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Virtual Reality Environments for Psycho-Neuro-Physiological Assessment and Rehabilitation

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Abstract. Virtual Reality Environments for Psychoneurophysiological Assessment and Rehabilitation - is an European Community funded project (Telematics for health - HC 1053 http://www.etho.be/ht_projects/vrepar/) whose aim is:
- to develop a PC based virtual reality system (PC-VRS) for the medical market that can be marketed at a price which is accessible to its possible end-users (hospitals, universities and research centres) and which would have the modular, connectability and interoperability characteristics that the existing systems lack;
- to develop three hardware/software modules for the application of the PC VRS in psychoneurophysiological assessment and rehabilitation. The chosen development areas are eating disorders (bulimia, anorexia and obesity), movement disorders (Parkinson's disease and torsion dystonia) and stroke disorders (unilateral neglect and hemiparesis).
This paper presents the rationale of the different approaches and the methodology used.

Key-words: Virtual Reality, Rehabilitation, Assessment, Eating Disorders, Body Image, Stroke Disorders, Unilateral Visual Neglect, Movement Disorders, Kinematic and Electromyographic Patterns, Movement Control.

1. Introduction

Although virtual reality is mature enough to have different medical applications, the common use of this technology outside the surgical field is actually limited due to different problems:

• The product seems to be “a solution in search of a problem”. As with early computer graphics products, the entry-level costs are relatively prohibitive. Although some attempts have been made to use PC-based virtual reality systems, the majority of the existing systems use RISC platforms whose cost is beyond the means of a normal Hospital Centre or Department. A complete VR environment, including workstations, goggles, body suits, and software, ranges from $60.000 to $1.000.000;
• The hyperbole and sensational press coverage associated with some of this technology has led many potential users to overestimate the actual capabilities of existing systems. Almost all of the applications in this sector can be considered "one-off" creations tied to their development hardware and software, which have been adjusted in the field by a process of trial and error. This makes them difficult to use in contexts other than those in which they were developed. Unless their expertise includes knowledge of the human-machine interface requirements for their application, their resulting product will rarely get beyond a "conceptual demo" that lacks practical utility;
• Although it is theoretically possible to use a single virtual reality system in many different applications, none of the existing systems can be easily adapted to different tasks. This means that two different wards/departments within the same organisation may find themselves having to use two different VR systems because of the impossibility of adapting one single system to their different needs;
• Fundamental questions remain about how people interact with the systems, how they may be used to enhance and augment cognitive performance in such environments, and how they can best be employed for instruction, training, assessment, rehabilitation and other people oriented applications.

To address at least in part these issues, the main goal of the VREPAR project, an EC funded Telematics for Health Project (HC 1053 - http://www.etho.be/ht_projects/vrepar/), is to develop a PC based virtual reality system to be used by psychologist, neurologists, physiopatologists and other specialists whose cost can be consistent with end-users economical capacity (hospitals, universities and research centres).

2. PC based VR for clinical use: is it possible now?

Due, in large part, to the significant advances in PC hardware that have been made over the last three years, PC based VR is approaching reality. While the cost of a basic desktop VR system is almost the same, the functionality has improved dramatically, both in terms of graphics processing power and VR hardware such as head-mounted displays (HMDs). The availability of powerful PC engines based on Intel's Pentium Pro and Pentium MMX, Motorola's PowerPC and Digital's Alpha processors, and the emergence of reasonably priced 3D accelerator cards allow high-end PCs to process and display 3D simulations in real time. According to The Gartner Group, 3D desktop visualisation will be the first VR technology to become widespread as soon as 1998. They further predict that by 1998, high-end desktop PCs will be able to generate virtual worlds as well as those generated by today's graphics workstations.

While a standard Pentium 75 with as little as 8 Mega of RAM can offer sufficient processing power for a bare-bones VR simulation, a 166 MMX enhanced Pentium with 32 Mega of RAM, can provide a convincing virtual environment, while a dual Pentium Pro configuration with OpenGL acceleration and 24 Mega of VRAM running Windows NT, can match the horsepower of a graphics workstation. As reported recently in the Virtual Reality Special Report magazine (May-June 96) "much of the graphics display quality of the Silicon Graphics (SGI) RealityEngine, which has been the Rolls Royce of the VR world with a six-digit price tag, can now be achieved with a new Intergraph (Huntsville, Ala.) graphics accelerator board plugged into a Pentium PC".

Immersion, too, is getting more affordable. Virtual i-O (Seattle), for example, now has an HMD that costs less than $600 and has headtracking built in. Two years ago the same quality costed on the order of 10 times this amount. A HMD with VGA quality is now about $8,000. But that price will probably lose a digit or two during the next five years. Input devices for desktop VR today are largely mouse and joystick based. This choice, even if it is not suitable for all the applications, can keep costs down, minimises the foreignness of VR applications and avoids the ergonomic issues of some of the up-to-date I/O devices like 3D mouses and gloves.

Software, too, has been greatly improved during the last three years. Despite the differences in the types of virtual worlds these products can deliver, the various tools are based on the same VR-development model: they allow users to create or import 3D objects, to apply behavioural attributes such as weight and gravity to the objects, and to program the objects to respond to the user via visual and/or audio events. Ranging in price from $800 to $4,000, the toolkits are the most functional of the available VR software options. While some of the them rely exclusively on C or C++ programming to build a virtual world (they consists of a library of C functions, but it's getting difficult to find such unfriendly interfaces), others offer simpler point-and-click operations to develop a simulation. In addition to supporting various software file formats, some of the toolkits offer graphics-creation capabilities and extensive object libraries.

In conclusion, the PC based VR is becoming real. In a recent interview recently published on the Computer Graphics World magazine (May 1996), Dick O'Donnell, vice president of world-wide marketing for Superscape, declared: "The bottom line is that VR suddenly has a lot more credibility today, and the real driving force is that people are able to look at it on a standard PC and get the kind of performance and resolution that you used to get only from a $100,000 SGI box. Granted, it's not Toy Story in terms of image crispness, but you can't navigate through Toy Story in real time."

3. The approach of the VREPAR project

To develop its PC based VR system, the VREPAR projects chose as its reference platform the high-end INTEL Pentium/Pentium PRO/CYRIX 686 based PCs (166/200 mhz, 32/64 Mega Ram). This choice will ensure availability, an open architecture and the possibility of benefiting from the improvements planned for these machine by INTEL and CYRIX-IBM, mainly faster processors and enhanced multimedia support. Actually, their prices are falling quickly: high-end Pentium/686 PCs are now (Jan. 97) in the range of US$ 2500/3500, while Dual Pentium Pro 200 Mhz based Machines are now approaching the US$ 4000/5000 tag.

The availability of 3-D cards for PC based machines is increasing, too. According to sources, some of the biggest computer companies are getting ready to launch 3-D GLINT based and S3 VIRGE based accelerators for PCs that will compete aggressively with the performance of Silicon Graphics workstations. Prices are expected in the US$ 400/2000 range. Actually the best price/performance ratio is offered by the 8WRAM Matrox Millenium PCI graphic accelerator (US$ 500) that we used as reference graphic card.

The operating system chosen for the VR system is the Microsoft Windows 95/Windows NT suite, actually the most widespread 32 bit compliant OSs. This choice will ensure both open architecture (Windows NT can be used on different platforms including Intel and Power-PC based systems) and an integrated network/Internet support.

For the development of the VR software the project used as its reference development toolkit the Superscape VRT 4.0. The VRT is Superscape's complete graphical environment for the creation of virtual worlds. Through the VRT's editors users can create and manipulate the virtual world in real time to give it whatever appearance and interactions they want. Over 600 specific commands are available for assigning behaviors within virtual environments. These can be applied on an object by object basis so the results can be evaluated immediately. Release 4 also includes VRML authoring, support for all leading VR devices, real time resolution switching up to 1280 x 1024, DXF transfer including layering support and Virtual Humans. The next release (V.5.0), with VRML 2.0 and Direct-X support, is expected in the first quarter of 1997.

Using Superscape Visualiser, the freeware VRT module containing the Superscape's real time 3D graphics engine, it is possible to freely distribute the developed world. Superscape has also developed a Visualiser for the Silicon Graphics machines, so will be possible to use the outcome of the VREPAR project also on more powerful machines, further reducing the technological risk.

We also verified the possibility of using a low-cost head mounted display in the system. We reviewed three low-cost HMD's: the Virtual I-O I-glasses, Forte VFX1 and CyberMaxx Cyber II. Even if the I-O I-glasses can be used for some applications (e.g. for the Eating Disorders module of the project), monitors or projection systems are needed for most practical applications, because HMDs cannot offer yet a good quality at affordable price.

An analysis has been done that deals with the use of auditory VR in psycho-neuro-physiological assessment and rehabilitation. Further special hearing of the human ear, in principle, was analysed as well as concepts for placement of virtual sound sources and afforded hardware requirements.

A special concern has been given to all the aspects regarding the possibile effects of human-computer interaction. This approach is particularly felt mandatory for high demanding and performing applications such as Virtual Reality in the health sector. A set of system requirements and specifications has been set together with a general framework of possibile warnings and guidelines to be followed. These are received by all the partners and will be applied since the prototyping phase to ensure the safe compatibility of all applications with the social and cognitive human environment.

4. The VR applications

Using the hardware/software platform described above, the VREPAR project also aimed at developing three hardware/software modules for the application of the VR system in psycho-neuro-physiological assessment and rehabilitation. The chosen development areas are eating disorders (bulimia, anorexia and obesity), movement disorders (Parkinson's disease and torsion dystonia) and stroke disorders (unilateral neglect and hemiparesis):

4.1 Eating disorders module

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4.1.1 Objectives

In contrast to the great number of publications on body image, only a few papers focus on the treatment of a disturbed body image in eating disorders. In general, two direct and specific approaches can be distinguished: a cognitive/behavioural approach aimed at influencing patients' feelings of dissatisfaction with different parts of their bodies by means of individual interviews, relaxation and imaginal techniques [1], and a visual/motorial approach which makes use of videorecordings of particular gestures and movements with the aim of influencing the level of bodily awareness [2].

An interesting possibility could be the integration of the two methods (cognitive-behavioural and visual-motorial) commonly used in the treatment of body experience disturbances within a virtual environment. A choice of this type would make it possible to use the psycho-physiological effects provoked by the experience for therapeutical purposes.

It is well known that in practically all VR systems, the human operator's normal sensorimotor loops are altered by the presence of distorsions, time delays and noise in the system. The somesthetic systems has a proprioceptive subsystem that senses the body's internal state, such the position of limbs and joints and the tension of the muscles and tendons. Mismatches between the signals from the proprioceptive system and the external signals of a virtual environments alter body perceptions and can cause discomfort or simulator sickness. In a recent study, Cioffi [21] analysed these effects and found that, in VR, the self-perception of one's own body undergoes profound changes that are similar to those achieved in the 1960s by many psychologists in their studies of perceptual distorsion. In particular, about 40% of the subjects felt as if they had "dematerialised" or as if they were in the absence of gravity; 44% of the men and 60% of the women claimed not to feel their bodies. Perceptual distorsions, leading to a few seconds of instability and a mild sense of confusion, were also observed in the period immediately following the virtual experience.

Such effects, attributable to the reorganisational and reconstructive mechanisms necessary to adapt the subjects to the qualitatively distorted world of VR, could be of great help during the course of a therapy aimed at influencing the way the body is experienced, because they lead to a greater awareness of the perceptual and sensory/motorial processes associated with them. When a particular event or stimulus violates the information present in the body schema (as occurs during a virtual experience), the information itself becomes accessible at a conscious level. This facilitates the process of modification and, by means of the mediation of the self (which tries to integrate and maintain the consistency of the different representations of the body), also makes it possible to influence the body image.

In particular we tried to integrate the two methods commonly used for treatment of body experience disturbances in the same way as images in the well-known method of guided imagery [3]. It's in Leuner's belief that the imagery evokes intense latent feelings that are relevant to the patient's problems. Guided imagery has been found to be a powerful tool in treatment approach ranging from psychoanalytic therapy [4] to behaviorism [5].

4.1.2 Methods

The aim of this study was to developed the Virtual Environment for Body Image Modification - VEBIM. VEBIM is a 6-zone virtual environment that tries to integrate in a VE the therapeutical methods used by Butter & Cash [1] and Wooley & Wooley [2]. After the subject entered a zone, the therapist described the situation and encouraged him/her to associate to it in pictures rather than in words, and to give a detailed description of them following the procedure described by Leuner [3] and Kearney-Cooke [6]. This procedure was repeated for each of the zones experienced.

The Virtual Environment for Body Image Modification - VEBIM was developed using a Pentium based immersive VR system (166mhz, 32 mega RAM, graphic engine: Matrox Millenium 4Mb WRAM) including an HMD subsystem (I-O Glasses) and a two-button joystick-type motion input device.

To test VEBIM, 65 normal subjects (41 males and 24 females: mean age: 22.19+/-7.14; mean weight: 65.12 Kg +/- 13.28; mean height: 171.2 cm +/- 7.05) were submitted to VEBIM for no more than ten minutes and no less than eight. Just before entering the virtual environment and just after, all the subjects were submitted two scales for assessing body experience: the Figure Rating Scale - FRS [7] and the Contour Drawing Rating Scale - CDRS [8].

In these tests subjects are asked to rate the figures based on the following instructional protocol: (a) current size and (b) ideal size. The difference between the ratings is called the "discrepancy index" and is considered to represent the individual's level of dissatisfaction. Both scales have good test-retest reliability.

4.1.3 Preliminary Results

We reported significant differences in the Ideal FRS ($p<0.005$) and Ideal CDRS ($p<0.05$) scores: both scores were higher after experiencing VEBIM. An analysys of the two discrepancy indexes revealed significant lower values for FRS ($p<0.01$) and CDRS ($p<0.07$) after the experience in the virtual environment. These results mean that VEBIM is able to reduce the body dissatisfaction of the subjects.

In the male sub-sample significant differences were found in the Real CDRS ($p<0.05$) and Ideal CDRS ($p<0.01$) scores: both scores were lower after the virtual experience. No significant differences were found in the discrepancy index.

For the female sub-sample the marginal homogeneity test reported a significant difference in the Ideal FRS scores ($p<0.005$): the scores were higher after experiencing VEBIM. An analysys of the discrepancy indexes showed a significant lower value for FRS ($p<0.005$) after the virtual experience.

4.1.4 Discussion

The present study shows that even a short-term application of VEBIM is able to modify the body image of the subject of our sample. Usually body-image treatment involves a cognitive/behavioural or a visuomotor therapy that require many sessions. The possibility of inducing a change in the body dissatisfaction after a 8-10 minutes virtual reality session can be useful to improve the efficacy of the existing approaches as a part of a comprehensive treatment package.

Of course these results are preliminary only. We have to test both the effects of the virtual environment on a clinical sample and how long the influence of the virtual environment will last. In this preliminary study we have limited the test to just one session, but from a therapeutic viewpoint it seems more reasonable to repeat the procedure. We have already planned an extention of the study in order to address these issues.

4.2 Movement disorders module

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4.2.1 Objectives

The term “basal ganglia” is used to describe five closely related nuclei: caudate, putamen, globus pallidus, subthalamic nucleus and sustantia nigra. The basal ganglia do not receive any direct sensory inputs and, like the cerebellum, do not send direct motor output to spinal cord. However, there is no doubt that these structures are involved in the control of movement. All diseases of the basal ganglia in man have some disorder of movement as their primary symptom. Common to all these conditions are either an excess of (abnormal) involuntary movements or a lack of spontaneous movements. In addition, there may be changes in muscle tone and defects of postural reflexes.

Many papers [9, 10, 11] have described the kinematics characteristics and the electromyographic patterns of movements, for example of the wrist, in patient with essential tremor, coexistence of bradykinesia and chorea in Huntington’s disease and Parkinson’s disease. These studies don’t take into consideration the relationship that exists between the visual sensory information and control of movement being performed. The aim of this research is the development and use of immersive virtual environments to study the aforementioned relationship in people affected by diseases of the basal ganglia, particularly Parkinson’s disease.

4.2.2 Methods

In order to analyze this relationship we propose to consider a simple touch task, studied under four different conditions. The conditions are:

a) *Quick Movement.* After hearing an acoustic signal (or seeing a visual signal) the subject is asked to reach a target as quickly as possible without there being any control over the force exercised during contact.

b) *Guided Quick Movement.* After hearing an acoustic signal (or seeing a visual signal) the subject is asked to reach a target as quickly as possible. He/she is asked to exercise the least force possible on the target while maintaining a direct visual control over the task being performed.

c) *Virtual Reality Guided Movement.* This condition differs from the previous one in the nature of the visual information about the task being performed. In fact the subject doesn’t maintain a direct visual control over the real test station but interacts with a virtual representation of the station.

d) *Unguided Controlled Quick Movement.* This condition differs from the previous two in the fact that the subject doesn’t have neither real nor virtual visual control over the task being performed.

The task under examination can consist in the subject touching a lamina equipped with strain gauge with the tip of his/her index finger. Only the movements of retraction-extension of the index finger of the hand are examined. The patients are seated on a chair situated in front of the test station. The forearm is placed on a support specially studied to prevent muscular fatigue and to ensure that the position of the metacarpophalangeal articulation of the index finger of the hand is fixed and precisely determined. The only movement allowed is the retraction-extension of the finger in a horizontal plane parallel with the support. By retracting his/her finger in the above mentioned plane the patient touches the lamina. The radial distance between the position of the metacarpophalangeal articulation and the lamina can be regulated according to the length of the phalanxes of the patient's finger. The first experiments were conducted by considering an angular range of 45 degrees (this is the range that should be obtained in correspondence to metacarpophalangeal articulation if the movement of the finger were completely rigid). The equipment described was tested by three operators, after a training period, in order to develop a certain confidence with the experimental devices. During each session, the subject repeated the task 10 times in each condition. The presentation order of the interfaces was randomised. Every subject was submitted to 4 trial sessions.

4.2.3 Preliminary results

The preliminary conclusions from the first series of tests are:

1) the circuit of human action is significant because the reactions are different according to the information sensed. If the feedback is direct, that is the operator is following the action by vision, the action is immediate. In the case the operator follows a diagram on the monitor, the delay is different and the burst of the neuromotor activity has different character;

2) the results show in a quantitative way that the human action presents different aspects if the man-machine loop is closed with the sensory presence of the man.

Data indicate that it is possible to quantify the influence of biofeedback, according to the use of an oriented paradigm of equipment and of tests, with the reliable software.

4.2.4 Discussion

In general, this experimental paradigm seems to be suitable for testing either the effectiveness of various types of visual control or individual performances in manipulation. A first therapeutic application is to rehabilitation of people disabled on the spinal cord activity because of injuries.

The next steps, already planned, are the development of a new version of the equipment, which will be fully portable and will include a position feedback glove, and its test in a clinical setting.

4.3 Stroke disorders module

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4.3.1 The problem

A significant percentage of individuals who suffer a stroke, subsequently present with unilateral neglect. This is manifest in an apparent disregard of visual space contra-lateral to the lesion. In many cases reduction of neglect is evident during the first 12 weeks post-CVA. In a small number of cases, however, neglect is experienced as a longer term problem. Classic symptoms of neglect include shaving only one side of the face and eating the food on just one side of the plate. Clinical indicators that have been used are errors in bisecting lines, letter cancellation and figure copying, where an ipsi-lateral bias is generally evident.

Although unilateral neglect is not evident in all patients following stroke the majority will experience some degree of lateral paralysis, manifest in the loss of muscular control and the impairment of muscular sensation for the contra-lesional side. Hemiparesis will often affect the facial musculature, lower limb and upper-limb, particularly the distal extremities such as the fingers. Recovery can occur quite rapidly over the first 3 months [12,13], but thereafter may follow a negatively accelerating curve reaching a plateau below full function. Typically, there may be considerable recovery for proximal musculature such as postural control and relatively poor control attained for hand and finger control or for control of the contra-lesional foot. A primary goal of therapy is to enhance acquisition, particularly during the latter stages of recovery and avoid the early plateauing of active function.

In these two examples the common thread is the need to direct attention. In the case of an attention deficit such as unilateral neglect there is a specific difficulty in focusing attention, where as in hemiparesis it is suggested that a sharpening of the focus may accelerate the re-acquisition of neuromuscular control. In all cases VE may provide a spotlight for the direction of attention.

4.3.2 Objectives

In a recent review paper, "Prospects for the rehabilition of Unilateral Neglect", Robertson et al. [14] conclude with five possible avenues for rehabilitation of neglect: Dynamic stimulation, Eye-patching; Vestibular Stimulation; Optokinetic Stimulation; and Fresnel Prisms. All of these interventions can be potentially made through the use of VR technology. Dynamic stimulation and Optokinetic stimulation can be produced by moving the individual or objects within a VE, or by superimposing moving objects over the natural world with see-through HMDs. Selective provision of visual information to the hemi-fields hemi-field (retinotopic, spatiotopic or body-centric) is achievable in a HMD configuration, as is the equivalent of prismatic displacement.

A common problem that plagues any assessment is the trade-off between internal and external validity, laboratory or clinical tests provide the former, whereas observation or field study provide the latter [15]. This is well demonstrated in neglect testing where performance on clinical test batteries may dissociate from every day function. Virtual Reality Environments offer a testing environment that can be as controlled as the standard laboratory and providing a similar quantity of high quality data. Additionally, however, Virtual Reality based tests can aim for a degree of 'ecological validity' (test that are similar to tasks attempted in real, everyday life) that has never been possible with standard measures.

A major role of therapy in the re-learning process is to stimulate the patient to explore strategies and highlight information that may guide the patient toward improved control [16]. A typical example is biofeedback, where significant, but limited gains can be demonstrated by providing hemiparetic patients with visual information about specific muscular activity. This project is following the suggestions of Wann & Turnbull [16], by translating bio-feedback principles to action-feedback in a VE setting. In action feedback it is proposed that a hemi-paretic patient attempts to drive a VE display through movements of the paretic limb. The coupling of limb motion to patterns of expansion, contraction and flow within a VE means that irregularities in the kinematics of the limb are reflected in the "stuttering" flow of the display and thereby taps into a particularly acute facet of human visual perception. Such displays are not contrived, the visual transformation accurately reflects the dynamics of the limb.

4.3.3 Methods

Rather than providing feedback about the patient's biological or muscular-function it is proposed that greater gains may be possible if the environment enhances and highlights the consequences of the patient's action, rather than reflecting aspects of their motor control.

In pathology naturally occurring cues, such as proprioception, may often be unreliable or have lost their salience. What is required is augmented feedback that can be fashioned to match the individuals capabilities and prompt the individual towards finding unique solutions to movement problems.

Physical laws impose constraints on the manipulation of naturalistic settings. It is difficult to slow down a falling ball to allow a child more time to organise his/her movements, or to stop water from spilling when a cup is moved jerkily towards the mouth. VE technology, however, can provide an interactive environment tailored to the needs and abilities of the patient. Restricted powers of movement and manipulation need not set limits upon the quality of interaction. The mapping between limb movement and movement in the VE is arbitrary, the input from a limb can lose its tremor, through low-pass filtering, or a single finger movement can control virtual locomotion. This flexibility allows the augmentation or amplification of sensory feedback to a perceptual system that may have lost some degree of its natural sensitivity.

As the content of a VE can be directly specified, the patient may be given progressively more complex and rich environments. Distracting objects can be banished and the laws of physics bent or relaxed. Simple training tasks can be set in a meaningful context thus developing skills that are immediately useful to the patient, thereby enhancing the patient's sense of accomplishment and engendering future interaction. Without moving from the treatment room the patient can experience information rich environments without the inconvenience often associated with complex natural settings.

4.3.4 Discussion

Virtual environments provide the potential to computationally specify the visual and auditory environment that is presented to an observer. This opens up interesting new avenues for exploring human skill acquisition [17, 18, 19], but also presents possibilities for guided learning in a remedial setting [16, 20] Kuhle & Dohle, 1995).

There is a clear potential for virtual environments in meeting those goals in a manner that is not possible within the constraints of a natural therapy setting. The power of the VE setting is the ability to selectively tune the environment to provide specific patient goals and the ability to provide real-time feedback with tuneable input-output gains. The principle benefits of the VE environment in a therapy setting are:

a) A 3-D virtual environment can "immerse" the patient to the degree that they will demonstrate appropriate limb & postural corrections in response to virtual environmental (VE) perturbations

b) The illusion of (a) coupled with the patients ability to directly manipulate the VE display will produce a considerably stronger learning environment than conventional therapy approaches

c) The ability of the patient to explore, interact and make errors in the VE will provide a facility for motor re-learning unparalleled outside of a VE setting

d) The novelty and intrinsic appeal of such an interaction will also provide a powerful motivation factor for rehabilitative exercise.

It is important, however, that the potential of VR is not squandered by "throwing" VE technology at the problem without a formal appraisal of where and how it may provide *added value*. The rehabilitation communities have traditionally welcomed interest from technology providers and therapists are often interested in the potential role that computing or sensor technology may have remedial programs. That goodwill may be lost if virtual reality applications are not clearly focused to capitalise upon the existing knowledge base in motor control and rehabilitation.

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