Virtual Environments in Physical Therapy

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1. Introduction

This chapter examines virtual environments which usually represent computer simulated environments, otherwise called virtual worlds or virtual reality and its application in physical therapy. Virtual environments present computer-generated three-dimensional (3D) representation of a physical presence of places in the real world as well as in the imaginary world. Users mainly interact with virtual environments using virtual reality headsets. Many of the current virtual reality environments are primarily visual experiences display either on a computer screens or through other stereoscopic displays. Applications of virtual environments are mainly focused on artificial reality that projects users into a 3D space generated by the computer with some sort of tracking devices which may be the virtual reality headsets worn or another 3D tracking device attached to the body of the user such as the electromagnetic tracker system. Research in virtual environments has made significant impact in the entertainment industry and in the training field such as the flight simulator (Stern, 1995).

Source description: Hospital Corpsman 2nd Class Tim Sudduth, from Vashowish, Wash., demonstrates the Virtual Reality (VR) parachute trainer, while Aviation Survival Equipmentman 1st Class, Jackie Hilles, from Ekland, Penn., controls the program from a computer console. Students wear the VR glasses while suspended in a parachute harness, and then learn to control their movements through a series of computer-simulated scenarios.

Fig. 1. Virtual Reality Parachute Trainer. Source:
http://www.news.navy.mil/view_single.asp?id=3523 Courtesy: The work of the United States Federal Government under the terms of Title 17, Chapter 1, Section 105 of the US Code.

In another view, some researchers like Strickland, Hodges, North and Weghorst (1997) describe virtual environments as computer presence and feel of another place with tracking of what the person does in this imaginary scene. They argued that when the headsets are used to remove the real background of the user, the mind is fooled and the senses are made to accept as reality this new imaginary environment. Some simulations of virtual environments add more sensory information to depict the imaginary world as close to reality as possible and advanced haptic systems are now being coupled with tactile information (force feedback) to create systems for medical and gaming applications. Advances in telecommunications have enabled remote communication environments which now provide virtual presence of users with the concepts of telepresence and telexistence (Liang et al., 2006; Szigeti et al., 2009). The example above demonstrates the use of virtual environment in parachute training. The system provides a parachute simulation where students learn how to control flight movements through a series of computer-generated scenarios.

2. Applications of virtual environments

The use of virtual environments in real life applications has grown tremendously in the last decade. A growing number of educators and researchers are reported to have found virtual environments useful for teaching and research, despite its challenging technical requirements. Many of the properties of virtual environments are viewed to be conducive for good learning as they tend to be interactive, engaging, and provide safe places for students to learn by doing and experimentation. There is also ample provision of scaffolding and immediate feedback to measure if learning has actually taken place. The report reveals that over 74 universities and colleges already have a presence (virtual campuses) within Second Life, an online virtual world created by Linden Lab, where a host of client programs (Viewers) enable Users (Residents) to interact with one another through avatars. The Residents can explore the virtual world, meet other Residents, socialize, participate in individual or group activities, trade virtual property and services with each other. Second Life, taunted as the Internet's largest user-created 3D virtual world community, has been used for distance learning, museum-style exhibits, corporate training, broadcasting information, or simply as an interactive supplement to traditional classroom environments. It is envisaged that virtual classes and virtual classrooms will become more commonplace, as the number of schools that hold online classes within Second Life continues to grow. As simulations and designed experiences, , researchers believe that virtual worlds are useful for experiential, exploratory learning and for teaching various content areas like business (e.g. virtual real estate, intellectual property), economics, art design and architecture, science, among other topics. It is also reported that Second Life already has over a million active users.

In the use for therapeutic applications, the field of motor rehabilitation, especially after a stroke assault, is one of the fields that have benefitted significantly from virtual environments applications. A number of virtual environment-based systems have been developed along the theory underlying neuronal mechanism targeting recovery. It is assumed that recovery could be facilitated by harnessing mechanisms underlying neuronal reorganization. O'Sullivan and Schmitz (2001) argued that motor recovery evolves from a complex set of neurological and mechanical processes that inform postures and that the brain normally provides signal that help with balance, coordination and orientation necessary for movements, especially walking. Molnar (2002) argued that stroke impairs

these complex set of processes involved in walking. Liepert and his colleagues in 2000 along with Jack and his fellow researchers in 2001 showed indications that virtual environments can be used to simulate artificial images that trigger biofeedback mechanisms that can aid in motor recovery.

In the work of Jack and his colleagues (Jack et al., 2001), a PC-based desktop system was developed that employed virtual environments for rehabilitating the hand function in stroke patients. The system uses two input devices, a CyberGlove and a Rutgers Master II-ND (RMII) force feedback glove, that allow users to interact with the virtual environment. The virtual environment presents four rehabilitation routines, each designed to exercise one specific parameter of hand movement e.g., range of motion. The authors used performance-based target levels to encourage patients to use the system and to individualize exercise difficulty based on the patient's specific need. Three chronic stroke patients were employed to carry out pilot clinical trials of the system daily for two weeks. Objective evaluations revealed that each patient showed improvement on most of the hand parameters over the course of the training.

In 2002, Boian and his colleagues used a similar virtual environment in a different context to rehabilitate four post-stroke patients in the chronic phase. The system developed was distributed over three sites (rehabilitation site, data storage site, and data access site) and connected to each other through the Internet. At the rehabilitation site, the patients underwent upper-extremity therapy using a CyberGlove and a Rutgers Master II (RMII) haptic glove integrated with PC-based system that provides the virtual environment. The patients interacted with the system using the sensing gloves, and feedback was given on the computer screen. The data storage site hosted the main server for the system. It had an Oracle database, a monitoring server, and a web site for access to the data. The data access site was a 'place-independent' site, being any computer with Internet access. The therapist or physician could access the patients' data remotely from any location with Internet connections. The patients exercised for about two hours per day, five days a week for three weeks, within the virtual environment to reduce impairments in their finger range of motion, speed, fractionation and strength. Results showed that three of the four patients had improvements in their thumbs' range of motion and finger speed over the three-week trial while all the patients had significant improvements in finger fractionation, and modest gains in finger strength.

Similarly, in the same year, Alma S. Merians, with some members of Boian's research group continued related work using the CyberGlove and the RMII glove, coupled with virtual reality technology, to create an interactive, motivating virtual environment in which practice intensity and feedback were manipulated to present individualized treatments to retrain movements in three patients who were in the chronic phase following stroke. The patients participated in a two-week training program, spending about three-and-half hours per day on dexterity tasks using real objects and virtual reality exercises. The virtual reality simulations were targeted for upper-extremity improvements in range of motion, movement speed, fractionation, and force productions. Results showed that one of the three patients, the most impaired at the beginning of the intervention, gained improvement in the thumb and fingers in terms of range of motion and speed of movement. Another patient improved in fractionation and range of motion of his thumb and fingers. The third patient made the greatest gains as that patient was reported to have gained improvements in the range of motion and strength of the thumb, velocity of the thumb and fingers, and fractionation.

These evidences showed the usefulness of virtual environments for rehabilitation therapy to improve movement performance and/or functional ability and add to other research efforts such as the study of computerized training in a virtual reality environment as an enhancement to existing methods of retraining the hand in patients in the later phase of recovery after a stroke (Merians et al., 2002), robot training using a virtual environment to enhance stroke rehabilitation (Krebs, Hogan, Aisen & Volpe, 1998), and Professor Baram's work on a virtual reality device that helps Parkinson's and stroke patients walk better (Garbi, 2002). Curtis (1998) and Merians et al. (2002) observed that the field of virtual reality was still in its infancy, especially for special needs; however, crossovers with fields such as computer graphics, Computer-Aided Design (CAD), acoustics, and human-computer interface, which are much better established, are currently making the creation of virtual environments more viable. Advances in technology, in terms of computer processing power and graphics hardware, have made it possible to create virtual environment on cheap computer platforms (e.g., 486 or Pentium IBM compatible PCs). These were previously only possible on high-end workstations such as silicon graphics machines. Breakthroughs in LCD technology are already being delivered in the form of cheaper and higher resolution virtual reality headsets, which are required for fully-immersive virtual environment. Global Positioning Satellite (GPS) technologies, such as compact gyroscopes, promise mass production of three-dimensional (3D) input devices, similar to those already found in the Phillips 3D mouse, to facilitate interactions at a very low cost, and fields such as Human Computer Interaction (HCI) have long been focused on the use of virtual reality as an alternative means of interaction (Snowdon, West & Howard, 1993). Telecommunication networks currently can deliver via the Internet high bandwidth graphical information required by virtual reality, and technology solutions are now being implemented using virtual reality for special needs (Boian et al. 2002; Smythe, Furner & Mercinelli, 1995). Web page designs can now utilize 3D capabilities using the Virtual Reality Mark-up Language (VRML), and the ability to extend healthcare's reach has been advocated (Plant, 1996).

3. Forms of virtual environments

Virtual environments are generally classified by the degree of immersion it provides through level of user interactivity, image complexity, stereoscopic view, field of regard and the update rate of display. A careful and complex combination of all these factors determine the level of immersion achieved as no one parameter is effective in itself.

3.1 Fully immersive environments

Virtual Environment can be fully immersive, where, in this sense, the user feels they are part of the simulated world. All the senses of the user are engaged, sight, sound, touch, smell, taste, with technology such as panoramic 3D displays for full sense of vision, surround sounds for auditory immersion, haptic and force feedback for tactile feelings, and smell and taste replications for olfactory and gustation experiences. This form of environment. Fully immersive environments provide the most direct experience of virtual environments and have been reported to be probably the most widely known VR implementation where the user either wears a Head Mounted Display (HMD) or uses some form of head-coupled display such as a Binocular Omni-Orientation Monitor or BOOM (Bolas, 1994).

3.1.1 Head Mounted Display (HMD)

This is a headset used for full immersion. It can contain a pair of goggles or a full helmet. In front of the eyes are two tiny monitors that present images in three dimensions. Most HMDs include a head tracker so that the system can respond to head movements. The small monitors placed in front of each eye provide stereo, bi-ocular or monocular images. The Stereo images come in a similar way to shutter glasses as only a slightly different image is presented to each eye. The major difference is that the two screens are placed very close (50-70mm) to the eye, while the HMD optical system keeps the image which the wearer focuses on much further away. Bi-ocular images can present identical images on each screen while monocular images are formed using only one display screen.

The most commonly used HMDs employ small Liquid Crystal Display (LCD) panels which provides enough screen resolution for many applications, but the more expensive ones employ Cathode Ray Tubes (CRT) that increase the resolution of the screen image. Fully immersive systems usually exclude the user's view of the real world and enhance the field of view of the computer generated world. The advantage of this method is that the user is provided with a 360° field of regard giving them a visual image in whatever direction they turn their head. The HMDs are central to achieving the sense of full immersion; hence their resolution, the update rate, and contrast and illumination of the display are critical factors.

Fig. 2. Virtual Reality Headsets

3.2 Non-immersive environments or desktop systems

These are the least immersive implementation of virtual simulation techniques. With Personal Computers on the desks, the virtual environment is created through a portal or

window by utilising a standard high resolution monitor. Users interact with the environment through conventional means such as keyboards, mice and trackballs, which can be augmented by using 3D interaction devices such as a SpaceBallä or DataGloveä.

The non-immersive systems are more economical to set up as they usually do not require the highest level of graphics performance and without any specialized hardware requirements. They can also be cloned on high specification Personal Computers. These are the lowest cost VR solutions that are being employed for many virtual environment applications. The reported drawback, however, is that they are usually outperformed by the more sophisticated systems. They are confined within the limit of the existing 2D interaction device and thus provide little or no sense of immersion hence of little use where the perception of scale is an important factor. It is expected that the growing use of Virtual Reality Modelling Reality Language (VRML), which is also being adopted as a de-facto standard for the transfer of 3D model data and virtual worlds via the internet, should fuel the use of non-immersive virtual environment applications. It is argued that the advantage of VRML is in its ability to run relatively well on personal computers as opposed to many other proprietary VR authoring tools and the growth in its use that can result in the current trends of commercial VR software having VRML as a tool incorporated in them to explore the commercial possibilities of desktop VR applications.

3.3 Semi-immersive virtual environments

In semi-immersive virtual environments, the viewer becomes partly but not fully immersed in this environment. These systems borrowed considerably from technologies developed in the flight simulation field and are a relatively new implementation of VR technology, which often consists of a large, concave screen, projection system and monitor similar to the large screen experiences seen at IMAX cinemas. They usually involve high end computer graphics. A flight simulator, for an example may present a semi-immersive simulation of an aircraft cockpit where the set up would consist of a physical display of the cockpit and chair with three dimensional images. The trainee does not need to wear virtual reality gear such as a data glove or head mounted display (HMD) and is still aware of the real world outside of the virtual environment. Semi-immersive systems present a few advantages over fully immersive systems such as a CAVE, an automatic virtual environment system, which includes cost, ease of use and logistics. But it has its disadvantages as well which include limited range of interaction devices and problems with multi-user applications

A semi-immersive system can be set up with a relatively high performance graphics computing system which can be coupled with a large screen monitor, a large screen projector system or a multiple television projection systems. They provide a greater sense of presence than non-immersive systems and also a greater appreciation of scale. Because the images can be of a far greater resolution than those of HMDs, semi-immersive systems possess the ability to share the virtual experience. This has been argued to be its advantage, especially in educational applications as it allows simultaneous experience of the virtual environment without the need for head-mounted immersive systems. Also, stereographic imaging can be achieved, using some type of shuttered glasses in synchronisation with the graphics system. According to vrs.org, Shutter Glasses are Liquid Crystal Shutter (LCS) glasses which consist of a lightweight headset with a liquid crystal lens placed over each eye. Stereopsis works on the principle that in order to perceive depth in a scene, the

observer must see slightly different images of the scene under regard in each eye. In the real world this occurs because the two eyes are placed slightly apart in the head, and so each eye views the scene from a slightly different position. Multi-user issues have been reported as one of the main advantages of these systems and designers must consider the handover of control between users as this technology develops.

Virtual environments applications continue to grow. Developers are coming out with new technologies that can simulate effects such as wind, vibration and lightning to enrich the virtual environment for a true model of reality. Virtual environments are being successfully used for applications such as driving and flight simulators and we are now witnessing some entertainment environment like the simulated Viruga Mountains in Rwanda to explore a tribe of Mountain Gorillas.

4. Some barriers and issues in virtual environment applications

Despite all the strides in virtual environment applications, research still shows inconsistencies in the reports on research efforts in virtual environments. One main contention is whether skills gained in virtual environments transfer to real-world conditions. This argument has come to the forefront in the widely use of virtual environment for therapeutic applications. For example, efforts to promote functional recovery through therapeutic interventions like neurofacilitation techniques, progressive strengthening, biofeedback and electrical simulation, after the occurrence of stroke, have yielded inconsistent results (Duncan, 1997; Feys et al., 1998; Merians et al., 2002; Richards & Pohl, 1999). O'Sullivan and Schmitz (1994) argued that these inconsistencies stemmed from inadequate training and skills in performing these procedures in order to ensure the validity and reliability of the tests. Wilson, Foreman and Tlauka (1996) reported that internal representations resulting from exploration of simulated space transferred to the real environment. Kozak et al. (1993), Deutsch, Latonio, Burdea and Boian (2001), argued that although subjects trained on a motor task in a virtual environment demonstrated the ability to improve performance in that environment, the learning did not always transfer to the real-world task. Jack et al. (2001) attributed this problem to the current paucity of investigation into the use of VR for motor skill training. These inconsistencies indicate that research in motor task training and transfer of that task to the real-world environment is neither fully understood nor entirely conclusive (Jack et al., 2001). These conflicting findings need to be more carefully explored in order to ascertain the usefulness of VR as an enhancement to traditional therapy. Fox and Fried-Oken (1996) also observed that many questions relating to the generalization of new learning to the natural environment remained largely unanswered.

Recent studies have shown that virtual reality technology can be used to provide this treatment approach based on its capability to create an integrated, interactive, motivating environment in which practice intensity and feedback can be manipulated to effect functional recovery or improvements in patients following stroke (Liepert et al., 2000; Merians et al., 2002; Taub, Uswatte & Pidikiti, 1999;).

5. A virtual environment case study

The author conducted a case study to justify his own belief on this inconclusive subject. The research undertaken also aims to justify or not research efforts in virtual environments

applications as alternative intervention techniques for motor rehabilitation for researchers and clinicians involved in rehabilitation engineering. The study specifically focused on the effect of using virtual environment to improve ambulatory function in stroke patients, and investigated whether the skills gained from the environment transfer to real-world conditions. A virtual reality system was developed to train stroke patients with lower extremity problems (Akinladejo, 2005, 2007). The product of the research study was developed using the i-glasses PC 3D HR Head Mounted Display and the Polhemus electromagnetic tracker system.

Fig. 3. The Author with the i-glasses PC 3D HR Head Mounted Display and the Polhemus electromagnetic tracker system (Akinladejo, 2005)

Fig. 4. The Author with sensors of the Tracker system on his legs. (Akinladejo, 2005)

Information about a scenario of interest to the patients was gathered. The VR system was used to present this scenario in the form of an environment where the patients performed a VR-based exercise in order to induce the therapy needed to correct their gait problems. The VR system was employed to present the patients with VR tasks (in the form of a painting exercise) closely linked with the therapy needed to correct or improve any abnormality in their walking patterns. This stage model phase modeled all the primitives, visual and audio, of both the task-specific exercise and the VR environment as formalized in the scenario stage. The virtual reality task was based on a painting exercise, which served the purpose of inducing the therapeutic movements needed for the functional recovery or improvements of the lower extremities of the patients. The VR-based painting exercise was employed for the purpose of simulating visually immersive therapy exercise on a PC without having to physically use real paints, brushes, boards or papers.

Research has recently been focused on the painting process and virtual reality technology (Lin, Baxter, Scheib & Wendt, 2004), and the clinical community for the work agreed that the painting task is capable of inducing the movement patterns that are closely linked with the therapy needed to correct ambulatory problems, especially in ankle and foot movements. The painting exercise induced in the leg the complex strokes associated with physical painting in the real world. A graphical user interface provided the therapist with a simple and minimal set of keystrokes with which the VR exercises were manipulated for the appropriate level of exercise difficulty for each patient. The VR-based painting exercise presented the patients with windows of different sizes to be covered. The patients were required to cover the windows with 'red blinds' using their hemiplegic legs. The window's color, initially cyan over a blue background, becomes red over a blue background when completely covered. The therapist viewed the painting process on a computer screen as the patient performed the exercise within a virtual environment using the head mounted display. The author designed a 'LegMouse' and a 'LegPad' (Akinladejo, 2005), which the patient used to accomplish the painting exercise. The LegPad was attached to the patient's hemiplegic leg for movements on the LegMouse. The LegPad was designed, in consultation with the clinical community, with a hemispheric base in order to allow dorsiflexion, plantar flexion, inversion and eversion movements of the ankle joints. As the patient moved his or her leg with the LegPad over the LegMouse, the painting program caused the cursor on the computer screen to 'paint' a defined window. There were four different window areas, each corresponding to the task difficulty level that the patient was performing. The painting process stopped whenever the cursor moved outside a window area. Thus the patient was constantly challenged with the task of keeping the cursor within the window area in the virtual environment, and also with the task of moving his or her hemiplegic leg in all directions for the painting process to continue. These movements (e.g., dorsiflexion and plantar flexion movements) helped to induce in the leg the therapy needed to correct or improve ambulatory problems in the ankle joint thereby leading to better walking skills. Some images that present the patient's view of the systems is presented. The painting exercise was modeled using OpenGL, an environment for developing portable, interactive 2D and 3D graphics applications. This application programming interface (API) is widely used on a number of computer platforms for innovative developments through its broad set of rendering, texture mapping, special effects, and other powerful visualization functions available for application developers (http://www.opengl.org/about/overview.html). OpenGL is a truly open, vendor-neutral, multiplatform graphics standard that provides consistent visual display results on any OpenGL API-compliant hardware irrespective of the

operating system. It offers complete independence from network protocols and topologies. Application developers are well shielded from underlying hardware as OpenGL drivers ensure proper encapsulation of hardware primitives, thus giving them ample flexibilities for innovative designs. The OpenGL standard provides language binding for C++ and Java, the two main languages employed for the research study. The virtual exercise system incorporated performance-based target levels to increase the patients' motivation (Jack et al., 2001). Feedback mechanisms informed the patients on the target levels and their actual performance on the VR system, and the therapists employed the GUI-based interface to tailor exercise difficulty to the patients' specific problems. The feedback provided an avenue for encouraging the patient to accomplish more trials in the virtual environment. To encourage motivating environment, the author identified, through interviewing the patients, that music will make the scenario of interest to them, and combined an audio system with the painting exercise, in a way that presented an interesting and motivating environment where the patients were unaware of the technology behind the VR-based exercise, just because they wanted to 'play the game' on the computer and enjoy the music.

6. A clinical trial

Qualified physiotherapists from the clinical community were employed for the clinical evaluation of the VR-based rehabilitation program. They also helped to recruit the research subjects for the work, and supervised their training sessions. The patients were required to use the virtual environment for regular rehabilitation for about half an hour per day, five days a week for a period of four consecutive weeks. A computer screen provided the therapists with feedback on the performance of the patient on the system, and the therapists were able to adjust the level of difficulty of each exercise based on the specific need of the individual patient. Adjustment was in terms of what the author termed Task Difficulty Level (TDL), which ranged from 1, the easiest to 4, the most difficult. The therapists observed the progress made by the patients while they performed the VR tasks, and also guided them in producing more refined movements to reduce movement errors. The clinical trial was carried out at the Sir John Golding Rehabilitation Centre, popularly known as Mona Rehab. Mona Rehab is a unique center for the rehabilitation of persons with physical disabilities in the Caribbean, and it is only a short distance from the researcher's place of work, which made it easily accessible. The researcher installed the system in the Physical Therapy Department. The patients' gait variables were obtained prior to and after the treatment, and were analyzed and used to ascertain the usefulness of virtual reality technology in rehabilitation program directed towards lower extremity problems in post-acute stroke patients. A test was carried out to determine whether skills gained within VR environments transfer to the real world.

7. The virtual environment system

The VR system executes and displays a welcome screen where user of the system will have to enter a password in order to gain access. The screen dump below shows the first interface of the system which the users, in the clinical trial case, the physical therapists, will use to gain access to the systems.

A valid password has been stored in the memory, which the system compares with the user's supplied password. A mismatch will allow the user two more attempts before the system logs out. A match will lead the user to the Patient Information Screen. The user will be required to
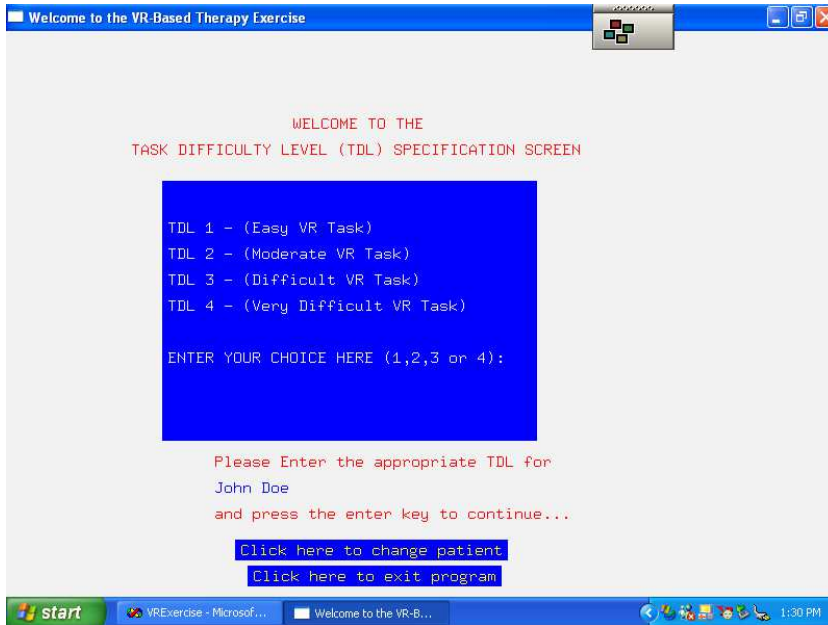
Fig. 5. The Interface for the Clinician. (Akinladejo, 2005).

supply a patient research number (PRN). If a PRN is not found, the system will give opportunity to either re-enter another PRN or add the current PRN to the database. There is an optional button to exit the program. If a PRN is found or is added, the system then leads the user to the Task Difficulty Level (TDL) screen where the user will specify the appropriate VR-based task that the chosen patient will undergo. The tasks range from one (1) the easiest to four (4), the most difficult. If an invalid TDL is entered, the system will default to TDL1.

The clinician can opt to change the patient from this screen or exit the program. The appropriate TDL choice leads to the exercise mode, where the patient performs the chosen exercise at its TDL level. The exercise mode displays the name of the current patient, the exercise type he or she is performing, the target time for that exercise and the time the patient starts the exercise. The exercise is to cover a window area with a blind, in the form of paint. The TDL of the VR exercise presents the patients with four different rectangular windows that they need to cover with a red blind. As the patients move the cursor over the window using their legs, the window is being covered with the red blind; hence, the patients paint the window area with the mouse until the window is completely covered. The system informs the patients once the window is completely covered, and displays the target time to complete the chosen TDL, the patients' start time, stop time and time taken to cover the window. The user can reset the exercise for the patient or exit the system using the exit button. On exit, the system writes the patients exercise data in an output file, which the author exports to an external application for analysis. The task difficulty level is influenced by the fact that the windows are of different sizes and the 'paint brush' has varying sized tips. These pose challenges in terms of the time and effort required to cover the windows. For example, TDL 1 has a wider window size and a thicker paintb\rush, while TDL 4 has a smaller window size and a thinner paintbrush.
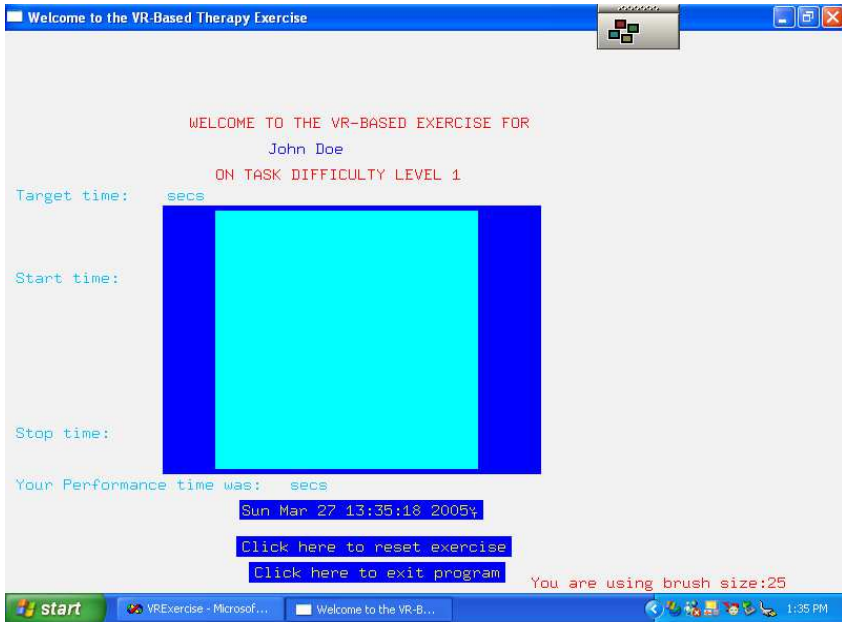
Fig. 6. The patient views this window in the virtual environment using the 3D i-glasses.
(Akinladejo, 2005).

Fig. 7. A sample of an exercise being performed in the virtual environment by one patient.
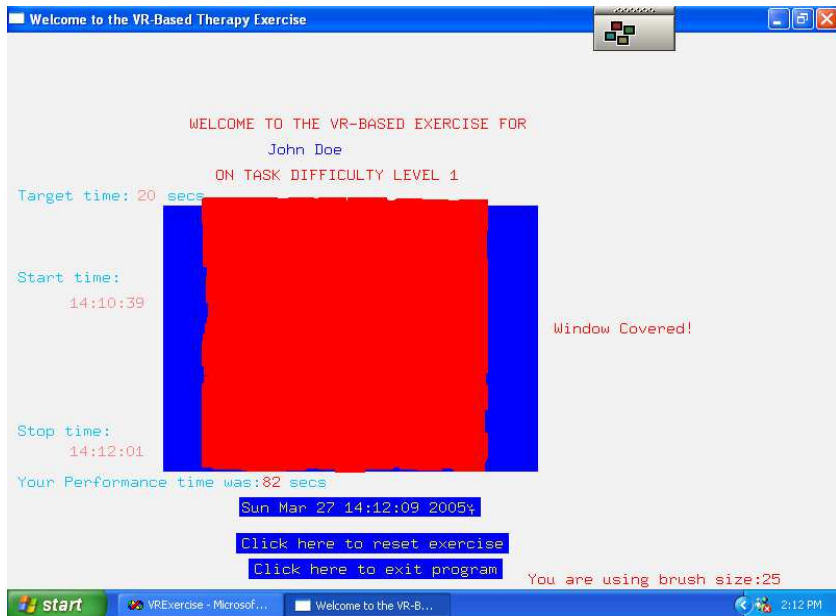(Akinladejo, 2005)

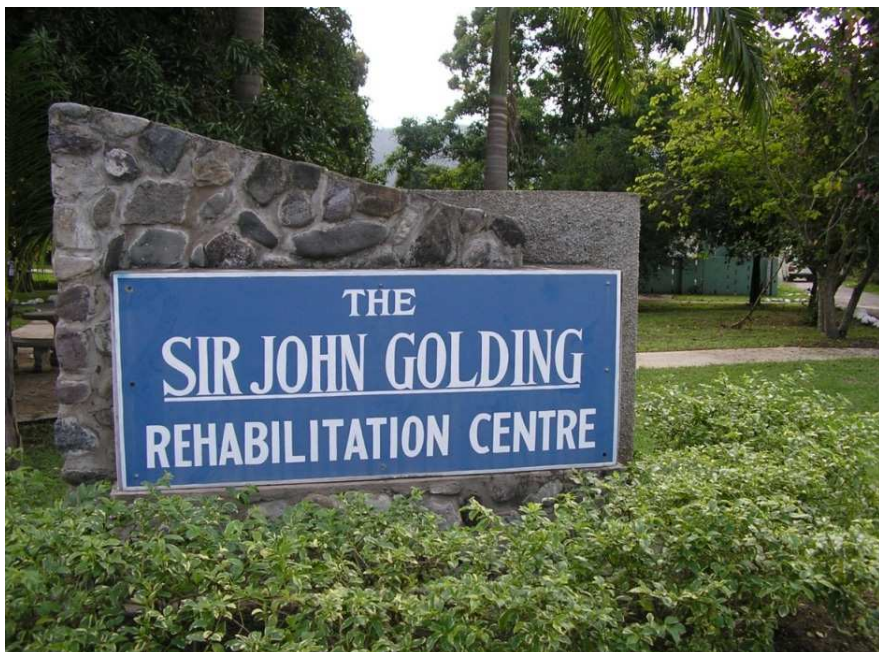Fig. 8. A Completed Task of Difficulty level 1 by a Patient in the Virtual Environment. (Akinladejo, 2005).

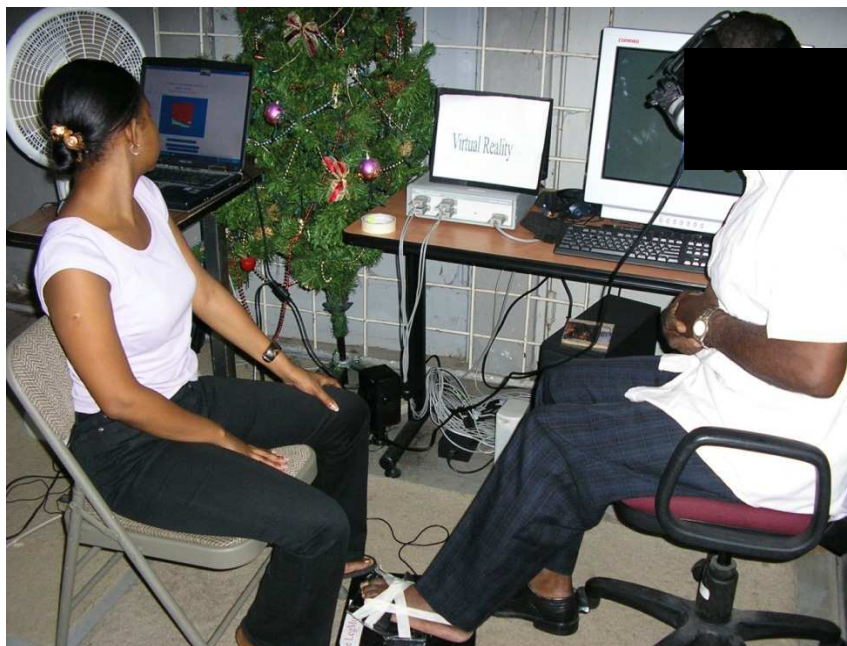Fig. 9. The Clinical Site. (Akinladejo, 2005).

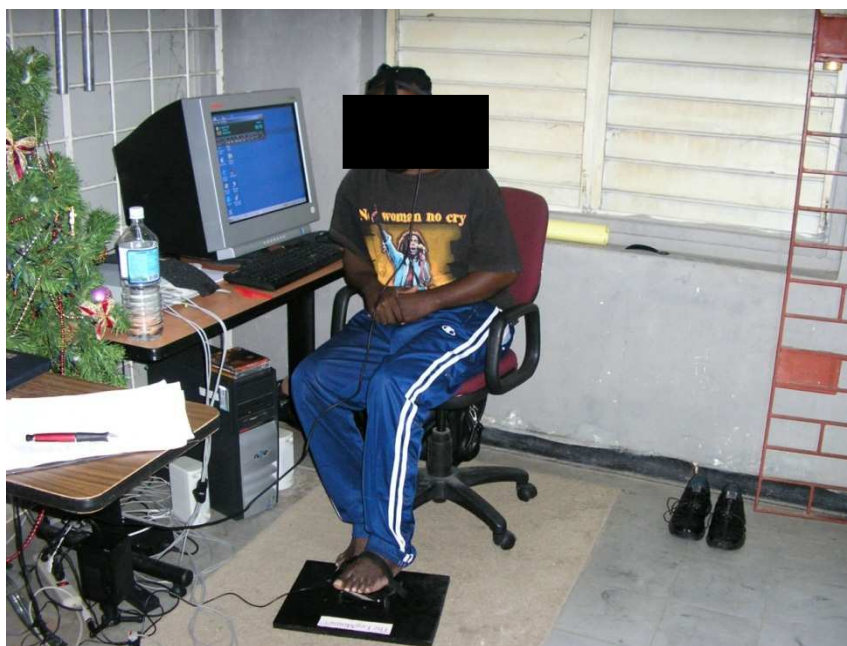Fig. 10. A Physical Therapist Guiding a Patient in the Virtual Environment. (Akinladejo, 2005)

Fig. 11. Another Patient in the Virtual Environment. (Akinladejo, 2005).

8. The research results

A number of analysis were carried out during the study and results obtained, details of which have been presented as in Akinladejo (2005). This chapter presents two results on two of the patients who used the virtual environment.

8.1 Performance results

For the exercise sessions in the virtual environment, the percentage of improvement in using the system was calculated based on the patients' performance data for the last day of week two and that of week four on the painting exercise. That is,

$$\frac{\text{LastDayData (Week2)} - \text{LastDayData (Week4)}}{\text{LastDayData (Week2)}} \times 100\%$$

The table below summarize the data.

Patient	Time taken on TDL 1 in secs	Time taken on TDL 2 in secs	Time taken on TDL 3 in secs	Time taken on TDL 4 in secs	Total time on exercise for the day in secs	Total time on exercise for the day in minutes
RB1	1007	594	545	885	3031	51
EO2	831	416	691	472	2410	40

Table 1. Last Day Data for Week Two

Patient	Time taken on TDL 1 in secs	Time taken on TDL 2 in secs	Time taken on TDL 3 in secs	Time taken on TDL 4 in secs	Total time on exercise for the day in secs	Total time on exercise for the day in minutes
RB1	365	302	161	449	1277	21
EO2	165	225	138	212	740	12

Table 2. Last Day Data for Week Four

The following are the percentage improvements for the patients on the VR task over the four-week period (note that improvement addresses the percentage reduction in time taken to complete the task in the virtual environment).
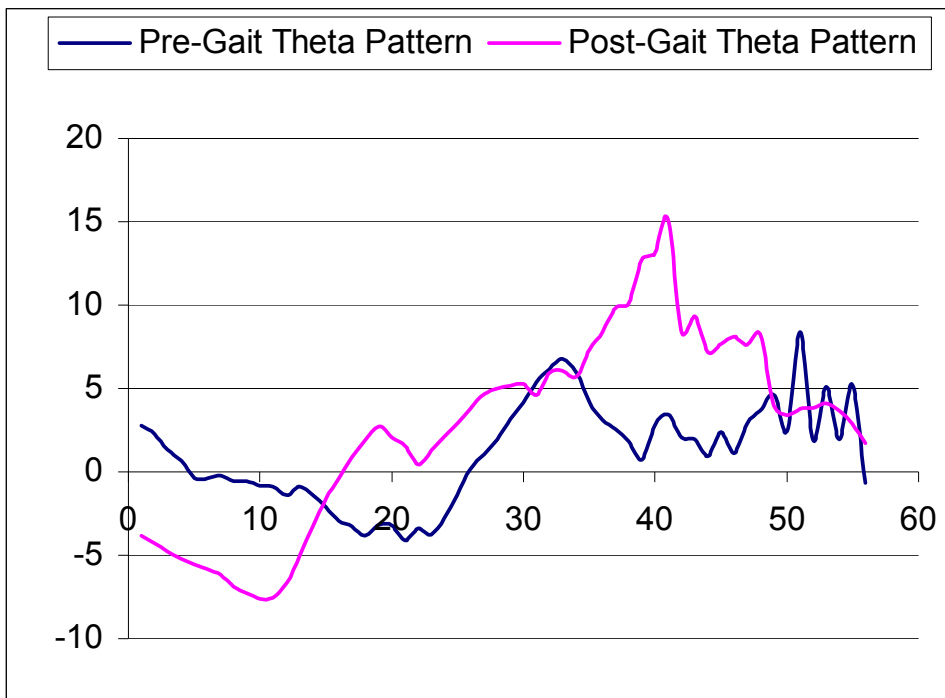
$$\text{RB1} = \frac{51 - 21 \times 100\%}{51} = 59\% \text{ improvement}$$

$$\text{EO2} = \frac{40 - 12 \times 100\%}{40} = 70\% \text{ improvement}$$

All the patients could not complete the four different levels of the VR task during the first week of the exercise. However, at the end of the second week, their performances had improved, and they were all able to complete the tasks at all the levels. Results from the analysis of the exercise data of the last day of week two and the last day of week four as in table 1 and 2 show that patient EO2 made the most improvement on the VR task(i.e. spent less time completing the task), while patient LP3 made the least improvement. EO2 diligently studied the painting movement and acquired the method of the painting process during the implementation period, hence the result. LP3, however, struggled until the last week before he started improving on the painting process. This result is significant to their functional gains as explained subsequently.
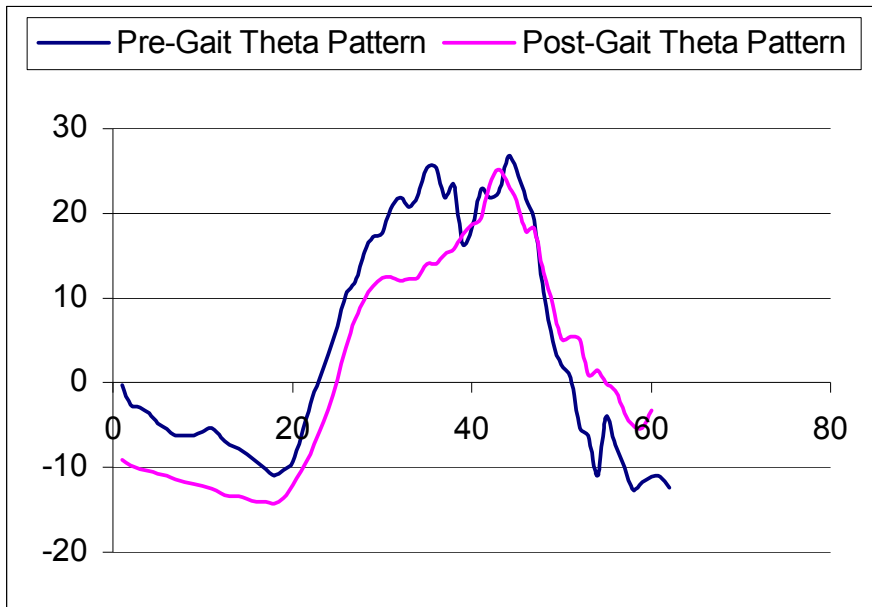
8.2 The clinical results

The gait variables of the patients were captured using the Polhemus Electromagnetic Tracker System before and after the intervention using the virtual environment, and Kaltenborn's convention (Akinladejo, 2005) was used to interpret the results. The graphs below were obtained for the two of the patients.

The pre- and post-intervention gait pattern for patient RB1

Fig. 12. Graph for Patient RB1. (Akinladejo, 2005).

The pre- and post-intervention gait pattern for patient EO2

Fig. 13. Graph for Patient EO2. (Akinladejo, 2005).

9. Interpretation

Before the intervention program, using the Kaltenborn's convention, patient RB1's **Range of Motion (ROM) was 8-0-4 as against the normal values 15-0-20** (see Whittle, 2003 for normal ranges for gait parameters). **The ROM was improved to 15-0-8 after the intervention program.** This means that patient RB1 had reduced dorsiflexion and plantar flexion due to spasticity before the intervention program but his ankle joint gained more movements after the program.

Patient EO2's ROM was 27-0-10 before the intervention but changed to 25-0-14 (normal values are 15-0-20). This means that his excessive dorsiflexion 27 was reduced to 25, and he had increased plantar flexion. Excessive dorsiflexion has been linked with tibia tilt, which presents a challenge for normal walking, hence the improvement observed in his walking skill.

10. The transfer of skill result

The transfer-of-skill observational measurements were carried out by one of the three physical therapists that supervised the clinical trial. The patients were followed up one week after the intervention program to observe whether the skills learnt transferred to the real world. Patients EO2 and LP3 transferred similar skills to the natural environment. They initially had mass movement of the limbs due to sluggish brain activity/coordination. It was observed that these patients were able to move their ankle joints on the floor, without

involving their hips. Synergy, according to the therapist, lost some of its control over the patients' motor acts during the clinical trial, and they were able to transfer these skills into the natural environment. Patient MR4, the third patient whose data was not presented here, had a smoother transition of her leg from the gas pedal to the brake during driving. This skill was similar to the movement of the leg during the painting exercise on the VR therapy. The therapy program induced increased brain activity; hence her increased reflex movement in the limb, as sensory activity from the brain was now more specific. She effectively transferred this skill to the real world condition. The transfer-of-skill analysis observed in this study supported the argument (Wilson, Foreman & Tlauka, 1996) that skills gained in virtual environments transfer to real-world conditions.

11. Conclusion

Results show that all the patients improved on their range of motion in the ankle joint due to the use of the virtual environment intervention program. These results buttressed the literature (Liepert et al., 2000; Merians et al., 2002; Taub, Uswatte & Pidikiti, 1999) that supported the usefulness of virtual reality technology in therapeutic rehabilitation. The transfer-of-skill analysis supported the argument that skills gained in virtual environments transfer to real-world conditions.

It is interesting that patient (EO2) with the highest improvement on the computer task was not the one with the highest improvement in the clinical measurement. Patient LP3, with the highest clinical gains had to struggle more than the other patients to complete the VR task. Patient EO2 was completing the exercise faster than LP3. This means that patient LP3 spent more time exercising his hemiplegic leg on the intervention program than the others who were completing the task faster than him, hence his high clinical improvements. This result suggests that the more difficult the virtual environment task is, the more beneficial it will be to therapeutic rehabilitation.

The results obtained from this research study have confirmed the usefulness of virtual environment technology in rehabilitation medicine, especially its efficacy in therapeutic intervention directed towards functional recovery or improvements of the lower extremities in post-acute stroke patients. It has also buttressed the argument that skills gained in the virtual environment transfer to real-world conditions. These results may be of particular benefit to professionals in the fields of physical therapy, physiology, sport physicians, and those involved in the study of human movement, who would want to train their clients to learn motor acts in a spatial environment for subsequent performance in the real world. The study has contributed to the current effort to provide wider access to therapeutic intervention technique using computer technology and should an asset to professionals in the field of physical therapy, physiology, bio-engineering, and all those involved in the study of human movement.

According to O'Sullivan (2001) the most pressing deficiency in rehabilitation feedback literature is the lack of controlled studies involving patients. She observed that most of the works so far have been based on normal subjects or small sample patients. Future research effort could be conducted that employ 'pure' statistical research methods using control and experimental groups with more research participants (like 40 patients) using the virtual environment. This design might likely appeal to the quantitative analysts.

Researchers are currently looking into the subject of what has been termed as Virtual Cocoon, a technology that aims to add the sense of smell into virtual environments. The quest continues.

12. Acknowledgement

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Virtual Reality and Environments

Edited by Dr. Cecília Sík Lányi

Virtual Reality is clearly interdisciplinary research. It has, not only Information Technology importance but social, educational, economical importance too. It combines multiple disciplines for the development of virtual reality systems in which the user has the immersive feeling of being in the real world. Virtual reality has several applications in almost all fields of real life. The most typical fields for the application of virtual reality are health-care, engineering and game industry. This book may be a solid basis for the novice and advanced engineers who would like to develop user friendly Virtual Environments for education, rehabilitation and other applications of Virtual Reality. Our book provides a resource for wide variety of people including academicians, designers, developers, educators, engineers, practitioners, researchers, and graduate students.

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