GIUSEPPE RIVA, BRENDA K. WIEDERHOLD, ENRICO MOLINARI (Eds.)
Virtual Environments in Clinical Psychology and Neuroscience

VIRTUAL REALITY IN PARAPLEGIA: A VR-ENHANCED ORTHOPAEDIC APPLIANCE FOR WALKING AND REHABILITATION

GIUSEPPE RIVA

Applied Technology for Neuro-Psychology Lab.
Istituto Auxologico Italiano, IRCCS
Verbania, Italy

Abstract: Spinal cord injuries (SCIs) have a profound physical, social and emotional cost to patients and their families. Obviously SCIs severely disrupt normal patterns of interaction with the environment. Firstly, the opportunities for active interaction are inevitably diminished due to motor or sensory impairment. Moreover, such problems may increase as the time since injury lengthens and the patient becomes more withdrawn and isolated in all spheres of activity. However, advances in Information Technology are providing new opportunities for rehabilitation technology. These advances are helping people to overcome the physical limitations affecting their mobility or their ability to hear, see or speak.
In this chapter an overview is given of the design issues of a VR-enhanced orthopaedic appliance to be used in SCI rehabilitation. The basis for this approach is that physical therapy and motivation are crucial for maintaining flexibility and muscle strength and for reorganizing the nervous system after SCIs. First some design considerations are described and an outline of aims which the tool should pursue given. Finally, the design issues are described focusing both on the development of a test-bed rehabilitation device and on the description of a preliminary study detailing the use of the device with a long-term SCI patient.

1. Introduction

According to the National Institute of Neurological Disorders and Stroke – NINDS - thousands of Americans each year are confined to wheelchairs [1-2] because of spinal cord injuries (SCIs). The lifetime cost of caring for one victim can exceed $250,000. However, the enormous financial burden of spinal cord injury pales beside the profound physical, social and emotional costs to patients and their families. Moreover, as noted by NINDS, "the sad truth is that SCIs usually happen to the young: an estimated two-thirds of the victims are 30 years old or under; the majority men".

But what are SCIs and how do people live following them? According to clinical literature, the level of the injury is grossly defined as the lowest level at which useful motor function is spared. If the legs are partially or completely paralyzed, the condition is called termed paraplegia, and if all four limbs are completely or partially paralyzed, it is called quadriplegia or tetraplegia.

Obviously SCIs severely disrupt normal patterns of interaction with the environment. Firstly, the opportunities for active interaction are inevitably diminished due to motor or sensory impairment. Interaction is further reduced as a consequence of impaired motivation, fatigue, and depression. SCIs patients usually report low availability and adequacy of social integration and exhibit high levels of depression [3]. A research on 9135 persons injured between 1973 and 1984 showed that suicide was the leading cause of death for persons with complete paraplegia and the second leading cause of death for persons with incomplete paraplegia [4].

Moreover, such problems may increase as the time since injury lengthens and the patient becomes more withdrawn and isolated in all spheres of activity [5, 6]. A recent study on 2000 recently injured paraplegics in Germany showed that only 45% of the medically rehabilitated population returned to their previous job, school or college [7]. A similar research from the Stockholm Spinal Cord Injury Study, showed that SCIs subjects, although provided with basic material commodities up to par with the general population, have less financial reserves and more frequently express worry about their finances. Less than half of the subjects of the sample are gainfully employed, when part-time jobs are also included. Social activities are more restricted, and more centered on the core social network [8].

However, advances in Information Technology are providing new opportunities for rehabilitation technology. These advances are helping people to overcome the physical limitations affecting their mobility or their ability to hear, see or speak. Systems are being designed to tackle tasks which were impractical a few years ago. These are becoming more sophisticated and user expectations have increased [9].

The use of rehabilitation robotic enables disabled users to interact with their environments, their physical limitations can thus be extended through the use of manipulator-like mechanisms which respond to their commands [10]. Moreover, virtual worlds enable users to navigate and interact with 3-D, computer generated environments [11]. The immersion capability which provides a synthetic environment could be exploited to design novel assistive devices. [10,12].

In this chapter an overview is given of the design issues of a VR-enhanced orthopaedic apparatus to be used in SCIs rehabilitation. First some design considerations are described and an outline of aims which the tool should pursue given. Finally, the design issues are described focusing on the development of the rehabilitation device.

2. Information Technology for Paraplegia: a VR-enhanced orthopaedic appliance for walking and rehabilitation of SCI patients

A large number of assistive robotic tools have been developed in the last twenty years with the aim to provide disabled people with some autonomy. Nevertheless, the production of these tools and acceptance by the patient are not easy to obtain [9]. Often user needs are misunderstood, nor input from medical specialist heard, reasons why many projects are unfinished prototypes [13]. To overcome these problems this paragraph starts from general design considerations to outline the aims which the tool should pursue. Finally, the design issues are described focusing on the development of the rehabilitation device.

2.1 General design considerations

Craig recently analyzed the overall design principles to be followed in the development of of assistive robotic devices [14]:

- *Flexible-Adaptable Systems*: Rehabilitation devices must allow the development of new functions/interfaces without significant redesign of existing systems. To be economically attractive, the rehabilitation devices should be adaptable to widely ranging needs, skills, environments and tasks.
- *Open-Modular Approach*: Modularity simplifies the addition of new functions/interfaces and reduces the cost of constructing individual systems by eliminating unnecessary items.
- *Maximize the Potential*: Products must be designed to be used by as many disable people as possible with minimum changes.

However, in the development of rehabilitation devices, human factors too play an important role. The device must provide a clear indication to the user of what it is doing; the user must be able to perceive how the system acts. The usefulness of an aid is highly linked to its adaptation to the characteristics of the users, not least their sensory means.

All individuals are different, in the case of individuals with disabilities, their physical abilities, perceptual skills and cognition are also different. Therefore, although rehabilitation devices could be designed for groups of individuals, these need to be tailored to the needs of users. For example the apparatus has to be adapted first to accommodate the user in comfort, then to allow him an easy access to the control interface, next this would be adapted to his physical capabilities.

Moreover, the use of certain devices require particular skills and hence training. The level of confidence of the user would depend on them. The question is how to coordinate training with the development aspects, knowing that the interface control equipment is to be adapted to user needs concurrently. The manner in which this is approached would influence the success of acceptance of the device.

The manner in which the rehabilitation mechanism would be integrated into living/work environment needs also to be considered. Questions such as the layout of living spaces, logistic concerns, maintenance and the interaction between the rehabilitation systems and surrounding environment need to be addressed.

In summary, the design-implementation of rehabilitation equipment is multi-disciplinary and very iterative, requiring a high degree of testing/evaluation. That is testing the correctness of the design (safety), reporting the effectiveness of training and support time and costs.

2.2 Characteristics of SCIs rehabilitation

The design of rehabilitation equipment is first of all human-centered and relies on the understanding of the users needs as well as on the manner in which his/her disability would evolve in time [9]. So, to develop a good rehabilitation device, the comprehension of all aspects of the rehabilitation process is required.

The main purpose of rehabilitation after SCIs is to help the patient establish control over his/her own health and life [15]. Aspects of rehabilitation include:

- regaining as much strength and function in the trunk and extremities as possible [16];
- management of bladder and bowel function [17,18];
- independent personal and community mobility [19,21];
- psycho-social and sexual function [22-24];
- and independent living and vocational rehabilitation [25];

Motivation and self-confidence, too, are major factors in successful rehabilitation [26-28]. They are required, first, to accept irreversible facts. It takes still more motivation and self-esteem to make the most of what has not been injured - talent, creative energies, intellectual resources.

A common problem in SCIs rehabilitation is the failure to address the patho-physiological response to trauma: specific problem areas such as memory or activities of daily living can be pursued without adequate attention to the likely contribution from underlying neuro-pathophysiological factors [29]. The rehabilitation process, for example, may not produce improvements in the specific areas targeted, but benefit may arise in an improved general state of arousal-activation or motivation of the individual recipients.

In this sense, it is reasonable to suggest that a logical first step in any rehabilitation programme should be to facilitate this fundamental process [29,30]. A more activated brain may be better able to benefit from more traditional rehabilitation interventions. Moreover, it could be useful to treat a common motor problem, muscle in-coordination, at least partially induced by the substantial brain reorganization that occurs after injury to the central nervous system [31].

Actually, an accessible route to improve arousal-activation may be by way of physical exercise, which has unequivocal benefits upon physical and mental status. In fact, inactivity accelerates the rates of decline of major physiological adaptive systems which eventually reach the point at which the individual's ability to prevent or recover from acute stresses is impaired. The individual's ability to cope with such stresses and preserve subsequent function depends upon the maintenance of adequate physiological reserves, particularly neurological control, mechanical performance and energy metabolism.

Activity and exercise are increasingly recognized as a way of improving mental health, with reports of reductions in depression and anxiety, and increased perceptions of self control [29]. The most likely basis for these benefits is a change in central monoaminergic activity. For example, it is suggested that the antidepressant effect of physical exercise shifts monoaminergic function back to normal in clinically depressed subjects. Brown et al [32] reported improvements in depression, anxiety, hostility, confused thinking, vigor, self efficacy and fatigue for psychiatric institutionalized adolescents.

Physical rehabilitation therapy can also help to restore depressed immune system functionality [33]. It is well known that in SCI patients both natural and adaptive immune responses decrease strikingly within 3 months after injury. However, Cruse et al. [33] reported that physical therapy was able to restore immune responses to near normal levels in most patients of the tested sample. Natural immune system depression, persisted in spinal cord injury patients not receiving physical rehabilitation therapy.

Finally, results from animal experimental studies suggest that chronic exercise may also result in permanent structural changes in the brain [29]. For instance, Black et al. [34], found that physical exercise in rats improves vascularisation in the cerebellar cortex, while a combination of motor learning with physical activity results in a greater communication network within the brain. Moreover, recent studies in animals with spinal cord injuries, indicated that physical therapy can also have a key role in recovery after SCI. Infact data shown that recovery of movement is linked to the types of training the animals receive: physical therapy and other rehabilitation strategies are crucial for maintaining flexibility and muscle strength and for reorganizing the nervous system. These factors will be vital to recovering movement following regeneration as well as maximizing the use of undamaged nerve fibers [31]. For example, Edgerton and his colleagues at the University of California, Los Angeles, have analyzed the aspects of recovery in adult cats with spinal cord injuries. They demonstrated that cats with such injuries can support their weight with their hind limbs while walking on a treadmill. While no hind limb training was necessary for the cats to walk at very slow speeds, such training did enhance the animals' ability to walk at faster speeds [35].

2.3 Virtual reality in SCI rehabilitation

Given these premises, physical therapy is usually a major part of the treatment program in rehabilitation centers [36]. According to the National Institute of Neurological Disorders and Stroke, a full physical therapy program for SCI patients usually includes [35]:

- *Progressive resistive exercises*. These are exercises done with weights, pulleys and special exercise machines.
- *Mat class*. Working on a mat, the patient relearns and practices the skills needed for independent living: changing position in bed, getting dressed, moving from one place to another.
- *Tilt table*. A table that can be positioned at various angles to the horizontal helps the cardiovascular system readjust to upright position after a patient has been in bed for extended periods.
- *Wheelchair class*. The patient learns to handle a wheelchair, especially on curbs, ramps, stairs, and in a car.

However, long-term physical therapy is very demanding and requires a strong motivation in patients. A strong support for overcoming these problems could arrive from Virtual Reality (VR). The basis for the VR idea is that a computer can synthesize a three-dimensional graphical environment from numerical data. Using visual and auditory output devices - usually head mounted displays - the human operator can experience the environment as if it were a part of the world. Further, because input devices sense the operator's reactions and motions, the operator can modify the synthetic environment, creating the illusion of interacting with and thus being immersed within the environment.

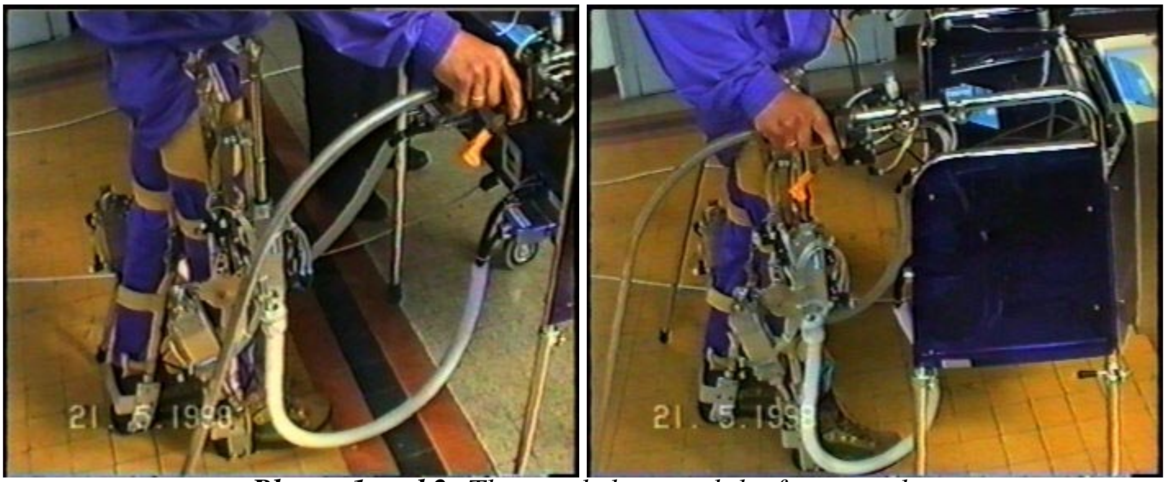
VR is highly flexible and programmable. It enables one to present a wide variety of controlled stimuli and to measure and monitor a wide variety of responses made by the user [37,38]. Both the synthetic environment itself and the manner in which this environment is modified by the user's responses can be tailored to the needs of each client and/or therapeutic application [39]. Moreover, VR is highly immersive and can cause the participant to feel "present" in the virtual rather than the real environment. In this sense VR provides a powerful means of increasing levels of environmental interaction in a highly controlled and structured manner. Infact, as noted by Johnson *et al.* [29], VR enriched environment offers the potential for significant gains in physical and mental function at all levels. This is especially true if patients are introduced to a graded physical exercise programme within an enriched VR environment, with the aim of increasing physical and mental parameters.

To reach this goal we have developed a test-bed orthopaedic appliance for walking and rehabilitation comprising:

- a semi-rigid exoskeleton for support of the bust and the lower limbs;
- a virtual reality system.

The device was developed according to the guidelines detailed before and is designed in order to be easy tailored to the needs of different users. The test-bed application was designed to reproduce the feeling of an excursion to the mountains. The expected end-user cost of the appliance, including the adaptation process required to match the specific physical characteristics of each SCI patient, is about 15000/20000 $.

In the next paragraphs a more detailed description of the apparatus will be given, together with the description of a preliminary study detailing the use of the device with a long-term SCI patient.



Photos 1 and 2*: The exoskeleon and the framework*

3. System design and implementation

3.1 The exoskeleton

The gait-inducing exoskeleton (Photos 1 and 2), patented worldwide, was designed and developed by Ferrati Benito, President and CEO of Ferrati Electronic, an Italian IT company based near Milano. It is composed by a compressed air operated semi-rigid sling, for supporting the bust and the lower limbs of the patient (Photo 1), together with a framework (Photo 2) designed as stable rest and support for the user.

The sling is equipped with small actuators (micro-cylinders), activated by compressed air, which move the lower jointed part of the sling in accordance with the human gait. The micro-cylinders are operated by the patient by means of a two-button interface located on both side of the framework grips: pressing the left button, the left leg moves forward; pressing the button on the right, the right leg moves forward. The framework has grips on both sides, wheels for moving on the floor and inside is located both the PC used for the virtual experience and the compressed-air delivery means.

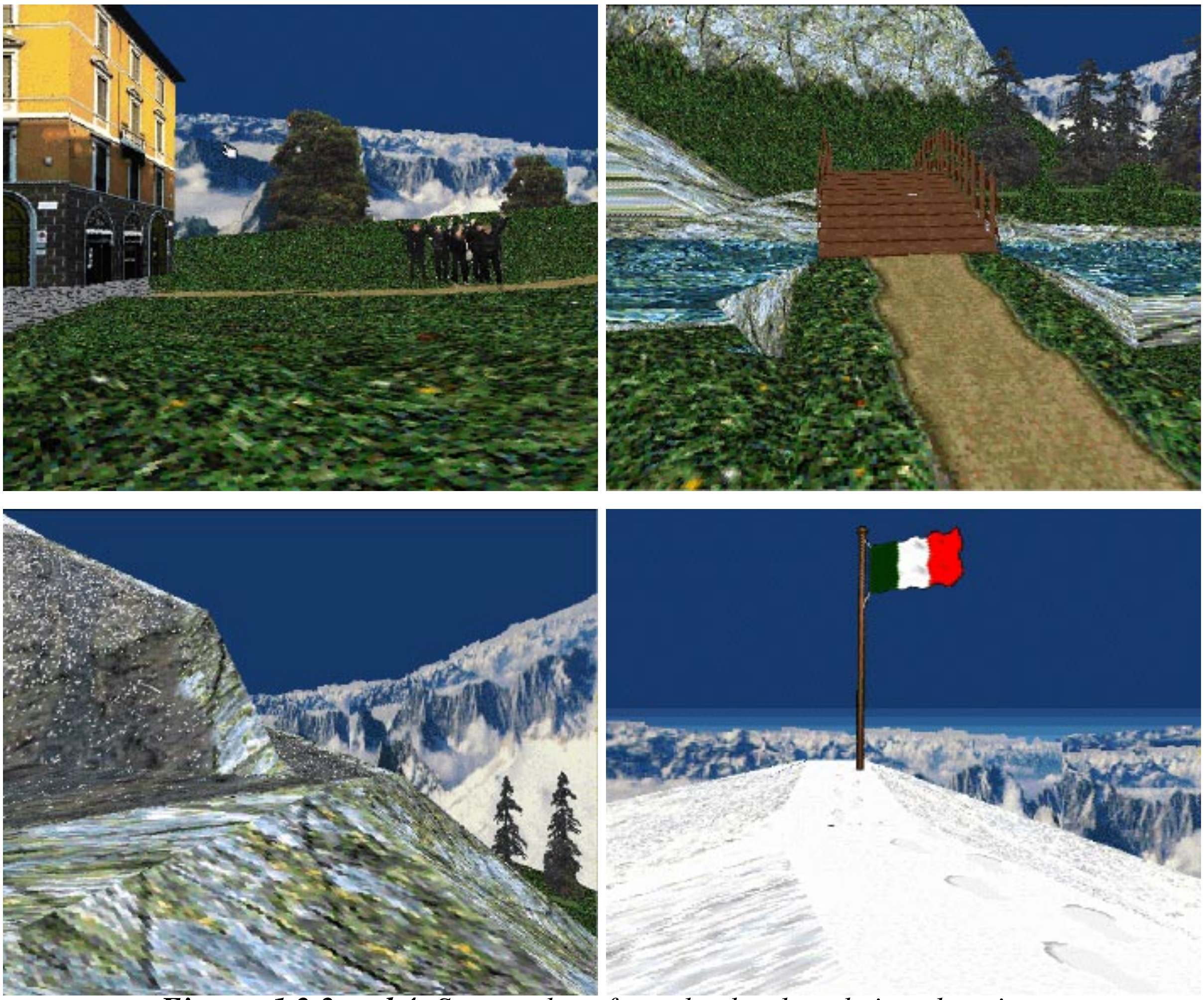
3.2 The virtual reality system

The VR-enhanced orthopaedical appliance uses a Thunder 400/C virtual reality system by Virtual Engineering of Milano-Italy. The Thunder 400/C is a Pentium II based immersive VR system (400mhz, 32 mega RAM, graphic engine: Matrox Millenium II 8Mb WRam) including an HMD subsystem.

A head mounted display (HMD) with 40° H and 30° V field of view (50° diagonal) provided the visual display. The HMD, developed by Retinal Displays Inc. - Los Altos (CA) - for Virtuality (UK), displays 800 lines of 225 pixels (180,000 active dots) to each eye and uses LCD technology (a full color AMLCD panel). The provided head tracker was used to sense head rotation.

The used HMD has not a stereoscopic display. Previous researches regard stereoscopy as important because it provides the user with good cues of depth [40]. However, the refresh rate of graphics decrease by 50% for the need of two different images for each eye.

Consequently, we decided against implementing a stereoscopic display. To compensate for the lack of binocular cues, we included perspective cues (light and shade, relative size, textural gradient, interposition and motion parallax) in the virtual environment [41].



Figures 1,2,3 and 4*: Screen-shots from the developed virtual environment*

The virtual environment used in the study was develeped by Virtual Engineering using VRT 5.5 from Superscape Ltd. (UK). The environment reproduces the feeling of an excursion to the mountains, by simulating a stroll through a mountain path (Figures 1,2,3 and 4).

To increase the realism of the experience, actual images of Alpine scenery were used together with sounds and voices typical of a natural environment. The virtual environment moves in sync with the patient's steps: each motion ahead is activated by the buttons located on both side of the framework.

4. A preliminary study

The first VR-enhanced orthopaedical appliance was developed for Nicola, a 26-year old paraplegic patient. Nicola injuried in a car accident when he was twenty. Since then he has having both legs completely paralized.

Two experimental sessions were conducted. Each session was composed by two fifteen-minute system trials interleaved by a ten-minute pause. During each trial, Nicola. completed the experience by walking through the virtual path till the peak of a snow-covered mountain.

However, during the second trial, a virtual runner was added, and the patient had to compete with him for reaching first the peak of the mountain.

Photos 3 and 4*: The patient before and during the second session*

Before and after each session Nicola had to assess his emotional and physical state using a questionnaire constructed according to the model of the semantic differential ratings [42]. The questionnaire was composed by 20 bipolar adjectives, each item having six levels of intensity (Table 1).

Table 1: Scoring sheet for semantic differential ratings

	1	2	3	4	5	6	
Fast							Slow
Unpleasant							Pleasant
Secure							Insecure
Unhappy							Happy
Invariable							Variable
Beautiful							Nasty
Weak							Strong
Heavy							Light
Optimistic							Pessimistic
Capable							Incapable
Active							Passive
Good							Bad
Tense							Relaxed
Indolent							Willing
Likable							Unlikable
Dynamic							Static
Imprudent							Prudent
Indispensable							Superfluous
Warm							Cold
Brave							Fearful

The first interesting result of this study is the lack of side effects and simulation sickness in our patient after both session, confirming the possibility of using VR for therapeutic purposes. Only during the first session Nicola reported an increased level of fatigue together with a slight pain in the left ankle.

From the analysis of the obtained ratings we found: an improved level of in self-confidence; higher level of optimism and motivation; increased relaxation and activity scores. In general the highest scores were obtained after the end of the second session.

N. also declared subjective improvement in his sense of well-being, mood and quality of sleep.

5. Conclusions

Although there is much potential for the use of immersive virtual reality environments in clinical rehabilitation, some problems have limited their application in this field. Some users have experienced side-effects, during and after exposure to immersive virtual reality environments. The symptoms experienced by these users are similar to those which have been reported during and after exposures to simulators with wide field-of-view displays [43]. These side-effects have been collectively referred to as "simulator sickness" and are characterized by three classes of symptoms: ocular problems, such as eyestrain, blurred vision and fatigue; disorientation and balance disturbances; nausea [44]. Exposure duration of less than 10 minutes to immersive virtual reality environments has been shown to result in significant incidences of nausea, disorientation and ocular problems [45].

The first interesting result of this study is the lack of side effects and simulation sickness in our patient after both session, confirming the possibility of using VR for therapeutic purposes.

Moreover, the developed test-bed orthopaedic apparatus has demonstrated the concept of a VR-enhanced device for walking and rehabilitation. The advantages of a VR system of this nature will have over actual rehabilitation devices are:

- the ability to increase the motivation of the patient. As we have seen before, the overall adjustment to a new life style is the overwhelming problem for the paraplegic. As one paralyzed veteran put it: "The impact on the patient is traumatic, to say the least. There is the realization that a once whole and healthy body is no longer fully functional and is plagued with a myriad of secondary disabilities. The psychological/emotional problem of learning to accept this condition and learning how to cope with it is devastating in itself" [46]. It requires motivation, first, to accept irreversible facts. It takes still more motivation to make the most of what has not been injured - talent, creative energies, intellectual resources. The possibility for SCI patients of experimenting again the walking experience, even if wearing an exoskeleton and only for a few minutes, is an enormous emotional boost.
- the capability of developing an enriched environment which offers the potential for significant gains in physical and mental function at all levels. As we have seen before, physical therapy is able to improve arousal-activation, to treat muscle in-coordination and to restore immune responses. Moreover, the use of enriched environment could help to improve the effects of new drug therapies (e.g. methylprednisolone or GM-1 gangliosideor) or neural prostheses. Infact, as noted by NINDS researcher, physical therapy and other rehabilitation strategies are crucial for maintaining flexibility and muscle strength and for reorganizing the nervous system. These factors will be vital to recovering movement following regeneration as well as maximizing the use of undamaged nerve fibers.

Of course these results are preliminary. From a clinical view point the issues that we have to address in the future are: further testing of the device using controlled clinical trials (expecially in patients just injuried); a follow-up study to check the persistence of the obtained results and how to integrate the use of the orthopaedical appliance into the usual rehabilitation process.

Acknowledgments

This work is the result of a long challenge that Benito Ferrati, President and CEO of Ferrati Electronics, has started more than tweny years ago. The author wants to acknowledge his valor and tenacity in facing such a demanding task.

References

[1] C. Abad, M. Mart, L. Marrero, M. L. Antõnez, and P. Sußrez, [Paraplegia following surgical repair of a ductus and of a coarctation of the aorta in childhood], *Cir Pediatr*, vol. 6, pp. 84-7, 1993.

[2] NINDS, *Spinal Cord Injury: Hope Through Research*. On-line: http://www.healthtouch.com: Medical Strategies, Inc., 1997.

[3] K. R. Hammell, Psychosocial outcome following spinal cord injury, *Paraplegia*, vol. 32, pp. 771-9, 1994.

[4] M. J. DeVivo, K. J. Black, J. S. Richards, and S. L. Stover, Suicide following spinal cord injury, *Paraplegia*, vol. 29, pp. 620-7, 1991.

[5] M. J. DeVivo and J. S. Richards, Community reintegration and quality of life following spinal cord injury, *Paraplegia*, vol. 30, pp. 108-12, 1992.

[6] F. W. van Asbeck, H. Raadsen, and M. L. van de Loo, Social implications for persons 5-10 years after spinal cord injury, *Paraplegia*, vol. 32, pp. 330-5, 1994.

[7] A. Berghammer, M. Gramm, L. Vogler, and H. H. Schmitt Dannert, Investigation of the social status of paraplegic individuals after medical rehabilitation, *Spinal Cord*, vol. 35, pp. 493-7, 1997.

[8] R. Levi, C. Hultling, and A. Seiger, The Stockholm spinal cord injury study: 4. Psychosocial and financial issues of the Swedish annual level-of-living survey in SCI subjects and controls, *Paraplegia*, vol. 34, pp. 152-7, 1996.

[9] J. Ibañez-Guzmán, Design of rehabilitation robots using virtual work platforms, presented at First European Conference on Disability, Virtual Reality and Associated Technology, Maidenhead, UK, 1996.

[10] W. Meredith, Virtual reality for patients with spinal cord injury, *MD Comput*, vol. 13, pp. 400-5, 1996.

[11] G. Riva, M. Bolzoni, F. Carella, C. Galimberti, M. J. Griffin, C. H. Lewis, R. Luongo, P. Mardegan, L. Melis, L. Molinari-Tosatti, C. Poerschmann, A. Rovetta, S. Rushton, C. Selis, and J. Wann, Virtual reality environments for psycho-neuro-physiological assessment and rehabilitation, in *Medicine Meets Virtual Reality: Global Healthcare Grid*, K. S. Morgan, S. J. Weghorst, H. M. Hoffman, and D. Stredney, Eds. Amsterdam: IOS Press, 1997, pp. 34-45.

[12] T. Kuhlen and C. Dohle, Virtual reality for physically disabled people, Comput Biol Med, vol. 25, pp. 205-11, 1995.

[13] A. Casals, R. Villa, and D. Casals, A soft assistant arm for tetraplegics, in *Rehabilitation Technology*, E. Ballabio, I. Placencia-Porrero, and R. Puig de la Bellacasa, Eds. Amsterdam: IOS Press, 1993.

[14] I. Craig, Tools for Living: Design Principles for Rehabilitation Technology, in *Rehabilitation Technology*, E. Ballabio, I. Placencia-Porrero, and R. Puig de la Bellacasa, Eds. Amsterdam: IOS Press, 1993.

[15] M. F. Cawley, G. M. Yarkony, and S. B. Bergman, Spinal cord injury rehabilitation. 5. Through the lifespan, *Arch Phys Med Rehabil*, vol. 78, pp. S73-8, 1997.

[16] K. E. Sloan, L. A. Bremner, J. Byrne, R. E. Day, and E. R. Scull, Musculoskeletal effects of an electrical stimulation induced cycling programme in the spinal injured, *Paraplegia*, vol. 32, pp. 407-15, 1994.

[17] K. C. Mudgal, R. Gupta, S. Singh, J. S. Bhatia, and M. Kalra, Bladder rehabilitation in spinal cord injury patients, *J Indian Med Assoc*, vol. 90, pp. 52-4, 1992.

[18] L. S. Baskin and R. A. Schmidt, Bladder rehabilitation with dorsal rhizotomy and ventral neuroprosthesis, *Paraplegia*, vol. 30, pp. 783-7, 1992.

[19] R. G. Platts and M. H. Fraser, Assistive technology in the rehabilitation of patients with high spinal cord lesions, *Paraplegia*, vol. 31, pp. 280-7, 1993.

[20] G. Wheeler, K. Krausher, C. Cumming, V. Jung, R. Steadward, and D. Cumming, Personal styles and ways of coping in individuals who use wheelchairs, *Spinal Cord*, vol. 34, pp. 351-7, 1996.

[21] F. Felici, M. Bernardi, A. Radio, P. Marchettoni, V. Castellano, and A. Macaluso, Rehabilitation of walking for paraplegic patients by means of a treadmill, *Spinal Cord*, vol. 35, pp. 383-5, 1997.

[22] M. L. Curcoll, Psychological approach to the rehabilitation of the spinal cord injured: the contribution of relaxation techniques, *Paraplegia*, vol. 30, pp. 425-7, 1992.

[23] C. J. Alexander, Psychological assessment and treatment of sexual dysfunctions following spinal cord injury, *J Am Paraplegia Soc*, vol. 14, pp. 127-31, 1991.

[24] M. L. Sipski, The impact of spinal cord injury on female sexuality, menstruation and pregnancy: a review of the literature, *J Am Paraplegia Soc*, vol. 14, pp. 122-6, 1991.

[25] R. Crisp, Vocational decision making by sixty spinal cord injury patients, Paraplegia, vol. 30, pp. 420-4, 1992.

[26] S. A. Jordan, W. R. d. Wellborn, J. Kovnick, and R. Saltzstein, Understanding and treating motivation difficulties in ventilator- dependent SCI patients, *Paraplegia*, vol. 29, pp. 431-42, 1991.

[27] D. M. Furst, T. Ferr, and N. Megginson, Motivation of disabled athletes to participate in triathlons, *Psychol Rep*, vol. 72, pp. 403-6, 1993.

[28] M. Solomonow, E. Aguilar, E. Reisin, R. V. Baratta, R. Best, T. Coetzee, and R. Dambrosia, Reciprocating gait orthosis powered with electrical muscle stimulation (RGO II). Part I: Performance evaluation of 70 paraplegic patients, *Orthopedics*, vol. 20, pp. 315-24, 1997.

[29] D. A. Johnson, S. Rushton, and J. Shaw, Virtual reality enriched environments, physical exercise and neuropsychological rehabilitation, presented at First European Conference on Disability, Virtual Reality and Associated Technology, Maidenhead, UK, 1996.

[30] J. P. Wann and J. D. Turnbull, Motor skill learning in cerebral palsy: movement, action and computer- enhanced therapy, *Baillieres Clin Neurol*, vol. 2, pp. 15-28, 1993.

[31] NINDS, Spinal Cord Injury: Emerging Concepts, presented at National Institutes of Health Workshop, Bethesda, MD, 1997.

[32] S. W. Brown, M. C. Welsh, E. E. Labbe, W. F. Vitulli, and P. Kulkarni, Aerobic exercise in the psychological treatment of adolescents, *Perceptual and Motor Skills*, vol. 74, pp. 555-560, 1992.

[33] J. M. Cruse, R. E. Lewis, G. R. Bishop, W. F. Kliesch, and E. Gaitan, Neuroendocrine-immune interactions associated with loss and restoration of immune system function in spinal cord injury and stroke patients, *Immunology Research*, vol. 11, pp. 104-16, 1992.

[34] J. E. Black, K. R. Isaacs, and B. J. Anderson, Learning causes synaptogenesis, whereas motor activity causes angiogenesis, in cerebellar cortex of adult rats, *Proceedings of the National Academy of Sciences - USA*, vol. 87, pp. 5568-5572, 1990.

[35] NINDS, Spinal Cord Injury Rehabilitation. On-line: http://www.healthtouch.com: Medical Strategies, Inc., 1997.

[36] M. J. Buck, [Integration of patient exercise/physical therapy in the rehabilitation team], *Rehabilitation*, vol. 31, pp. 154-6, 1992.

[37] G. Riva, Virtual reality as assessment tool in psychology, in *Virtual reality in neuro-psycho-physiology*, G. Riva, Ed. Amsterdam: IOS Press, 1997, pp. 95-112.

[38] G. Riva, Virtual reality in psychological assessment: The Body Image Virtual Reality Scale, *CyberPsychology & Behavior*, vol. 1, pp. 37-44, 1998.

[39] K. Glantz, N. I. Durlach, R. C. Barnett, and W. A. Aviles, Virtual reality (VR) for psychotherapy: From the physical to the social environment, *Psychotherapy*, vol. 33, pp. 464-473, 1996.

[40] P. T. Barham and D. F. Mc Allister, A comparison of stereoscopic cursors for the interactive manipulation of B-splines, presented at Stereoscopic Display and Applications II, 1991.

[41] Q. E. Dolecek, Computer-generated stereoscopic displays, *John Hopkins APL Technical Digest*, vol. 15, pp. 137-142, 1994.

[42] G. Riva, The role of emotional and socio-cognitive patterns in obesity: Eating attitudes in obese adolescents before and after a dietary-behavioral therapy, *Psychological Reports*, vol. 79, pp. 35-46, 1996.

[43] E. C. Regan and K. R. Price, The frequency of occurrence and severity of side-effects of immersion virtual reality, *Aviat Space Environ Med*, vol. 65, pp. 527-30, 1994.

[44] G. Riva, Virtual Reality vs. Virtual Body: The use of virtual environments in the treatment of body experience disturbances, *CyberPsychology & Behavior*, vol. 1, pp. 129-137, 1998.

[45] E. C. Regan and K. R. Price, Some side-effects of immersion virtual reality: the effects of increasing head movements, of rapid interaction, and of seated subjects, Army Personnel Research Establishment, Farnborough (UK) Report 93R022, 1993.

[46] NINDS, *Electronic Aids & Long-Term Treatment Of Spinal Cord Injuries*. On-line: http://www.healthtouch.com: Medical Strategies, Inc., 1997.