

# **Immersion without encumbrance: adapting a virtual reality system for the rehabilitation of individuals with stroke and spinal cord injury**

R Kizony<sup>1,2</sup>, N Katz<sup>1</sup>, H Weingarden<sup>2</sup> and P L Weiss<sup>3</sup>

<sup>1</sup>School of Occupational Therapy, Hadassah-Hebrew University,  
Jerusalem, Israel

<sup>2</sup>Chaim Sheba Medical Center, Tel Hashomer, Israel

<sup>3</sup>Department of Occupational Therapy, University of Haifa, Mount Carmel, Haifa, Israel

*rachelk@zahav.net.il, noomi.katz@huji.ac.il, harold\_h@netvision.net.il, tamar@research.haifa.ac.il*

*[http://hw.haifa.ac.il/occupa/hebrew/cv/tamar\\_w.html](http://hw.haifa.ac.il/occupa/hebrew/cv/tamar_w.html)*

## **ABSTRACT**

The purpose of this paper is to present results describing the use of a projected, video-based VR system in neurological rehabilitation. The first part describes the adaptation of several of the VividGroup's Gesture Xtreme projected VR scenarios (control of the type, speed, location and direction of all stimuli) and documentation of all subjects' performance. The second part of paper presents initial results in which the system is being used in a clinical study with stroke patients who display symptoms of left unilateral neglect and other cognitive deficits, with those who require balance training as a result of complete or incomplete spinal cord injuries, and young, non-speaking adults who have cerebral palsy and moderate mental retardation.

## **1. INTRODUCTION**

Injury or disease to the central or peripheral nervous systems typically results in a decreased ability to perform activities of daily living, due to the resulting cognitive and motor deficits. An essential part of the rehabilitation process is remediation of these deficits in order to improve the functional ability of the patient, and to enable him or her to achieve greater independence. One of the major challenges facing therapists in neurological rehabilitation is identifying intervention tools that are effective, motivating, and enable transfer of the skills and abilities achieved during rehabilitation to function in the "real" world.

In recent years, virtual reality technologies have begun to be used as an assessment and treatment tool in rehabilitation (e.g., Brown et al., 1998; Christiansen et al., 1998; Grealy et al., 1999; Rose et al., 1999; Rizzo et al., 1997; Schultheis and Rizzo, 2001; Riva et al., 1999; Weiss et al., 2002; Linden et al., 2002). These first studies have yielded encouraging results that support the further exploration of VR as an intervention tool in rehabilitation (Schultheis and Rizzo, 2001). Positive attributes include its suitability for the objective measurement of motor and cognitive performance in settings that are safe, ecologically valid, may be delivered in a standardized protocol and may be tailored to each individual's functional level via precise gradation of stimuli.

The majority of VR rehabilitation applications have focused on the development of virtual environments, and demonstration of their reliability and feasibility. However, to date, its effectiveness as an intervention tool in neurological rehabilitation has been insufficiently explored, especially with the VR systems based on video projection. Moreover, some of the current studies use relatively expensive VR systems whose cost and technical complexity preclude their adoption in most clinical settings. There is also concern that use of immersive VR systems that rely on externally affixed devices (e.g., a head-mounted display) may cause disturbing side effects, particularly in patients who suffer from neurological deficits.

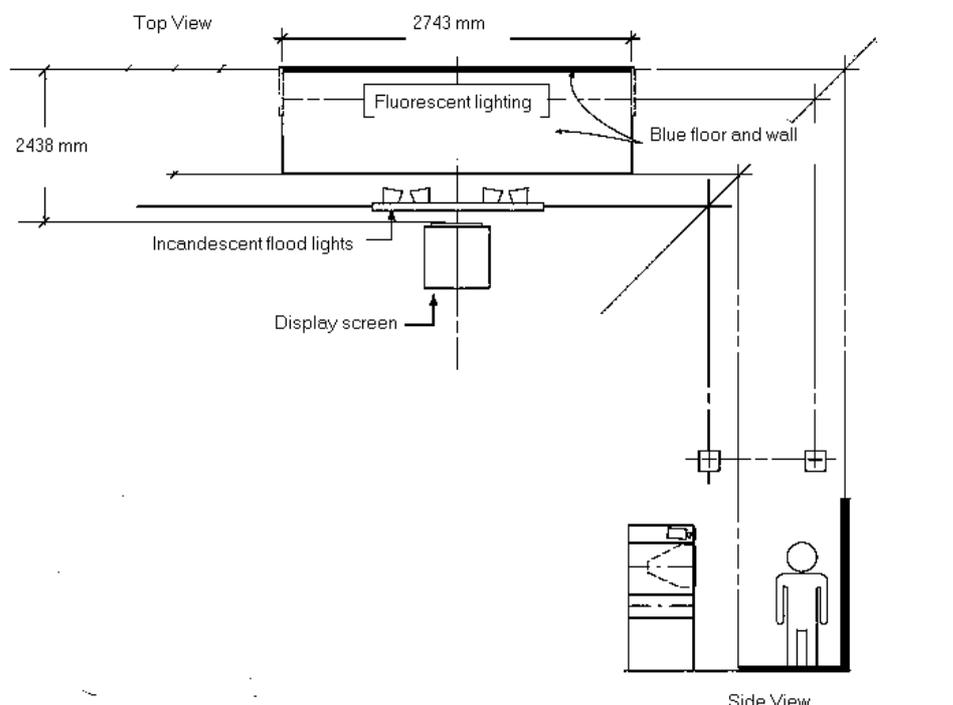
The purpose of this paper is to present results describing the use of a projected, video-based VR system for use in neurological rehabilitation. Our first objective is to present work carried out in our laboratory over

the past year that has resulted in the adaptation of several of the VividGroup's Gesture Xtreme projected VR scenarios such that it is now possible to completely control the type, speed, location and direction of all stimuli and to document subjects' performance. Our second objective is to present initial results of our currently ongoing research in which the system is being used in a clinical study with stroke patients who display symptoms of left unilateral neglect and other cognitive deficits, with those who require balance training as a result of complete or incomplete spinal cord injuries, and young, non-speaking adults who have cerebral palsy and moderate mental retardation.

## 2. VIVIDGROUP'S GESTURE XTREME VR SYSTEM

We have commenced a series of studies using VividGroup's Gesture Xtreme VR System, a unique approach to virtual reality, which has potentially important applications for the rehabilitation of children and adults with physical and/or cognitive impairment [www.vividgroup.com]. When using the Gesture Xtreme VR system, users stand or sit in a demarcated area viewing a large monitor or projected image that displays one of a series of simulated functional tasks, such as catching virtual balls or swimming in a virtual ocean (See Figure 1). A digital video camera converts the video signal of the user's movements for processing by unique software. The participant's image is processed on the same plane as screen animation, text, graphics, and sound, which react accordingly depending on his or her movement. This process is referred to as "video gesture", i.e., the initiation of changes in a virtual reality environment through video contact. The participant's live on-screen video image responds at exactly the same time to movements, lending an intensified degree of realism to the virtual reality experience. The result is a complete engagement of the user in the simulated task.

The Gesture Xtreme VR system was originally developed as an entertainment system, designed to demonstrate VR in science museums and popular expositions. It is only via adaptations complying with principles based on rehabilitation intervention principles that permit its use as an effective rehabilitation intervention tool.



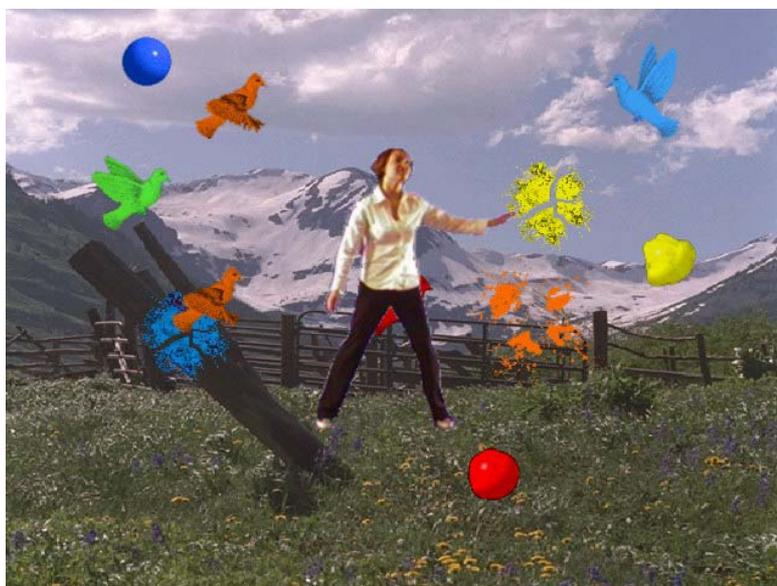
**Figure 1.** Block diagram of Gesture Xtreme system (adapted from [http://www.vividgroup.com/techsupport/design\\_plans/gx100\\_page3.jpg](http://www.vividgroup.com/techsupport/design_plans/gx100_page3.jpg)).

The Gesture Xtreme VR system contains a number of virtual environments. In our studies we are initially using four of these environments, three of which we have adapted as an intervention tool:

- **Birds and Balls** - The user sees himself standing in a pastoral setting (Figure 2). Balls of different colors emerge from different locations and fly towards the user. Touching these balls with any part of the body causes them to turn into doves (if the touch is “gentle”) or to burst (if the touch is “abrupt”). Our adaptations include the ability to control the direction in which the balls appear on the screen, and the addition of stimuli in a different shape (e.g., a star) as a distracter.
- **Soccer** - The user sees himself as the goalkeeper in a soccer game. Soccer balls are shot at him from different locations, and his task is to hit them with different parts of his body in order to prevent them from entering the goal area. Successfully repelled balls remain white while the ones that enter the goal crease change color from white to orange. Our adaptations for grading the level of difficulty include changing the number of balls that appear simultaneously as well as their direction and speed.
- **Snowboard** - The user sees a back view of himself mounted on a snowboard. As he skis downhill he needs to avoid rocks, trees and other obstacles by leaning from side to side or moving his whole body. We adapted the level of difficulty of this environment by changing the speed of skiing.

For the above three environments we added a database that records the participant’s performance.

- **Sharkbait** - The user sees himself immersed within an ocean surrounded by fish, eels and sharks. His objective is to swim within the environment and catch floating stars while avoiding the electric eels and sharks.



**Figure 2.** Screen shot of VividGroup’s birds and balls environment.

The Gesture Xtreme system appears to be suited to the rehabilitation of individuals with motor and cognitive deficits for several reasons. First, the user does not have to use a head-mounted display or other special apparatus in order to feel immersed within the virtual environment. This both reduces the likelihood of developing side effects and eliminates a source of encumbrance that would likely hinder the motor response of patients with neurological deficits. Although the newer Head Mounted Displays (HMDs) and stereoscopic glasses are considerably less cumbersome than previous models, little information is available regarding their use by individuals with cognitive deficits and brain injury.

The second feature of the Gesture Xtreme system that encourages its use for rehabilitation intervention is the fact that the user views himself actively participating within the environment rather than being represented by an avatar. The use of the user’s own image has been suggested to add to the realism of the environment and to the sense of presence (Nash et al., 2000). The third feature relates to how the user controls his movements within the virtual environments; rather than relying on a pointing device or tracker, navigation with the Gesture Xtreme environments is accomplished in a completely natural and intuitive

manner. Not only is the control of movement more natural, it also involves the use of as many body parts as are deemed to be suitable to the therapeutic goals. For example, the user may respond to the projected balls via a specific body part (e.g., the head or hand) when it is appropriate to have the intervention directed in a more precise manner, or via any part of the body when intervention is more global. Finally, the existing scenarios provide opportunities to facilitate a patient's residual cognitive, motor and sensory abilities in functionally meaningful contexts. Since the ultimate goal of rehabilitation is to maximize a patient's independence in activities related to daily performance skills, functional relevance and integration of performance components are of paramount importance.

The Gesture Xtreme system does have several limitations which should be taken into account when considering the use of this system in rehabilitation. The use of a single camera means that the environments and movement within them are essentially two dimensional. This is in contrast with HMDs in which the user is fully located within a three dimensional world. Moreover, the feedback provided is visual and auditory with no additional sensory information such as haptic. Although the haptic sense is not yet widely used in rehabilitation there is some evidence (Boian et al., 2001) that it can be an effective addition towards the accomplishment of certain treatment objectives (e.g., increasing joint range of motion and force). The various attributes of the Gesture Xtreme VR system are summarized in the table.

**Table 1.** *Attributes of the Gesture Xtreme system for intervention in rehabilitation.*

<b>Advantages</b>	<b>Disadvantages</b>
<ul style="list-style-type: none"> <li>• Use specific body part or all body parts</li> <li>• The user views himself not an avatar</li> <li>• The user controls his movements directly</li> <li>• Do not need to wear HMD, data glove or other external device</li> </ul>	<ul style="list-style-type: none"> <li>• The scenarios and interactions are two dimensional</li> <li>• Only visual and auditory feedback is given</li> </ul>

To date published reports of the use of this system have been limited to brief description of its clinical use with a small number of elderly individuals who have a high risk of falling and post stroke patients (e.g., Cunningham and Krishack, 1999). Despite the obvious methodological limitations of this study, it did demonstrate the feasibility of using the Gesture Xtreme VR system for the rehabilitation of neurological and elderly patients.

We first designed and carried out a pilot study in order to characterize the adapted virtual reality system and, specifically, to examine and describe the sense of presence it creates in comparison with a non-immersive virtual reality system, a desktop street crossing VR scenario (Naveh et al., 2000; Weiss et al., 2002). We found no significant differences in the scores of the presence questionnaire (Witmer and Singer, 1998) although there appeared to be a trend in favor of the Gesture Xtreme system (Kizony et al., 2002). When analyzing the results of a short presence questionnaire composed for the purpose of the study (based on the Witmer and Singer's (1998) presence questionnaire), which was filled by the participants after they experienced each scenario we found differences in their response to individual environments. The soccer scenario created the highest level of presence followed by snowboarding, street crossing, birds and balls and, finally, sharkbait which created the lowest sense of presence. These findings suggest that the virtual scenarios which are more functionally relevant and more similar to realistic, true to life activities such as soccer or street crossing, create higher levels of presence regardless of the type of the virtual reality system. Thus it seems that the type of the virtual scenario or environment and the extent to which it is perceived as being functional and realistic plays an important role in creating a sense of presence. Based on these results we decided to carry out our initial intervention studies with the soccer, snowboarding and birds and balls environments and not to adapt or use the sharkbait application.

The characteristics of the adapted Gesture Xtreme VR system appear to make it a potentially useful treatment tool for cognitive and especially attention deficits as well as motor impairments. For example, the adaptation will allow simultaneous movement in the environment and recognition of specific stimuli and allocation of attention to it. The ability to control the number, speed and type of stimuli enable training of specific attention components, for example, divided attention in cases where the user has to touch one

stimulus and avoid another and sustained attention when one has to sustain attention for a long period of time. This, in turn, is assumed to have a major impact on functional outcomes.

### 3. CLINICAL PILOT RESULTS

#### 3.1 *Patients with stroke (motor and cognitive deficits).*

Stroke is a major cause of disability in the adult and elderly, which can result in different motor and cognitive impairments, and functional disability (Woodson, 1995). Almost half of the patients suffering from stroke retain substantial disability (Stineman & Granger, 1991) affecting their performance of occupational activities of daily living such as bathing and dressing (Bernspong et al., 1989; Zhu et al., 1998), and sandwich and drink preparation (Katz et al., 2000). Cognitive and motor deficits have been found to be related to functional disability after stroke (Hajek et al., 1997; Katz et al., 1999). In addition attention deficits are common after brain damage (Lezak, 1995) and have severe functional consequences since the attainment of a sufficient level of attention is required for learning which is an essential process for recovery of function after brain damage (Robertson, 1999). One of the manifestations of attention deficits is unilateral neglect which is characterized by a reduced ability to respond to stimuli presented to the contralesional space (Heilman et al., 1993). Unilateral neglect was found as one of the major impairments related to decreased rehabilitation outcome after right hemisphere stroke (Kalra et al., 1997; Katz, et al, 1999; Paolucci et al., 1996).

To date we have tested three people who have had a stroke. These participants were able to use the system at different levels of task difficulty and they described the experience as enjoyable and expressed their interest in continuing to use it as part of their rehabilitation process. Their responses to the presence questionnaire indicated that they felt a marked sense of presence during their VR experiences. One of the participants suffered from unilateral neglect; analysis of his performance revealed that in the beginning of the virtual reality session he used only his right hand and did not move within the environment. As the session progressed, he began to use both sides of his body and became much more mobile. The other participant suffered mainly from motor deficits; analysis of his performance revealed an increase in his ability to raise the affected arm as well as maintain his balance. Specific performance data from these and additional participants with stroke will be presented.

#### 3.2 *Patients with paraplegic (complete or incomplete) spinal cord injuries (balance training).*

Spinal cord injury can affect physical, psychological and emotional aspects of occupational performance. The impairments and disability resulting from SCI depend on the level of injury. The role of rehabilitation in these cases is to bring the patient to maximal independence in all aspects of life (Hollar, 1995). Rehabilitation after SCI encourages patients with lower, incomplete injuries to stand and ambulate with orthoses for therapeutic, psychological and functional purposes. Balance is prerequisite to functional activities in standing and depends on the integrity of the central nervous system (e.g. motor ability and postural movements and sensory information). Functional activities provide greater postural challenge; an individual's ability to engage in functional activities is often limited due to impaired balance and the need for constant upper limb support (Middleton et al., 1999). The role of the therapist is to help patients find motivating ways to maintain or improve their balance. The Gesture Xtreme VR system can provide purposeful means to improve balance in SCI patients. To date we have tested four participants with complete or incomplete low spinal cord injuries. Their responses were similar to the subjects with stroke and analysis of their performance shows that they make considerably more effort with respect to balance training and postural adjustment than during conventional training. Indeed, during the virtual reality sessions, they were able to stand while using their hands for longer periods of time. Specific performance data from these and additional participants with spinal cord injury will be presented.

#### 3.3 *Young adults with cerebral palsy and moderate mental retardation (leisure, self competence, control)*

Due, in large part, to a pervasive lack of opportunity, children with cerebral palsy and mental retardation, especially those who are non-speaking, often develop dependent behavioral patterns and learned helplessness (Mirenda and Mathy-Leikko, 1989). Our major objective in using virtual environments with a group of non-speaking young adults was to improve their self-esteem and sense of self-empowerment and to give them positive experiences during physical interactions with external environments. To date we have tested 5 individuals with cerebral palsy and moderate mental retardation who are non-speaking and who are confined

to wheelchairs. These participants demonstrated an exceptional degree of enthusiasm during each VR experience, reacting to the various stimuli via appropriate and goal-oriented responses. Their responses to the presence questionnaire indicated that their level of involvement was considerable. Specific performance data from these and additional participants with cerebral palsy and mental retardation will be presented.

#### 4. FUTURE DIRECTIONS

We have begun the development of several new virtual environments, to be experienced within the Vivid platform. We contend that, to date, insufficient attention has been given towards the identification of which VR attributes are of greatest importance in achieving its effect as a rehabilitation intervention tool. These include the effect of using of two-dimensional versus three-dimensional visual presentation, representation of the patient as an avatar or as a realistic image embedded within the virtual environment, and the ability of the patient to control his location and movements via non-intuitive actions (e.g., joystick manipulation) or via natural movements. Our efforts in this direction involve the import and adaptation of Rizzo et al.'s (2000) virtual classroom and virtual office. We plan to concurrently compare subject performance (both controls and individuals with neurological disabilities) while engaged in these environments within the Vivid platform and within the customary HMD and tracker platform. Such comparisons will give us greater insight into the relative attributes of the two approaches to immersive VR and will help us to identify the ideal platform for the various therapeutic objectives in rehabilitation.

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