School of Medicine in the Department of Psychiatry and Behavioral Sciences and director of the Trauma and Anxiety Recovery Program at Emory. She received her PhD in clinical psychology in 1986 and specializes in research on the treatment of individuals with anxiety disorders, particularly focusing on posttraumatic stress disorder (PTSD). She received the Diplomate in Behavioral Psychology from the American Board of Professional Psychology. She is on the Board of Directors of the International Society of Traumatic Stress Studies (ISTSS) and is Associate Editor of* The Journal of Traumatic Stress.

Readers may contact Hodges at College of Computing, Georgia Institute of Technology, Atlanta, GA 30332-0280, email hodges@cc.gatech.edu.