Virtual Reality Technology for Assessment and Treatment of Rehabilitation Patients: Considerations for Research

Laurel J. Buxbaum, Psy.D.

1. Strengths of virtual reality applications in rehabilitation.

The past decade has witnessed burgeoning interest in the use of virtual reality (VR) technology for assessment and treatment of rehabilitation patients. VR applications have a number of desirable features from a rehabilitation perspective. First, VR presents an opportunity to create assessment and rehabilitation scenarios that incorporate naturalistic challenges and are highly relevant to real-world functioning. For example, a number of virtual homes, classrooms, cities, and kitchens have been produced, and some are well-correlated with performance in the real-world environment (Rizzo et al. 2004). Second, VR permits experimental control over stimulus timing, visual appearance, auditory attributes, and other stimulus characteristics. These attributes can be manipulated in service of a number of goals; for example, to optimize similarity to real-world functional environments, parametrically vary or titrate aspects of the stimuli along some desired dimension, and/or test specific hypotheses about the role of various environmental factors in patterns of performance. VR applications also permit delivery of feedback to patients on a desired schedule (e.g., immediately, or with reference to an automated schedule), and provided in the desired sensory modalities, for example, via audition or vision. The virtual environment (VE) additionally allows the assessment or training procedure to be temporarily “paused” for the purpose of evaluation and discussion with the patient or rehabilitation staff. VE’s can be developed to incorporate game-like elements that may improve patient motivation to participate in therapy, and may be used for self-guided independent training for continued practice after discharge from the rehabilitation hospital. Thus, VR appears both well-suited to rehabilitation and worthy of additional research.

2. Equipment and other practical considerations for using virtual reality systems in rehabilitation research.

A critical feature of VR applications is interaction with the VE and with virtual objects within the environment. A number of different types of hardware and software may be used to create VE’s with differing capabilities. Many systems consist of a computer with a three-dimensional (3-D) graphics card, hardware devices to measure movement kinematics and/or provide haptic or force feedback, and specialized software.

Another important feature of virtual reality is the provision of a sense of actual presence or immersion in the simulated environment. Recent work suggests that physiological measures including heart rate and galvanic skin response correlate strongly with subjective user impressions of immersion.

Several options are available for stimulus display, ranging from flatscreen desktop monitors to head-mounted displays (HMD's) to highly immersive VR "caves" that provide multi-person, room-sized 3-D graphics. It turns out, however, that for many purposes, the degree of graphic realism of the VR display is of circumscribed relevance in influencing the subjective feeling of presence in the VE. For example, a number of VR scenarios presented on flatscreen or HMD systems designed to treat specific phobias through exposure have resulted in subjective fear responses and elevated physiological indices of distress (and ultimately, have proven successful) despite the fact that the display is not actually "mistaken" for the real world (e.g., Macedonio et al. 2007). On the other hand, there are clearly research questions that warrant the use of more immersive systems. For example, the laboratory of Emily Keshner at Temple University is studying the contribution of visual, tactile, and vestibular cues to balance controls; an area of research for which an immersive "cave" system is well-suited (e.g., Keshner, Dokka and Kenyon 2006). To this point, displays presented on large (> 48") flat screens have performed with strong ecological validity in several studies with rehabilitation patients (see Buxbaum et al. 2008, for example). Flatscreen systems also avoid the "cybersickness" (dizziness, nausea, headache, loss of coordination, and/or loss of balance) frequently encountered with head-mounted displays. An additional difficulty with head-mounted displays is that they must be adjusted to fit a wide range of individual participants, as is often necessary in clinical and research environments.

Many VR systems operate with standard mouse and/or joystick interfaces. In addition, several types of motion-tracking devices may be used to monitor movements of the arms, trunk, and/or legs. Electromagnetic tracking devices are commonly used. Instrumented gloves fitted with vibrotactile devices may be used to provide tactile feedback when a virtual object has been "touched". Robotic arms, hands, or fingers that generate force feedback may also be used.

As pointed out by Holden (2005), the efficacy of various systems depends largely upon how well-versed developers are with the underlying rationale for the particularities of these systems as they relate to the specific deficits of the patient population (e.g., in terms of scientific theories and findings in the domain of motor learning). At the same time, engineering knowledge is required to understand the capabilities and limitations of various technologies. Thus, to be successful, experiments using VR technology require collaboration among clinicians, engineers, and researchers.

3. Some highlights of research on use of virtual reality as relevant to rehabilitation.

A number of studies indicate that motor skills can be learned in a virtual environment and transferred to real-world environments (see Holden, 2005, for review), even when the motor response required in the former (e.g., a joystick movement) is substantially different than the one required in the latter (e.g., ambulation). In addition, there is growing evidence that the opportunity for enhanced feedback and guided practice in a VE may result in learning that is in some cases superior to learning in real-life settings (e.g., (Todorov, Shadmehr and Bizzi 1997; Brooks et al. 1999).

Several recent VR applications from the laboratory of Maureen Holden and colleagues at the Massachusetts Institute of Technology (MIT) have capitalized on the concept of learning to imitate a “virtual teacher” who performs movements many times over within the context of virtual functional tasks (e.g., wiping a virtual tabletop or lifting a cup to the mouth). To facilitate movement matching, a pre-recorded trajectory of the correct movement is displayed alongside the real time trajectory of the patient’s own movement. The degree of “match” may also be quantified to provide augmented feedback in the form of a score or other verbal feedback. To this point, such systems have shown good generalization to similar real world tasks (Holden 2005; Holden, Dyar and Dayan-Cimadoro 2007).

Another recent system, developed by a team at Rutgers University, focuses on rehabilitation of the hand. The system incorporates a commercially-available glove that monitors hand position and provides feedback about movement kinematics, along with a laboratory-developed glove containing pneumatic pistons that is used for training of strength and finger fractionation. Similar to the MIT system, patients receive immediate feedback in the form of a virtual hand on the screen, as well as a quantitative score. Studies to date suggest improvement in the timing of hand preshaping, as well as the range of motion of individual fingers (Adamovich et al. 2004).

The Rutgers group has also developed a haptic device for training ankle control that provides resistive forces to patients’ feet during game-like exercises. There is preliminary evidence that the system may improve power, strength, and gait speed in at least some patients. In one of the few studies reviewed to provide a control group (see below for discussion), researchers at the Palo Alto Veterans Administration recently compared training of obstacle avoidance during walking using VR software with vibrotactile feedback to a real-world obstacle avoidance task, and demonstrated that the VR group showed greater improvement in post-training movement speed (Jaffe et al. 2004).

A considerable number of other VR systems have been the subject of at least preliminary research, including systems for training and/or evaluating perceptual-motor skills (Connor et al. 2002), activities of daily living (Davies et al. 2002; Zhang et al. 2003), and wheelchair mobility (Webster et al. 2001).

Finally, several groups are investigating the provision of VR rehabilitation services in the home via so-called “telerehabilitation” delivered over the internet. Such systems may prove invaluable to patients with limited access to outpatient clinics or insufficient endurance to make such trips. Some limited improvements have been noted in patients using such systems (Piron et al. 2001; Holden 2005).

4. Recommendations for future research with virtual reality applications.

VR has many attributes that render it well-suited to training and evaluation of rehabilitation patients. VR appears feasible to use with rehabilitation patients, has demonstrated some success in generalizing to real-life settings, and in some instances appears to lead to rehabilitation outcomes that are better than those achieved through standard therapies. Because the technology is relatively young, however, much of the research to date on the use of VR as an evaluation or training tool is limited to small studies geared toward feasibility or proof of concept, and lacking appropriate (or any) control groups. This area of investigation appears to have matured to the point where well-controlled group studies are warranted to determine how various VR techniques fare when compared to "standard" clinical assessment and therapy practices. In addition, considerable work remains to determine the types of patients best suited to VR rehabilitation techniques. Many of the studies to date, for example, have been performed with mildly-impaired patients with considerable remaining cognitive and motor capacity, and it is unclear whether these remaining capacities are required for successful outcomes. In addition, when a given VR treatment appears successful, it is frequently not clear which aspect(s) of the treatment are critical in achieving these outcomes. Further research is required to dissect out the "ingredients" that contribute to these demonstrated successes.

Finally, in part because the technology is new and compelling, there may be a tendency to focus research questions around the capacities of a particularly interesting (and sometimes complex or highly engineered) system, rather than selecting the simplest system(s) capable of answering the research questions at hand. As with any integration of technology into research, it is important to maintain focus on the major aims of the rehabilitation research endeavor and to recognize that VR, like any other technology, is a tool that can be used to address these goals.

5. Links to laboratories conducting rehabilitation research with VR.

Following are several useful websites that provide a sample of the notable rehabilitation research activities currently being conducted using VR technologies.

Rutgers University:
http://www.caip.rutgers.edu/vrlab/

University of Southern California:
http://ict.usc.edu/projects/virtual_reality_psychology_and_social_neuroscience/C50

Massachusetts Institute of Technology:
http://web.mit.edu/bcs/bizzilab/projects/index.html#telerehabilitation

University of Haifa:
http://hw.haifa.ac.il/occupa/LIRT/

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Holden, M. (2005). "Virtual environments for motor rehabilitation: A review." Cyberpsychology and Behavior **8**(3): 187-211.

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Jaffe, D., D. Brown, et al. (2004). "Stepping over obstacles to improve walking in individuals with poststroke hemiplegia." Journal of Rehabilitation Research Development **41**(3A): 155-172.

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Macedonio, M., T. Parsons, et al. (2007). "Immersiveness and physiological arousal within panoramic video-based virtual reality." Cyberpsychology and Behavior **10**(4): 508-515.

Piron, L., F. Cenni, et al. (2001). "Virtual reality as an assessment tool for arm motor deficits after brain lesions." Studies in Health Technology and Informatics **81**: 386-392.

Rizzo, A., M. Schultheis, et al. (2004). "Analysis of assets for virtual reality applications in neuropsychology." Neuropsychological Rehabilitation **14**(1-2): 207-239.

Todorov, E., R. Shadmehr, et al. (1997). "Augmented feedback presented in a virtual environment accelerates learning of a difficult motor task." Journal of Motor Behavior **29**: 147-158.

Webster, J., P. McFarland, et al. (2001). "Computer-assisted training for improving wheelchair mobility in unilateral neglect patients." Archives of Physical Medicine and Rehabilitation **82**: 769-775.

Zhang, L., B. Abreu, et al. (2003). "A virtual reality environment for evaluation of daily living skill in brain injury rehabilitation: reliability and validity." Archives of Physical Medicine and Rehabilitation **84**: 1118-1124.