

Virtual reality in neurorehabilitation

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Imagine the following scenario. Stuck in traffic, you have your digital agent make contact with the secretary at the Rehabilitation Center via your wireless palmtop. You are immediately provided with a verbal listing of your daily schedule. It is clear that you will have a tight timetable, and already anticipate a hectic day filled with clinical rounds, research meetings and an afternoon lecture for third year medical students. You request your digital agent to retrieve last year's lecture presentation on the rehabilitation of patients with Parkinson's disease, and to locate abstracts of the latest research on this topic. These files will be waiting for you on your office computer when you arrive at the Rehabilitation Center. Finally traffic starts to move, and you make it to your office. Clinical rounds have been delayed and you use the opportunity to complete your daily exercise routine on your stationary bike which is facing an omniround screen. Viewing a virtual mountain path winding through the Swiss Alps, you are inspired to cycle uphill for a full 15 min. Your digital agent calls you just as you warm down to notify you that ward rounds are about to begin. The first patient is a 45-year-old businessman who is at the Center for intensive rehabilitation following knee arthroscopy. The patient is anxious to return home so you ask your intelligent agent to contact the agents of the surgeon, physiotherapist and occupational therapist who are not currently at the Center. All team members gather around an interactive, collaborative workspace to examine the X-rays, digital probe and ultrasound as well as other clinical outcome measures. The decision is to discharge with a course of telerehabilitation; the patient will sign on daily to a remotely supervised exercise program. You then ask the surgeon

to demonstrate the procedure he used to the ward resident via a virtual knee arthroscopy simulator. The manipulation is somewhat complex but with some practice the resident gains a good sense of what the procedure entails. Upon your return to your office, you log onto your synchronous distance learning platform to connect up with the third year students who are in their classroom on campus. They can each see your slide presentation on their personal tablets and hear you lecture. They each activate emoticons to indicate their response to your lecture as it unfolds. After reviewing the basic concepts of the disease etiology, prevalence and clinical signs and symptoms, you ask them to each don a cyberglove in order to feel the difference between Parkinsonian rigidity and upper motor neuron spasticity. They next put on a miniature liquid crystal display (LCD) lens while you run through a series of simulations that enable them to evaluate the improvement in Parkinsonian gait experienced by these patients when provided with virtual overground cues. The students use their own microphones to participate in an interactive discussion about the advantages and limitations of these and other recent non-invasive interventions. As you complete the class and prepare for the intake of a new patient you reflect in amazement that not a single student fell asleep! This is a certainly different from the days when you went to medical school.

13.1 Introduction

Not so very long ago the "high tech" gadgets of the type used by Dr. McCoy of Star Trek fame were

considered to be intriguing but far from attainable. Beaming through space, scanning medical diagnostic “tricorders” and “genetronic replicators” came from the creative imaginations of the hit television shows creators. Although the future has not yet arrived, recent developments in technology have succeeded in changing the practice of today’s clinician. Indeed, technology has enhanced a variety of clinical, administrative, academic and personal tasks facing the clinician of the new millennium. Virtual reality (VR) is one of the most innovative and promising of these developments and promises to have a considerable impact on neurorehabilitation over the next 10 years (Schultheis and Rizzo, 2001).

VR typically refers to the use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear and feel similar to real world objects and events (Sheridan, 1992; Weiss and Jessel, 1998). Users interact with displayed images, move and manipulate virtual objects and perform other actions in a way that attempts to “immerse” them within the simulated environment thereby engendering a feeling of “presence” in the virtual world. One way to achieve a stronger feeling of presence, users are provided with different feedback modalities including visual and audio feedback and, less often, haptic and vestibular feedback of their performance. Depending on the characteristics of hardware, software and task complexity, VR aims to provide users with more than just an engaging experience, and is hence quite different in both scope and intensity than traditional computer simulation games. The purpose of this chapter is to provide an overview of applications of VR to rehabilitation.

13.2 Key concepts related to VR

Presence is widely considered to be the subjective feeling of being present in a simulated environment. Sheridan (1992) has defined it as being “... experienced by a person when sensory information generated only by and within a computer compels a feeling of being present in an environment other than the

one the person is actually in” (Sheridan, 1992, p. 6). Presence is believed to be a major phenomenon characterizing a person’s interaction within a virtual environment, but the term is used inconsistently by different researchers (Slater, 2003). Slater (1999) suggested that presence includes three aspects – the sense of “being there”, domination of the virtual environment over the real world and the user’s memory of visiting an actual location rather than a compilation of computer-generated images and sounds. Witmer and Singer (1998) related presence to the concept of selective attention. Despite the numerous studies that have attempted to merge the various definitions of presence, it continues to be viewed as a complex concept that may be influenced by numerous interdependent factors (Schuemie et al., 2001; Mantovani and Castelnuovo, 2003).

One set of factors relates to characteristics of the system that presents the virtual environment (see Fig. 13.1). These include the extent to which the user is encumbered with sensors, the way in which the user is represented within the virtual environment (Nash et al., 2000), whether the platform supports two- (2-D) or three-dimensional (3-D) interactions, and the number and quality of feedback modalities (e.g., Durfee, 2001). Another set of factors relates to a given user’s characteristics. These include age, gender, immersive tendencies, prior VR experience and disability (e.g., Stanney et al., 1998). Finally, a third set of factors relates to characteristics of the virtual environment and the task that is being performed within it (Nash et al., 2001^{AQ1}). These include the meaningfulness of the task (Hoffman et al., 1998), how realistic it is and the intuitiveness of the interaction (Rand et al., 2005).

A second key concept related to VR is immersion. Immersion relates to the extent to which the VR system succeeds in delivering an environment which refocuses a user’s sensations from the real world to a virtual world (Slater, 1999, 2003). Whereas immersion is an objective measure referring to the VR platform, it does not immediately correspond to the level of presence (which is a subjective measure), produced by the system. Immersion is thus dependent, in large part, upon the quality of the technologies used with

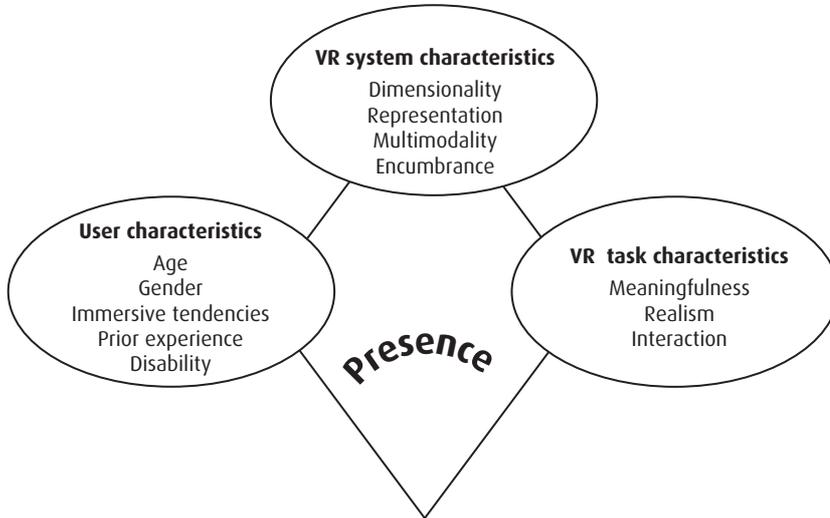


Figure 13.1 Factors contributing to the user's sense of presence.

the VR system (e.g., their resolution and speed of response) (Slater, 2003). Virtual environments may be delivered to the user via a variety of different technologies that differ in the extent to which they are able to “immerse” a user. In contrast to past references to immersive versus non-immersive VR systems, it is preferable to regard immersion as a continuum, ranging from lower to higher degrees of immersion. The relationship between the sense of presence, immersion and performance within the virtual environments is still not fully understood (Mania and Chalmers, 2001; Nash et al., 2001). Nevertheless, there is considerable evidence indicating that a high sense of presence may lead to deeper emotional response, increased motivation and, in some cases, enhanced performance (Schuemie et al., 2001). The use of a more immersive system does not necessarily generate a higher level of presence (Rand et al., 2005) nor does it guarantee clinical effectiveness. Taken together, there are many intertwined issues involved in building a successful VR rehabilitation tool.

A third issue is cybersickness which refers to the fact that some users experience side effects during and following exposure to virtual environments delivered by some of the more immersive VR systems, a factor that may limit its usability for all

patients under all circumstances (Kennedy and Stanney, 1996; Kennedy et al., 1997). Effects noted while using some VR systems can include nausea, eye-strain and other ocular disturbances, postural instability, headaches and drowsiness. Effects noted up to 12 h after using VR include disorientation, flashbacks and disturbances in hand-eye coordination and balance (e.g., Kennedy and Stanney, 1996; Stanney et al., 1998). Many of these effects appear to be caused by incongruities between information received from different sensory modalities (Lewis and Griffin, 1998). Other factors that may influence the occurrence and severity of side effects include characteristics of the user and the display, the user's ability to control simulated motions and interactivity with the task via movement of the head, trunk or whole body (Lewis and Griffin, 1998). VR systems which include the use of a head mounted display (HMD), have a greater potential of causing short-term side effects, mainly oculomotor symptoms (Lo Priore et al., 2003). The potential hazard of side effects for patients with different neurologic deficits has not been sufficiently explored although there is increasing evidence that their prevalence is minimal with video-capture VR systems (see below) that are growing in popularity for clinical applications (Rand et al., 2005).

13.3 Instrumentation

Virtual environments are usually experienced with the aid of special hardware and software for input (transfer of information from the user to the system) and output (transfer of information from the system to the user). The selection of appropriate hardware is important since its characteristics may greatly influence the way users respond to a virtual environment (Rand et al., 2005). The output to the user can be delivered by different modalities including visual, auditory, haptic, vestibular and olfactory stimuli, although, to date, most VR systems deliver primarily visual auditory feedback. Visual information is commonly displayed by HMDs, projection systems or flat screens of varying size. An HMD, such as Fifth Dimension Technologies (www.5dt.com) unit shown in Fig. 13.2, is essentially composed of two small screens positioned at eye level within special goggles or a helmet. Thus users view the virtual environment in very close proximity. Advanced HMDs even provide stereoscopic 3-D displays of the environment and usually are referred to as more immersive systems. Other VR applications use projection systems whereby the virtual environment is projected onto a large screen located in front of the user. VividGroup's Gesture Xtreme (GX)-VR system (www.vividgroup.com), shown in Fig. 13.3, is an example of a video-capture projection system. The user sees him or herself within the simulated environment, and is able to interact with virtual objects that are presented. Some expensive projection systems, such as the CAVE (<http://evlweb.eecs.uic.edu/info/index.php3>), are composed of several large screens surrounding users from all sides such that the virtual environment may be viewed no matter where they gaze. A third way of displaying visual information is based on simple desktop monitors, used singly or sometimes in clusters of screens positioned around the user providing a quasi-panoramic view of the virtual environment (Schultheis and Mourant, 2001). This method is the least immersive but its low cost supports wider distribution to clinics and even to patients' homes.



Figure 13.2 Fifth Dimension Technologies (www.5dt.com) HMD.

Sophisticated VR systems employ more than specialized visual displays. Engaging the user in the virtual environment may be enhanced via audio display, either ambient or directed to specific stimuli (Västfjäll, 2003). In recent years, haptic display has been introduced to the field of VR. Haptic feedback enables users to experience the sensation of touch, making the systems more immersive and closer to the real world experience. Haptic gloves, such as the Rutgers Master II shown in Fig. 13.4, may provide force feedback while manipulating virtual objects (Jack et al., 2001) or for strength training (Deutsch et al., 2002). Haptic information may also be conveyed by simpler means such as a force-feedback joystick (Reinkensmeyer et al., 2003) or a force-feedback steering wheel (Kline-Schoder, 2004). Other, less frequently used ways of making the virtual environment more life-like are by letting the user stand on a platform capable of perturbations and thereby providing vestibular stimuli such as that available with Motek's CAREN multisensory system (<http://www.e-motek.com/medical/index.htm>). Still more rare is the provision of olfactory feedback to add odor to a virtual environment, a feedback channel whose potential is now being investigated (Harel et al., 2003).



Figure 13.3 VividGroup's GX-VR system (www.vividgroup.com) video-capture projection VR system.



Figure 13.4 Rutgers Master II force-feedback glove.

The technologies mentioned above address only the output aspect of the VR experience. Equally important to achieving a realistic experience within a virtual environment is the ability of the user to navigate and manipulate objects within it. Thus the user must be able to interact (directly or indirectly) with the environment via a wide array of input technologies. One class of input technologies may be considered as direct methods since users behave in a natural way, and the system tracks their actions and

responds accordingly. Generally, this is achieved by using special sensors or by visual tracking. With the sensor approach, such as used by Intersense's (www.isense.com) InterTrax2, a three degree of freedom, inertial orientation tracker used to track pitch, roll and yaw movements, the user wears a tracking device that transmits position and orientation data to the VR system. With the visual tracking approach, such as used by VividGroup's video-capture VR system, the user's motion is recorded by video cameras, where special software processes the video image, extracts the user's figure from the background in real-time, and identifies any motion of the body.

A second class consists of indirect ways for users to manipulate and navigate within a virtual environment. These include activation of computer keyboard keys, a mouse or a joystick or even virtual buttons appearing as part of the environment (Rand et al., 2005).

In addition to specialized hardware, application software is also necessary. In recent years, off-the-shelf, ready-for-clinical-use VR software has become available for purchase. However, more frequently, special software development tools are required in order to design and code an interactive simulated environment that will achieve a desired rehabilitation goal. In many cases, innovative intervention ideas may entail customized programming to construct a virtual environment from scratch, using traditional programming languages.

VR hardware that facilitates the input and output of information, in combination with programmed virtual environments provide the tools for designing tasks that enable users to perform in ways that help them achieve established rehabilitation goals. When creating a specific virtual rehabilitation tool the clinician and technical team face the challenge of choosing and integrating the software and hardware, and the input and the output methods. For example, should one use an HMD, attach to it an orientation tracker and move around the virtual environment with a joystick? Or, should the user be positioned in front of a virtual environment projected onto a large screen and employ visual tracking to capture the user's responses? Such decisions have to take many

factors into account including budget, physical space, mobility of the system, the nature of the patient population, the complexity of the task with respect to the patient population and the extent of immersion desired from the system.

13.4 VR attributes for rehabilitation

In recent years, VR technologies have begun to be used as an assessment and treatment tool in rehabilitation. The rationale for using VR in rehabilitation is based on a number of unique attributes of this technology (Riva et al., 1999; Schultheis and Rizzo, 2001). These include the opportunity for experiential, active learning which encourages and motivates the participant (Mantovani and Castelnovo, 2003). In addition, there is the ability to objectively measure behavior in challenging but safe and ecologically valid environments, while maintaining strict experimental control over stimulus delivery and measurement (Rizzo et al., 2002)^{AQ2}. VR also

offers the capacity to individualize treatment needs, while providing increased standardization of assessment and retraining protocols. Virtual environments provide the opportunity for repeated learning trials and offer the capacity to gradually increase the complexity of tasks while decreasing the support and feedback provided by the therapist (Schultheis and Rizzo, 2001). Moreover, the automated nature of stimulus delivery within virtual environments enables a therapist to focus on the provision of maximum physical support when needed without detracting from the complexity of the task. For example, several objects can be displayed simultaneously from different directions while the therapist supports the patient's paretic shoulder. Finally, the ability to change the virtual environments relatively easily enables clinicians to assess more efficiently different environmental modifications, which endeavor to enhance clients' accessibility. A summary of these attributes are listed in Table 13.1 together with some applications taken from the literature.

Table 13.1. VR attributes and some applications taken from the literature.

Attributes	Examples
Safe and ecologically valid environments	Training patients with neglect to safely cross the street (Naveh et al., 2000; Weiss et al., 2003 ^{AQ13}) Assessment of driving with patients following traumatic brain injury (Schultheis and Rizzo, 2001)
Control over delivery of stimuli via adaptation of the environment and task to elicit various levels of performance	Adaptation of the GX-VR system in terms of color, direction, speed and amount of stimulus (Kizony et al., 2003 ^{AQ14})
Gradual changes in task complexity while changing extent of therapist intervention	Using video-based VR system with patients following spinal cord injury (Kizony et al., 2003b)
Increased standardization of assessment and treatment protocols	Assessment of cognitive function using a virtual kitchen (Christiansen et al., 1998)
Objective measurement of behavior and performance	Documenting hand function (e.g., range of motion of fingers) after stroke (Jack et al., 2001) Analyzing behavior (movements of body parts as well as success in virtual task) of children with ADHD (Rizzo, 2000 ^{AQ15} , 2002)
Provision of enjoyable and motivating experiences	Providing leisure opportunities using video-based VR with young adults with physical and intellectual disabilities (Weiss et al., 2003)

ADHD: attention deficits hyperacture disorder.

13.5 VR applications in neurologic populations

VR applications in rehabilitation are expanding at a rapid pace and a large variety of platforms and programs are currently being used and developed. Due to limitations in space this review is by no means comprehensive.

13.5.1 Assessment and remediation of cognitive, meta-cognitive and motor deficits

13.5.1.1 Cognitive deficits

VR has been used as a medium for the assessment and rehabilitation of cognitive processes, such as visual perception, attention, memory, sequencing and executive functioning (Pugnetti et al., 1998; Rizzo et al., 2000). For example, a meal preparation task in a virtual kitchen viewed via an HMD examined the sequencing of 30 steps during a soup preparation task. The evaluation was found to be reliable and valid for the assessment of cognitive functioning of 30 patients with closed head injury (Christiansen et al., 1998). In a second study with the same VR scenario the subtasks were categorized into information processing, problem solving, logic sequence and speed of responding; in all components, participants with brain injury showed significantly worse performance when compared to healthy volunteers (Zhang et al., 2001).

Grealy et al. (1999) combined a bicycle exercise program with three virtual environments (a Caribbean Island, a town and countryside and snowy mountain with ski runs) that were linked to a cycle ergometer and displayed on a screen while steering within the virtual course. The study aimed to improve cognitive abilities via exercise within different virtual environments. An experimental group included 13 patients with traumatic brain injury (TBI) who were treated for 4 weeks with pre- and post-testing of standard cognitive measures such as digit span, trail making and memory (auditory, visual and logic). The control group consisted of 12 patients from the same hospital who did not receive this treatment but were

matched for other variables. Results showed significant improvement in auditory and visual learning following the VR treatment but not in complex figure and logic memory tasks. Speed of information processing was also enhanced, suggesting that learning may have been facilitated by an increase in arousal activation level (Grealy et al., 1999).

In a different series of studies, a street crossing virtual environment, run on a desktop VR system, with successively graded levels of difficulty was developed to provide users' with an opportunity to decide when it is safe to cross a virtual street. It was initially tested on 12 subjects, six stroke patients and six matched controls (Naveh et al., 2000; Weiss et al., 2003a). Results showed that the program is suitable for patients with neurologic deficits in both its cognitive and motor demands. Currently, the program is being used in a controlled clinical trial to train patients with right hemisphere stroke and unilateral spatial neglect (USN) in order to improve their attention and ability to scan to the left. Measures included standard paper and pencil cancellation tests, as well as pre- and post-performance within the virtual environment and during actual street crossing. Initial results from 11 patients who used the virtual environment (VR street test) versus a control group of eight patients who used non-VR computer-based scanning tasks showed that both groups improved in their scores, namely the number of correctly canceled items on the star cancellation from the behavioral inattention test (BIT) (Wilson et al., 1987) and Mesulam symbol cancellation test (Weintraub and Mesulam, 1987); however, the VR group completed the tests in less time which may also be an indicator of improvement, while the control group needed longer time to perform (Katz et al., in press). The performance of the VR group in the VR street test showed training effects, as all patients improved in looking to the left and most of them had fewer accidents during the virtual street crossing at post-test, while the majority of the control group did not change their performance from pre- to post-test on the VR street test.

The GX video-capture VR system has recently been investigated to determine its potential for remediation of cognitive and motor deficits (Kizony et al.,

2002; Reid, 2002; Sveistrup et al., 2003; Weiss et al., 2004) and to provide recreational opportunities for people with severe disabilities (Weiss et al., 2003b). For example, Kizony et al. (2003a) described an example of a patient following a right hemisphere stroke with attention deficits 6 months after the event. During VR treatment he was required to pay attention to the entire visual space as well as moving his affected arm in the neglected space, as for example, he played the role of a soccer goalkeeper whose task was to deflect balls that came towards him from all directions. During the game, he saw himself within the virtual environment, and received immediate visual and auditory feedback to help him improve his performance. The patient expressed enjoyment and motivation to continue with this kind of treatment. The adaptations applied to these VR environments enable the treatment of visual spatial attention and USN common symptoms following brain damage, by controlling the direction, number and color of stimuli and by adding distracters to the scenario (Kizony et al., 2003a). This is an example of where off-the-shelf software has been adapted to make it more applicable for clinical use.

A study is now underway in which the effect of training with this VR system to remediate attention and USN deficits of patients with right hemisphere stroke is being evaluated. Both the street crossing environment as well as the video-capture games (such as soccer) are examples of the use of VR technology as applied to the treatment of stroke patients with attention deficits and USN, a phenomenon described more fully in Chapters 28 and 36 of this volume. The desktop VR system focuses mainly on visual scanning whereas the video-capture system combines visual scanning with motor activation both of which have been shown to be important rehabilitation goals.

Another approach for the assessment and rehabilitation of attention and memory processes is one that makes use of HMD-delivered virtual environments such as the applications developed by Rizzo and colleagues (Rizzo et al., 2000; Schultheis and Rizzo, 2001; Rizzo et al., 2002). A virtual classroom was developed for the assessment and training of attention in children with attention deficits hyperactive

disorder (ADHD), and a Virtual Office was developed for assessment of memory processes in patients with TBI. The virtual classroom contains the basic objects (e.g., tables, chairs, blackboard, windows) and subjects (e.g., female teacher, pupils) found in a typical classroom. Both visual (e.g., car outside the window, paper airplane flying above the classroom) and auditory (e.g., steps in the hallway) distracters inside and outside the classroom randomly appear, as a child who wears an HMD to view the environment, performs various tasks of selective, sustained and divided attention. The child's performance is measured in terms of reaction time. Behavioral factors such as head turning and gross motor movement related to distractibility and hyperactivity are also recorded. An initial clinical trial compared eight children aged 6–12 years with ADHD and 10 control children on standard tests and VR performance. Results showed that the children with ADHD had slower and more variable reaction times, made more omission and commission errors and showed higher overall body movements than did the control children (Rizzo et al., 2002). Hyperactive motor movements tracked from the head, arms and legs were greater for the children with ADHD and more pronounced when distractions were presented.

The Virtual Office is modeled on the same principles as the virtual classroom; however, in addition to attention, memory was also tested (Rizzo et al., 2002). Sixteen objects are placed in the environment; eight of the objects would typically be found in an office environment (e.g., clock) whereas eight would not be (e.g., fire hydrant). The user is asked to scan the office via an HMD for 1 min and then to recall the objects from memory. Both the classroom and office virtual environments have considerable potential to train individuals to improve their attention and memory abilities within a task that is relevant, similar to real world settings, but still controlled with the possibility of systematic and precise measurement.

In a recent review of the use of VR in memory rehabilitation, Brooks and Rose (2003) discussed one example of a virtual four-room bungalow which runs on a desktop computer for the assessment of prospective memory, an ability that is critical for

multitasking. Twenty-two patients with stroke and a control group were requested to perform a furniture removal task (using a mouse or a joystick) while they were required to remember certain conditions of cue, activity and timed-based tasks. The differences between the groups indicated that using VR as a rehabilitation intervention enabled a more comprehensive and controlled assessment of prospective memory than did standard memory tests (Brooks et al., 2002).

13.5.1.2 *Executive functions deficits*

VR environments have the potential to enhance cognitive neuropsychologic tests of executive function since they generate a better subjective perception of presence and immersion than do artificial laboratory tests (Lo Priore et al., 2002). Moreover, virtual environments appear to offer a way to systematically assess and rehabilitate executive functions, since they have ecologic validity and can be readily designed to simulate the demands found in everyday tasks as noted above (Rizzo et al., 2002, in press).

Pugnetti et al. (1995; 1998) was one of the first groups to assess executive functions via VR. They developed an HMD-delivered virtual environment that embodied the cognitive challenges that characterize the Wisconsin card sorting test (WCST).

The four-room bungalow environment described above was successfully used to test executive functions by Morris et al. (2002). They defined components of strategy formations, rule breaking and prospective memory for 35 patients with focal prefrontal neurosurgical lesions as compared to 35 matched controls. Their results showed that the VR test procedure was successful in differentiating between the groups on all measures.

Lo Priore et al. (2002) developed the V-store, a desktop VR-based tool for the rehabilitation of executive functions for patients with TBI. This environment requires the patient to choose and place different pieces of fruit in a basket in accordance with verbal commands. Six tasks are graded in complexity with the aim of eliciting the need for executive functions, problem solving, behavioral control,

categorical abstraction, memory and attention. A series of distracting elements are included to generate time pressure and elicit management strategies. An initial study of control subjects who used the V-store environment via an immersive HMD display as well as via a non-immersive flat screen display was carried out (Lo Priore et al., 2003). Outcomes including physiologic, neuropsychologic and presence measures showed no major differences between the VR systems.

In another study, McGeorge et al. (2001) compared real world and virtual world "errand running" performance in five patients with TBI who had poor planning skills and in five normal control subjects. The video taped performance of subjects was coded and compared while performing a series of errands in the University of Aberdeen Psychology Department (real world) and within a flat screen VR scenario modeled after this environment. Performance in both the real and virtual environments, defined as the number of errands completed in a 20-min period, was highly correlated. This finding suggests that performance in the real and virtual worlds was functionally similar, emphasizing the ecologic validity of the VR. Finally, measures of both real and virtual world performance showed concordance with staff observations of planning skills (Rizzo et al., in press). Initial evidence points to the value of VR technology for the rehabilitation of executive functions in TBI. Background material on executive functions and TBI are presented in Chapters 30 and 33 of this volume.

13.5.1.3 *Motor deficits*

The majority of VR-based interventions used to train motor deficits have been used with patients who have had a stroke. Piron et al. (2001) used a virtual environment to train reaching movements, Broeren et al. (2002) used a haptic device for the assessment and training of motor coordination, and Jack et al. (2001) and Merians et al. (2002) have developed a force-feedback glove to improve hand strength and a non-haptic glove to improve the range of motion and speed of hand movement. Based on the results of the latter study, which included three patients

who had a stroke, it appears that training within a virtual environment may lead to improvements in upper extremity function in this population even when at a chronic stage (Merians et al., 2002).

Since many of the VR applications for rehabilitation have used desktop VR systems wherein the user interacts within the virtual environment via a keyboard, mouse or joystick, the focus of intervention has often been cognitive, meta-cognitive or functional or limited to wrist, digit or ankle movements as illustrated above. More recently the use of other methods of interaction has enabled applications that can also be used for the improvement of motor deficits. For example, individuals with acquired brain injury have been trained to perform specific arm movements within a virtual environment and have then been able to generalize this ability and engage in daily functional use of the affected arm (Holden et al., 2001).

The VividGroup's GX system was used to develop an exercise program for balance retraining in which users see their own mirror image. Following 6 weeks of training at an intensity of three sessions per week, improvement was found for all 14 participants in both the VR and control groups (Sveistrup et al., 2003). However, the VR group reported more confidence in their ability to "not fall" and to "not shuffle while walking". Kizony et al. (2004)^{AQ3} presented results of 13 patients who had a stroke and who used a number of virtual games via the GX-VR system. The findings showed that the system is suitable for use with elderly patients who have motor and cognitive deficits. In addition all participants expressed their enjoyment from the experience.

The same VR system has been used to explore its potential to train balance for patients with spinal cord injury (SCI) (Kizony et al., 2003b). Such training for these patients is essential in order to help them achieve maximal independence, namely remediation of motor deficits via compensatory strategies to maintain balance. Initial results from a usability study of nine patients showed that they enjoyed doing the tasks, were highly motivated to participate and asked to have repeated sessions with the VR system. More importantly, they were able to maintain balance under the very dynamic conditions available

within the virtual environment (Kizony et al., 2002) and appeared to make considerably more effort than during conventional therapy (Kizony et al., 2003b). It was also evident that the task was highly motivating for him (Kizony et al., 2003b). This preliminary evidence demonstrates the value of VR technology for balance training and SCI, topics that are presented in Chapters 20 and 37 of this volume.

13.5.2 Functional evaluation and training

13.5.2.1 Instrumental activities of daily living

VR shows promise for training activities of daily living with different populations. Davies et al. (1999, 2002) developed three desktop applications for rehabilitation of daily tasks – a virtual kitchen, a service and vending machine and a hospital and university way-finding environment. The functional tasks and the 3-D way finding within the virtual environment were carried out using an adapted keyboard or a touch screen. A virtual kitchen was also developed by Gourlay et al. (2000) to enable practice that is safe, controlled and stimulating for patients with stroke and TBI, who have cognitive deficits, prior to practice within an actual kitchen. These researchers developed a "telerehabilitation" system for use at home under supervision by practitioners from a clinic, thus enabling training without having to travel which is difficult for many patients.

Initial support for the ecologic value of VR "route finding training" can be found in a case study by Brooks et al. (1999). In this report, a patient with stroke and with severe amnesia showed significant improvements in her ability to find her way around a rehabilitation unit following training within a virtual environment modeled on the unit. This was most notable given that prior to training the patient had resided on the unit for 2 months and was still unable to find her way around, even to places that she visited regularly. Four additional patients were trained on this system using four different routes. Results showed that for all patients virtual training was found to be as successful as real training (Brooks and Rose, 2003).

Another activity of daily living is street crossing. Safe street crossing is a major concern for many patients with neurologic deficits as well as for elderly people, and is thus an important goal in rehabilitation. The VR desktop system of street crossing described above (Naveh et al., 2002^{AQ4}; Weiss et al., 2003a) aimed at testing the effectiveness of virtual training for patients with stroke who had USN or other deficits of spatial perception, and to determine whether these skills transferred to performance in the real world.

Application of VR to driving assessment and training has had, to date, very promising results (Schultheis and Rizzo, 2001). A VR-based driving assessment system using an HMD was developed and tested at Kessler Medical Rehabilitation. The rehabilitation of driving skills following TBI is one example where individuals may begin at a simple level (i.e., straight, non-populated roads) and gradually progress to more challenging situations (i.e., crowded, highway roads, night driving) (Schultheis and Mourant, 2001). The first study compared the VR-based driving system with the behind the wheel (BTW) evaluation, the current "gold standard", and found comparable results for the two approaches (Schultheis and Rizzo, 2001). Next, an analysis of the demands for safe driving was carried out, and the issue of divided attention was studied by adding a task of calling out digits appearing on the screen while maintaining driving at differing speed levels. The comparison of three patients with TBI to matched healthy controls showed that speed of driving was consistent and similar for the two groups, but the patients failed to call the digits, while the healthy performed this task significantly better than the patients. Thus, the patients with TBI showed a serious problem in dual tasking. The results on the divided attention task were highly correlated with neuropsychologic tests, validating the method of testing during VR driving. An extensive research project is underway to test the system for different neurologic populations. As in the case of the street crossing program, described above, both cognitive variables which may explain the difficulty of performing the actual task (crossing streets or driving) and the functional evaluation and training for transfer and generalization to the daily

tasks are combined. This provides for ecologic validity of VR systems which is missing in traditional standard measures.

13.6 A model of VR-based rehabilitation

The VR experience is multidimensional and appears to be influenced by many parameters whose interactions remain to be clarified. A proposed model for VR in rehabilitation is presented in Fig. 13.5. This model was developed within the context of the International Classification of Functioning, Disability and Health (ICF) (World Health Organization, 2001) terminology (Kizony et al., 2002) and consists of three nested circles, the inner "interaction space", the intermediate "transfer phase" and the outer "real world".

When using VR in rehabilitation we construct a virtual environment that aims to simulate real world environments. In contrast to real world settings, the virtual environment can be adapted with relative ease to the needs and characteristics of the clients under our care. The ultimate goal of VR-based intervention is to enable clients to become more able to participate in their own real environments in as independent manner as possible.

As represented schematically in Fig. 13.5, two primary factors within the "interaction space" influence the nature of the interaction between the user and the virtual environment. The first of these factors relates to the user's personal characteristics (body functions and structures). The second factor relates to characteristics of the virtual environment including both the type of VR platform and its underlying technology and the nature and demands of the task to be performed within the virtual environment. The characteristics of the virtual environment may be either barriers or enablers to performance. The client interacts within the virtual environment, performing functional or game-like tasks of varying levels of difficulty. This enables the therapist to determine the optimal environmental factors for the client. Within the "interaction space" sensations and perceptions related to the virtual experience take place (sense of presence, meaning and actual performance).

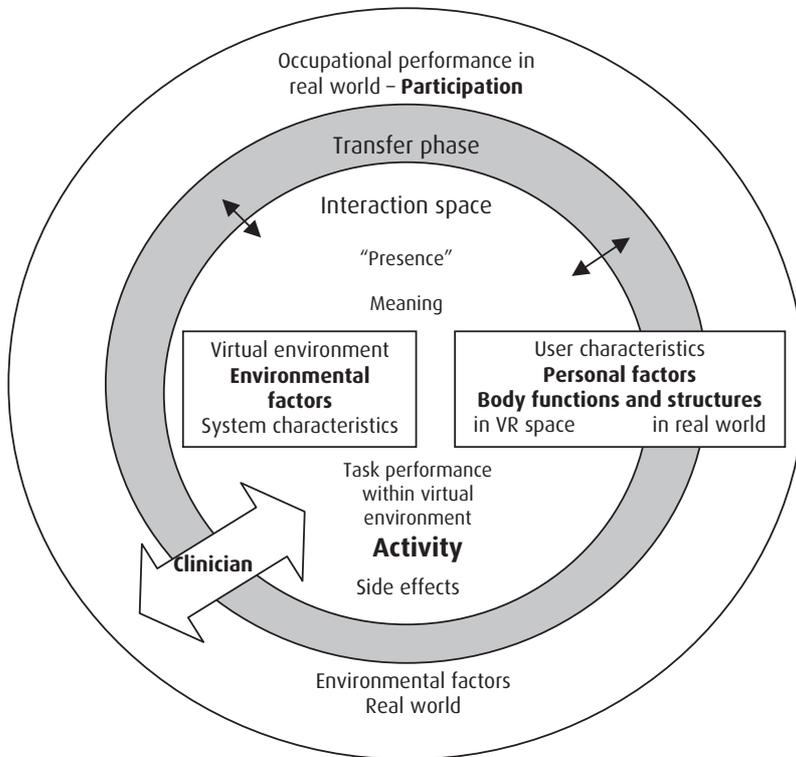


Figure 13.5 A model of VR-based rehabilitation within the context of terminology from the ICF (indicated in bold).

From the interaction space (inner circle) we move to the transfer phase (intermediate circle) since our goal in rehabilitation is to improve daily function in the real world and this requires transfer of the trained skills or tasks as well as environmental modifications from the virtual environment to the real world. Finally, the large, outer circle represents real world environments illustrating that the ultimate goal is to help the client achieve participation in the real world environment by overcoming, adapting to or minimizing the environmental barriers. The entire process is facilitated by the clinician whose expertise helps to actualize the potential of VR as a rehabilitation tool.

13.7 Conclusions

It is clear from the above review that the future holds great promise for the further development of

applications of VR to rehabilitation. In addition to the many exciting rehabilitation applications presented above, VR-based therapy has been very effective in other realms of medicine such as in the treatment of phobias (Hodges et al., 2001) and to reduce of pain during burn care (Hoffman et al., 2000) and venipuncture (Reger et al., 2003).

VR has also been shown to be highly effective as a means for providing alternate modes of feedback in cases of sensory impairment such as the substitution of auditory (Sanchez et al., 2000) and/or haptic (Yu and Brewster, 2002) cues for individuals with severe visual impairment via interactive virtual environments.

The cost of equipment is decreasing and the availability of off-the-shelf software is growing such that it is now feasible for many clinical facilities to embrace this new technology. As presented above, the literature to date strongly suggests that these

technologies are poised to have a major impact on evaluation and intervention for cognitive, motor and functional rehabilitation due to the unique attributes of VR-based therapy. These attributes make it highly suitable for the achievement of many rehabilitation goals including the encouragement of experiential, active learning, the provision of challenging but safe and ecologically valid environments, the flexibility of individualized and graded treatment protocols, the power to motivate patients to perform to their utmost capability and the capacity to record objective measures of performance.

Nevertheless, further development of VR-based rehabilitation depends, to some extent, on the resolution of certain issues that currently present either technological or financial limitations. The cost of some of the more immersive VR systems is still prohibitive rendering them more suitable to investigative studies rather than to routine clinical applications. Continued development of off-the-shelf, low-cost virtual environments that can be displayed on standard desktop equipment or via dedicated microprocessors (e.g., the Sony PlayStation II's "EyeToy" application, www.eyetoy.com) will make the use of VR affordable to a variety of treatment and educational settings. Of course, the clinical effectiveness of these less expensive applications must be verified prior to their wide promotion and adoption.

There is also a need to address issues related to the number and quality of feedback channels used with virtual environments. As indicated above, visual and auditory feedback is extensively used; haptic, vestibular and olfactory feedback is far less commonly available. The cost of devices capable of transmitting feedback of high quality is often high and their potential for encumbering users is also significant. The relationship between feedback quality and effectiveness is not certain, nor is the relationship between the number of feedback channels and effect of therapy known. Considerably more research as to impact that VR feedback has on clinical intervention is therefore needed.

Finally, it is encouraging to note that much progress has been made in the demonstration of the transfer of abilities and skills acquired within

virtual environments to the real world performance. Although continued efforts are needed to firmly establish that attainments with virtual environments are both the transferable and generalizable to function within the real world, the evidence to date substantiates the initial promise of these dynamic technologies.

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