

VIRTUAL REALITY THERAPY AS A REHABILITATION TOOL

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Abstract: Most human motor skills involve the use of a tool to complete the desired action. The objective of this paper was to study recent virtual reality applications as a therapy for patients with neuromotor problems. Specifically this applies to victims of conditions such as stroke, acquired brain injury, multiple sclerosis, cerebral palsied children. Computerized literature searches were performed using the PubMed, MEDLINE and REHABDATA databases. This resulted in ninety-four journal articles. Fortyfive studies were related to upper-limb extremity training, five to lower-limb training, twentyfive to motor learning in virtual environments and nineteen to gait rehabilitation. Our research data suggest that the current evidence on the effectiveness of using VR in motor rehabilitation is limited but sufficiently encouraging to justify additional clinical trials. Although this field of research appears to be in its early stages, the new Virtual Reality (VR) Therapy for rehabilitation approaches is emerging as an important option for clinicians and patients. © 2007 by the Division of kinetotherapy, Univ. of Craiova

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1. INTRODUCTION

Virtual Reality (VR) Therapy is one of the emerging and most effective applications of VR technology, where patients are exposed to stimuli in fully controllable environments (Rizzo *et al.*, 2004; Riva, 2003). Whether it is immersive, such as a CAVE-like environment, or non-immersive, such as desktop-like displays, the idea is to recreate a believable artificial environment that stimulates physical responses similar to those of a real environment that can be individually controlled, replicated, and tailored to the patient's experiences. The patient is presented only with environmental features that he can control, such as difficulty level, complexity, and amount of stimuli. This enables a highly scalable and controllable environment. In addition, patients are motivated by the novel and entertaining nature of the experience. This improves dramatically the patient's focus and compliance with the activity in therapy. Continuing

advances in VR and haptics technology along with concomitant system cost reductions have supported the development of more usable, useful, and accessible VR systems that can uniquely target a wide range of physical, psychological, and cognitive rehabilitation concerns (Standen *et al.*, 2005), surgery-related applications (Riva, 2003) and related research questions.

Techniques for producing experiential effects may result in a relatively nonimmersive environment. Such arrangements typically employ a video screen and headphones or loudspeakers for presentation of audiovisual stimuli and a mouse or joystick for patient response. While one may think that the subject involvement is at a low level in such a situation, consider the strong hold that the typical video game exerts on the participant. Direct bodily movements also can direct the computer to produce a strongly interactive environment. Increasing levels of immersion require more sophisticated

input/output devices. These include wide-field stereoscopic head-mounted displays (HMDs) for audio and visual stimuli, with modification of video and audio stimuli in accordance with patient movement, to simulate scene changes with head and body movement. Haptic (force-feedback) devices provide reaction to the subject's movements by producing forces simulating those generated in an actual subject environment. These devices may take the form of simulated endoscopic instruments, such as bronchoscopic devices that can be combined with imaging (CT) for 3-dimensional modeling and surgical instruments to provide texture and resistance feedback. Transducers may simulate pilot controls of an airplane or can be configured as gloves or even bodysuits that measure subject movement and respond to force, vibrational inputs, and regional temperature changes. Input from these transducers can control virtual musical instruments and increase the precision of motor control for persons with disabilities, while sensory augmentation can compensate for visual loss. Olfactory simulators can be integrated within the HMD for additional limbic stimulation and realism. Vibrational and acceleration stimulation can assist in simulating posterior column and vestibular inputs of an actual subject environment.

2. MEDICAL APPLICATIONS

2.1 Neurologic investigation

VR applications for neurologic investigation and therapy are being developed quickly. If the evolution of medical VR applications is considered, then one can proceed from an essentially open-loop condition toward a closed-loop condition. That is, the computer in fact generates many of the features of the virtual environments previously described. The presentation is varied according to the response, but the patient remains in an artificially created milieu. As virtual surgery and dynamic imaging develop, the operating feedback loops between human and machine will be closing and therefore will become more functional and clinically applicable. This functional enhancement will be realized for systems involving both microsurgical and imaging responses to patient space, whether using actual or computed images (eg, CT scan, MRI). The computer must manipulate images derived from an actual physical environment rather than images developed by its internal program. VR can be applied for measurement and therapeutic approaches to neurologic diseases on the basis of more complete closure of the patient-VR loop. Rather than dealing with pre-acquired images (as with virtual surgery or imaging), the computer must interact on a real-time basis with salient features of the patient and his or her environment and immediately respond to these features to produce audiovisual, haptic, and tactile

responses to correct maladaptive or impaired behavior.

2.2 Upper extremity rehabilitation

Several groups of researchers have been working to develop VR systems for upper extremity (UE) rehabilitation in patients with stroke, using a variety of approaches.

MIT group. Holden and colleagues, based at Massachusetts Institute of Technology (MIT), Cambridge, Massachusetts, were the first to report successful use of VR to retrain movement in patients with stroke (Holden *et al.*, 2001). The VR motor re-training system they have developed is centered around the concept of "learning by imitation" of a virtual teacher (Holden, 2001) and allows the user to retrain a wide variety of arm movements (including shoulder, elbow, wrist, and hand) in any part of the UE workspace, within the context of functional or goal-directed tasks.

Study results. In the first study reported by Holden *et al.*, the purpose was to assess whether participants with stroke would even be able to use a virtual environment to practice motor tasks, and if so, whether any movements that they learned in VR would generalize to performance in the real world on similar and untrained tasks. Two participants with stroke (3.5 and 1.5 years post-stroke; one with right hemiparesis and aphasia; one with left hemiparesis, parietal lobe symptoms, left side inattention and hemianopsia) were trained on a complex reaching task on their involved side, requiring shoulder flexion with external rotation, elbow extension, and forearm supination combined with grasp. Before and after training, participants were assessed on their reaching ability using a 3-D kinematic test performed in the real world. Results for the kinematics test indicated that, not only could participants transfer what they learned in VR practice to the real world, but also, that they generalized the motor learning to untrained spatial locations. Both participants showed significant improvement for distance errors to the target across both trained and untrained locations. Hand orientation errors improved in the trained location and for five of eight untrained locations; as expected, the control of hand orientation while reaching and grasping proved more difficult to learn than control of reach with no constraint on hand orientation. In a second study, the issue of motor generalization was examined in greater depth. The study provided further evidence that movements trained in VR in patients with stroke can be generalized to similar real world tasks and to certain types of untrained tasks. In this study, two movements were trained in a virtual environment using the same system as in the first study, but with the addition of quantitative feedback about trajectory match with the virtual teacher that could

be presented in the form of a score following each trial. Specific and non-specific motor generalization was assessed. Results for the clinical testing (non-specific generalization) of these participants showed that the mean values post-training were significantly higher on both the FM Motor and FM total scores, indicating improvement. These results indicate that most of the improvement was in motor function, but some participants also had decreased pain, increased range of motion and improved sensory scores post-training.

Rutgers group. A second group, Burdea and colleagues, based at Rutgers University and the University of Medicine and Dentistry of New Jersey, has centered their development around the hand. *System description.* Their UE system makes use of the commercially available Cyberglove™ to monitor hand position and to provide feedback about kinematics of hand movement during training, and a laboratory-built glove, Rutgers Master II, to provide haptic monitoring and feedback combined with position sensing (Bouzit, M. *et al.*, 2002). Four types of hand exercise routines have been developed: (1) range of motion (ROM); (2) speed; (3) fractionation; and (4) strength.

Study results. The Rutgers group has used their hand rehabilitation system in two clinical studies with chronic stroke patients. The first study used the system on three participants with right hemiparesis (Jack, D. *et al.*, 2001, Merians, A.S. *et al.*, 2002). In this initial study, the VR treatment was combined with another type of treatment for UE rehabilitation, constraint-induced (CI) therapy. Participants were treated for 5 hr per day for 9 days, with one 2-day break. The majority of the time (approximately 3.5 hr/day) was spent in CI therapy, while the remainder was spent in VR therapy (approximately 1.5 hr/day). Because two different treatments were used in combination, it is not possible to determine whether, or to what extent, the VR therapy contributed to the changes found in the participant's post-training. Participants' progress following this combined therapy was measured using quantitative measures of ROM, speed, fractionation, and work, derived from the VR training data (performance of first 2 days vs. last 2 days). In addition, a clinical test of hand function and dynamometer measures of grip strength were performed. Results for the measures derived from the VR training data showed a variable pattern, with all three participants showing improvement on at least some of the measures. In the second study reported by Burdea and colleagues, (Boian, R.F. *et al.*, 2002, Adamovich, S.V. *et al.*, 2003) eight participants with stroke were treated using the VR system alone. Preliminary results from the first four of these participants are presented in the first report,⁶⁶ while results for all eight participants are presented

in a more recent report.⁷¹ For the quantitative VR measures (ROM, speed, fractionation, and work), results are not averaged across participants; rather, they are presented for each participant individually, as "each participant showed improvement on a unique combination of movement parameters." The most impressive areas of change seem to be for thumb ROM (four of eight participants improved by >40%) and for fractionation where six of eight participants improved by >40%). The changes for speed and work are small and likely not clinically significant, though the authors report "statistical significance" based on results of unpaired *t*-tests, performed individually for each participant. For example, on the speed measure, only three of 16 cases (16 = 8 finger + 8 thumb measures) had >20% improvement, and only three of the eight participants had >20% change on the work measure. For the Jebson test of hand function, results were pooled across participants, and a 15% improvement was found. However, since these data were pooled across participants, it is not clear whether the 15% change reflects a large improvement by a few participants, or a smaller change by most participants. For the grasping task, hand kinematic data were analyzed in terms of movement time, averaged across participants. No change in movement time was found for the transport phase, but an 18% decrease in movement time was found for the grasping phase, although three of the eight participants did not decrease their grasp movement time. Although the authors report that they performed a discriminant analysis on the hand kinematic data as a way to assess hand preshaping during the evolving movement, the results of this analysis are presented for only one participant's data in graphical form. For this participant, classification errors from the discriminant analysis are shown to decrease as the movement evolves, indicating an improvement in the timing of hand preshaping during the grasping task.

2.3 Lower extremity/gait rehabilitation

Several lower extremity VR applications have been developed using different technologies. Preliminary data suggest potential benefits of various systems.

For example, a report based on two case studies using the Vivid GX video capture technology demonstrates improvements in upper extremity function (Kizony R. *et al.*, 2003). The first individual had a T9 complete spinal cord injury requiring use of wheelchair for all mobility activities. His primary rehabilitation goal was to improve sitting balance in order to enable him to perform functional activities such as reaching out for a book placed on a shelf. Analysis of videotaped records of performance revealed that initially he used only one hand at a time to interact with the virtual objects while leaving the other on his lap or

on the wheelchair arm rest in order to maintain balance. As sessions with the VR system progressed, he began to use both hands during the tasks relying on weak trunk muscles to maintain balance. The second individual had a right hemispheric stroke and ambulated with a cane due to poor control of foot and poor standing balance. He had functional movement in the upper extremity, suffered from mild attention deficit and required some help when dressing the lower extremity. The application he used consisted of balls appearing in the VE from all sides requiring that he pay attention to the entire visual space. After 3 minutes of interaction, he asked to get up and continue with therapy while in a standing position (although therapist behind was necessary for safety). Both participants reported enjoyment and wanted to repeat experience if possible. Importantly, they acknowledged the relevance of the experience to their rehabilitation process.

Burdea and colleagues have also developed a VR haptic device for use in training ankle control, the "Rutgers Ankle." (Boian R. F. *et al.*, 2003). The system consists of a Stewart platform-type haptic interface that provides 6 DOF resistive force to the patient's foot, in response to his or her performance in a game-like VR exercise. The patient is treated in the sitting position, with the foot attached via a footplate to the device. Two exercise games have been developed. In the first, the patient pilots a virtual airplane, by using the foot, through a virtual sky. As the plane moves forward, a series of open square hoops are presented on the screen. The goal is for the participant to maneuver the plane through the hoops without hitting the sides. This is done by mapping the ankle kinematics to the flight path (e.g., ankle dorsiflexion causes the nose of the plane to point upward, eversion causes the plane to go toward the left). Difficulty level can be adjusted by changing the number and placement of hoops, airplane speed, and the amount of resistance provided by the haptic interface. A second game calls for the participant to pilot a virtual speedboat over the ocean while avoiding buoys, again by moving the ankle up/down or in/out. A recent addition to these games is the ability to apply task-related haptic effects such as a "jolt" when a buoy or hoop is hit, or to change the environmental conditions by adding turbulence to the air or water (implemented by generating a low frequency side-to-side vibration of the platform - Boian R. F. *et al.*, 2003).

Keshner and colleagues (Keshner E.A. *et al.*, 2004) have united an immersive dynamic virtual environment projected onto a wall with a linear accelerator (sled) that is translated in the anterior-posterior direction. Study participants stand on the sled in front of a screen on which a virtual image is projected. Various combinations of inputs (i.e., translating the support surface, moving the virtual scene, or combining different motions) are used to

determine responses elicited when conflicts of different magnitudes between visual and vestibular/somatosensory signals are delivered. The results of initial experiments clearly demonstrate the non-linear effect in the postural response from single versus different combinations of inputs. These findings suggest that using this or similar complex, multimodal environments for rehabilitation intervention would promote ongoing recalculation of sensory inputs that would result in appropriate updates of posture within realistic environmental contexts.

A locomotor interface, GaitMaster2 (GM2), intended to provide the user with the sense of forward movement while his/her actual position in space is constant, has been tested with two individuals with hemiplegia following a stroke (Yano H. *et al.*, 2003). The user stands on two footpads that move individually with each user's foot providing a sense of movement over a virtual terrain. The footpads in the GM2 follow the trajectory of a healthy individual when walking. The user thus experiences a corrected foot trajectory for each step. Modifications in gait patterns of two hemiplegic patients following gait training with the GM2 included moderate improvements in gait speed, improvements in leg muscle activity, increased symmetry during gait and improvement in QOL.

2.4 Tele-Rehabilitation

A number of trends are creating a favorable environment for pervasive healthcare. First, broadband networking technology is now ubiquitously available. DSL and cable modem connections are affordable and can provide bandwidth capacities that allow not only data transmissions, but also interactive monitoring of patients from a distance via video or audio channels. Un-tethered wireless devices enable the free roaming of patients within their homes, unencumbered by wires. At the same time, the current aging population is technologically savvier than earlier generations and may be more willing to try novel monitoring and treatment options. Recent improvements in computer and sensor technology now make it possible to develop portable home telerehabilitation systems that have the potential to dramatically improve rehabilitation outcomes for neurological and musculoskeletal injuries, while reducing overall rehabilitation costs by decreasing the need for in-person treatment (Lewis *et al.*, 2006).

3. CONCLUSION

Presently, VR represents a broad range of techniques that rapidly are evolving from the melding of diverse fields of computer graphics and

haptics, coupled with the increasing availability of sufficiently powerful hardware platforms. VR applications to clinical neurology and psychiatry are in their infancy, but they will revolutionize many concepts in rehabilitation, neurophysiology, and neuropharmacology. This paper gives a brief overview of the considerable number of applications for VR technology in the area of motor rehabilitation. In some cases, notably in the treatment of stroke, case-study subjects have reported marked improvements in their condition. However VR research for many medical conditions is still at an early development stage and validation using well-controlled case studies with an ample number of subjects is necessary.

There are many reasons why VR applications are so effective for rehabilitation: VR is an interactive, experiential medium, creates a safe setting where patients can explore and act without feeling threatened. In motor rehabilitation VR creates a safe, controlled environment for repetitive practice, provides immediate, real-time feedback about performance. Despite the technology limitations, which will surely be overcome in the future, we conclude that VR technology offers great potential as a next generation health care tool.

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