Advanced Hybrid Technology for Neurorehabilitation: the HYPER Project

Alessandro De Mauro[1], Eduardo Carrasco[1], David Oyarzun[1], Aitor Ardanza[1], Anselmo Frizera-Neto[2], Diego Torricelli[2], José Luis Pons[2], Angel Gil Agudo[3], and Julian Florez[1]

[1] eHealth and Biomedical Department, VICOMTech. San Sebastian, Spain
ademauro@vicomtech.org
[2] Bioengineering Group, CSIC. Madrid, Spain
frizera,torricelli,jlpons@iai.csic.es
[3] Biomechanics Unit, National Hospital of Paraplegics. Toledo, Spain
amgila@sescam.jccm.es

Abstract

Disabilities that follow cerebrovascular accidents and spinal cord injuries severely impair motor functions and thereby prevent the affected individuals from full and autonomous participation in activities of daily living. Rehabilitation therapy is needed in order to recover from those severe physical traumas. Where rehabilitation is not enough to restore completely human functions then functional compensation is required. In the last years the field of rehabilitation has been inspired by new available technologies. An example is given by rehabilitation robotics where machines are used to assist the patient in the execution of specific and physical task of the therapy. In both rehabilitation and functional compensation scenarios, the usability and cognitive aspects of human-machine interaction have yet to be solved efficiently by robotic-assisted solutions. Hybrid systems combining exoskeletal robots (ERs) with motor neuroprosthesis (MNPs) emerge as promising techniques that blends together technologies that could overcome the limitations of each individual one. Another promising technology which is rapidly becoming a popular application for physical rehabilitation and motor control research is Virtual Reality (VR). In this chapter, we present our research focuses on the development of a new rehabilitation therapy based on an integrated ER-MNP hybrid systems combined with virtual reality and brain neuro-machine interface (BNMI). This solution, based on improved cognitive and physical human-machine interaction, aims to overcome the major limitations regarding the current available robotic-based therapies.

Introduction

Cerebrovascular accidents (CVA) and spinal cord injuries (SCI) are the most common causes of paralysis and paresis with reported prevalence of 12,000 cases per million and 800 cases per million, respectively. Disabilities that follow CVA or SCI severely impair motor functions (e.g., standing, walking, reaching and grasping) and thereby prevent the affected individuals from healthy-like, full and autonomous participation in daily activities.

The main goal of neurorehabilitation is to favor the re-learning process of the Central Nervous System (CNS) in the execution of coordinated movements. This process of neural reorganization involves complex sensorimotor mechanisms, which are nowadays in the focus of intense investigation in (the fields of) neurophysiology. From a therapeutic point of view, the outcome of the neurorehabilitation process depends on two main issues [9, 20]:

- the quality and amount of physical activity performed by the patient.
- the cognitive involvement of the patient in the rehabilitation process.

The traditional rehabilitation therapy is mainly focused on physical exercise, aiming to strengthen the active muscles in several parts of the body. Different modes of exercises are used, ranging from aerobic therapies (e.g. treadmill walking, cycling movement with arm-leg ergometry or seated stepper), and non-aerobic training, to enhance strength or flexibility (e.g. weight machines, isometric exercises, stretching).

In this context, occupational therapy is a specialized profession aimed to train individuals to relearn the tasks of daily living that have personal meaning and value, such as eating, dressing, and grooming.

The latest advancements in robotics and neuroscience have generated a great impact in the field of neurorehabilitation. In the last decade, a number of robot-assisted rehabilitation systems have been developed in order to support and improve the therapist's action by delivering intensive physical therapy and providing objective measures of the patient's performance [16, 5, 51].

In this context, the use of bio-inspired hybrid systems combining exoskeletal robots (ERs) and motor neuroprostheses (MNPs) is emerging. ERs are person-oriented robots, operating alongside human limbs to physically support the function of a limb or to replace it completely [38]. MNPs constitute an approach to restoring neuromotor function by means of controlling human muscles or muscle nerves with Electrical Stimulation. The combination of robotic actuation and bio-electrical stimulation emerges as a promising technique that blends together technologies that could overcome the limitations of each individual one, in both rehabilitation and functional compensation scenarios [15, 33]. The orchestration of the hybrid system with the latent motor capabilities of the patient involves several issues, principally related to the *cognitive* aspects of human-machine interaction: the rehabilitation machine must be capable of deciphering user's volitional commands in a robust manner in order to act reliably and in concert with the subject [21].

In this context, multimodal human-machine interfaces gained relevance as a means to convey a high number of signals of different nature into meaningful feed-forward and feedback information. These signals can be related to muscular activity (EMG), cerebral activity (EEG) and visual, auditory and tactile perception. Virtual Reality (VR) environments have emerged as a powerful tool for integrating such multimodal interfaces within robotic-based rehabilitation scenarios.

In the first two sections of this chapter the authors present the state of the art of the application of Robotics and Virtual Reality in the field of neurorehabilitation. Thereafter, focus is put on the research in the frame of the HYPER project "Hybrid Neuroprosthetic and Neurorobotic devices for Functional Compensation and Rehabilitation of Motor Disorders" [2], which aims at the development of a new hybrid system based on the combined action of NR, MNP and VR, in order to overcome the major limitations of current rehabilitation solutions.

1 Robotics in Neurorehabilitation

In this chapter, first a brief introduction of the state of art in the field of neurorehabilitation is presented. As concrete application of the presented concepts, the HYPER project and the current development is detailed in the following sections. In such project, robotic solutions to assess CVA and SCI (figure 1) are currently being developed by a team of clinical and engineering staff.

In the last decades an increasing number of robotic systems have been made available in the field of rehabilitation. The presence of a robot basically permits to support the therapists in the passive mobilization of the patient's limb. The main advantages of this robotic intervention are twofold: i) therapeutic, in terms of the amount of physical exercise provided during the therapy, and ii) economical, since a reduced number of employees is required to support the patient during the execution of movement.

The recent advances in the fields of human-robot interaction (HRI) [38] have allowed thinking to the machine not only under the point of view of physical interaction, but also as a means to stimulate the mental activity of the subject during the therapy. Here, the cognitive processes involved in the interaction with the machine are crucial. The term cognitive alludes to the close relationship between cognition - as the process comprising high level functions carried out by the human brain, including perception, comprehension, construction, planning, self-monitoring - and motor control.

Cognitive and physical interactions are not independent. On the one hand, a perceptual cognitive process in the human can be triggered by physical interaction with the robot. On the other hand, the cognitive interaction can be used to modify the physical interaction between human and robot, for instance to alter the compliance of an exoskeleton.

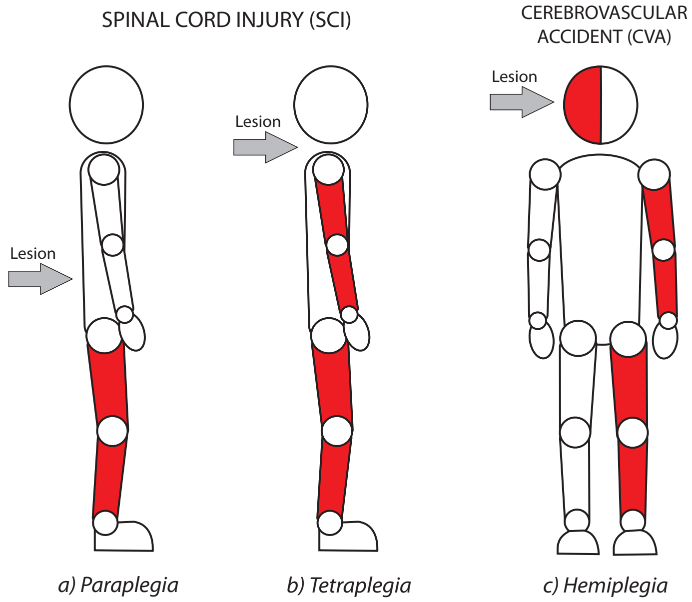

Fig. 1. Disabilities that follow CVA and SCI. a)Paraplegia refers to the loss of motor and/or sensory function in thoracic, lumbar or sacral segments (SCI). Consequently, the arm function is spared, but the trunk, legs and pelvic organs can be affected. b) Tetraplegia refers to the loss of motor and/or sensory function in the cervical segments of the spinal cord (SCI). It results in an impaired function of the arms, trunk, legs and pelvic organs. c) Hemiplegia is paralysis of the contralateral side of the body occurring after a CVA. It may comprise weakness of the leg on the affected side, where the drop-foot syndrome often prevents walking.

1.1 Key factors in robot-assisted therapy

The main goal of neurorehabilitation is to favor the re-learning process of the Central Nervous System (CNS) in the execution of coordinated movements. This process involves complex sensorimotor mechanisms, which are nowadays in the focus of intense investigation in neurophysiology. There is no consensus on what are the most adecuate intervention for neurorehabilitation [25, 56]. Nevertheless, some key factors (KFs) for successful robotic-assisted therapy can be identified:

KF1 - Active role of the patient. Brain activity plays a fundamental role on the modulation of the neural mechanisms that generate movement [8, 29]. Passive, repetitive training is very likely to be suboptimal, as it leads to the phenomena of "learned helplessness", that is, the lower spinal cord becomes habituated to the training action, decreasing the performance of the therapy [57]. Thereby, active cooperation of the patient is needed to achieve a more functional outcome of the therapy. A solution to this problem is to make the system respond to the physical actions of the patient, in order to re-establish the connection between causes (forces) and effects (movements) [39].

KF2 - Motivation. Motivation is one of the most important factors in rehabilitation and it is commonly used as a determinant of rehabilitation outcome [30], since it is strongly correlated with the degree of patient's activity. User's motivation can be achieved by means of various different types of feedback and modes of interaction, so influencing the motor re-learning process at different levels [6].

KF3 - Assist-as-needed. In order to imitate the action of the physical therapist in supporting the movement of the limb, the new-generation of robotic systems have been provided with the so called Assist-as-needed (AAN) paradigm [11]. The AAN paradigm is intended to simultaneously activate the efferent (motor) and afferent (sensory) pathways, by providing only the minimum assistance necessary during the execution of the movement. This mechanism has been proven to favor cortical reorganization [55].

KF4 - Challenge. Contrary to the assistive techniques, which help the user to reach the task, the challenge-based robotic strategies aim at opposing to the user's intention of movement, using resistance or error-amplification strategies. This approach is based on evidences that resistive exercises requiring high cognitive effort can help improve neuromotor functions [53].

KF5 - Biofeedback. Biofeedback is a crucial factor for the success of the therapy, as it informs about the patient's degree of activity and is a key to maintain and encourage the motivation and increasing the active participation of the patient. Currently, biofeedback in rehabilitation relies mainly on a single source of information, i.e. force-based feedback. By combining other forms of feedback, such as brain activity (EEG), muscular activity (EMG) and visual information on limbs motion, a more accurate and effective outcome might be achieved [28].

KF6 - Bioinspiration. Due to the close cooperation between human and robot, it is necessary to know the properties of the human motor system in order to define the design requirements of a rehabilitation device. With the help of a biological model it is possible to predict the system's behavior and optimize the robotic intervention, in terms of adaptability, functionality and energy consumption [37] (see also paragraph 1.3).

As depicted in the figure 2, the above stated key factors are not independent, like so the technological solutions, which are not univocally defined. This multidimensional problem strongly directs to a multimodal approach solution.

1.2 Hybrid Wearable Technology

The use of wearable devices has shown to be a good solution to achieve the mentioned therapy in which the patient plays such an important role. Wearable robots (WRs) [38] are person-oriented robots and therefore more adapted to the interaction with users. They are worn by human operators to supplement the function of a limb, e.g. exoskeletons. WRs exhibit a close interaction

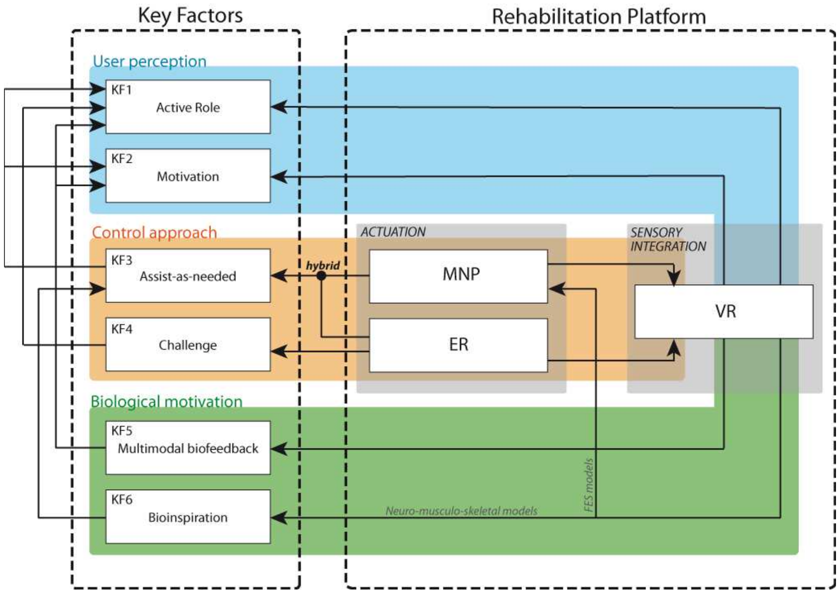

Fig. 2. Cognitive interaction in robotic-assisted rehabilitation. In this scheme, the key factors of neurorehabilitation (KFs) have been classified by their relation with the three main conceptual actors involved in cognitive human-machine interaction: i) user perception, ii) machine control intelligence and, iii) biological motivation. The path followed by the cognitive information responsible of the KFs reinforcement, as well as the interdependencies among the KFs themselves, are shown by arrows.

with the human user but structurally are similar to robots, i.e. rigid links, actuators, sensors and control electronics. A wide range of prototypes have been proposed.

The Fraunhofer Institute of Berlin developed Haptic Walker [43, 42] (Fig. 3 left), a system in which the patient feet are placed on two separated platforms. The patient weight and the device components are supported by a mechanical structure, where the movements of two platforms related to the feet reproduce the kinematics of the leg joints. Haptic Walker is used mainly for gait rehabilitation and includes a module providing VR rehabilitation.

Veneman et al. [51] (Fig. 3 right) have introduced a new gait rehabilitation device that combines a 2-D-actuated and translatable pelvis segment with a leg exoskeleton composed of three actuated rotational joints (two at the hip and one at the knee). Practically it is an exoskeleton that moves in parallel with the legs of a person walking on a treadmill. An interesting outcome of their research is that the system allows both a patient-in-charge and robot-in-charge mode, in which the robot is controlled either to follow or to guide a patient, respectively.

The Cyberthosis project [31] (funded by the Fondation Suisse pour les Cyberthses, FSC) combines closed-loop electrical muscle stimulation with motorized orthoses. It is composed of two subsystems (devices): MotionMaker [44, 45], which is a couch equipped with two orthoses enabling a controlled movement of the hip, knee and ankle joints (Fig. 4 left) and WalkTrainer [47], composed of a body weight support, a gait and pelvic orthosis and several electrodes for electrostimulation (Fig. 4 right).

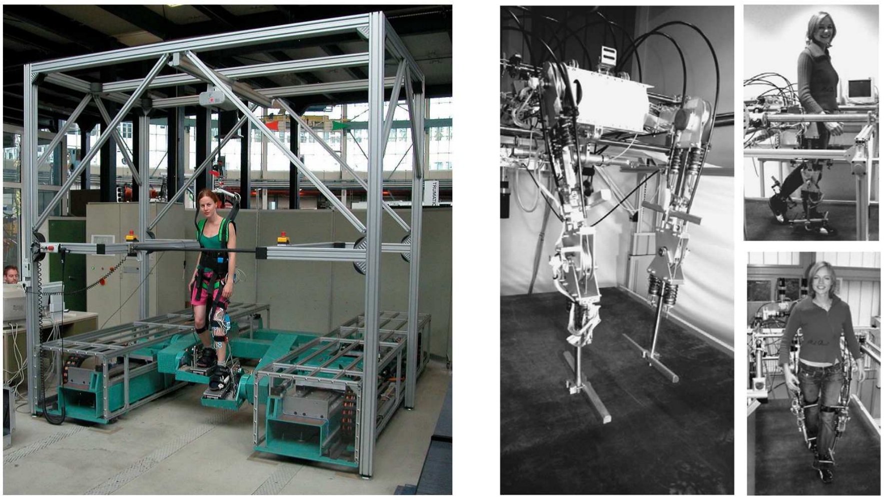

Fig. 3. On the left side: Haptic Walker (Fraunhofer Institute Berlin, Germany). On the right side: the Lopes prototype developed by Jan F. Veneman et al. (Institute for Biomedical Technology, University of Twente, Netherlands).

Together with the mentioned wearable robotic solutions, a different approach in leading to the concept of Soft Robots (SRs). SRs also rely on wearable devices, but use functional human structures instead of artificial counterparts, e.g. artificial actuators are substituted by Functional Electrical Stimulation (FES) of human muscles. The borderline between human and robot becomes fuzzy and this immediately leads to hybrid Human-Robot systems.

It is in this context that Neurorobots (NRs) and Motor Neuroprostheses (MNPs) emerge. They may be considered as a bypass of damaged sensory-motor systems: via Brain-Machine interfaces (BMIs), users can volitionally trigger the device by using the functional part of the body above lesion, e.g. residual muscle activity and/or cerebral activity; MNPs constitute an approach to restoring function by means of artificially controlling human muscles or muscle nerves with Functional Electrical Stimulation (FES). Electrical pulses stimulate motor and/or sensory nerves, thereby generating movement by activating paralyzed muscles.

Fig. 4. Prototypes of MotionMaker (on the left) and Walktrainer (on the right) which are parts of the Cyberthosis project.

A schematic representation of the combined action of MNP and NR on the patient is shown in Fig. 5.

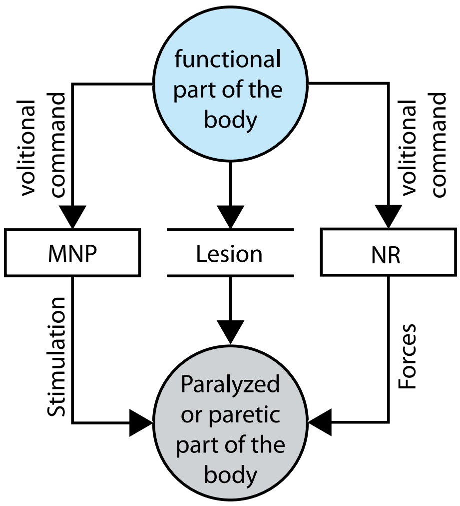

Fig. 5. Hybrid system concept. NRs use volitional commands to drive paralyzed or paretic part of the body, while MNPs bypass the damaged sensory-motor systems using functional electrical stimulation (FES).

NRs use volitional commands for controlling a (mechatronic) WR, which applies controlled forces to drive the affected limbs. Wearable Neurorobotics is more versatile as to the implementation of motor actions: (1) precise kinematics and impedance control is readily available, (2) biomimetic control architectures, e.g. Central Pattern Generators, internal models and reflexes, can be readily applied, and (3) built-in artificial proprioception and vestibular sensors can be used to drive non-volitional motor actions, e.g. control of balance. As a serious drawback, the transmission of motor actions (forces) to the human musculoskeletal system takes place through soft tissues, thus the interaction is to be carefully thought in terms of compatible kinematics and application of controlled forces.

1.3 Bioinspiration

Actual efforts in rehabilitation research are integrating neuroscience knowledge into engineering to develop new effective means for neurorehabilitation, based on a deeper understanding of the human control system. Scientific knowledge in the field of neurophysiology can provide engineers with sources of inspirations for the development of biologically motivated systems and the refinement of human body models. At the same time, mathematical and engineering models of the human body can provide clinicians and neuroscientists with powerful tools to test and simulate a wide range of motor control theories prior to in-vivo experimentation.

The contact between bioinspiration and engineering arose and developed in technical areas which were (and are) not specifically directed to rehabilitation. In particular, the field of human body simulation devoted specific effort to replicate the neuro-musculo-skeletal interactions of walking [50, 34, 35, 19]. Nevertheless, due to the complexity of the problem, further work is needed to translate these simulation results to a real-life environment. In this direction, some interesting approaches have been proposed in the field of bipedal robotics, where the imitation of the structure of the CNS is providing good features for stability enhancement in walking and standing control [27, 14, 46]. An increased interest on the application of biologically motivated methods to rehabilitation robotics and prosthetics is proven by the presence of promising recent research works based on neurophysiological principles [10].

2 Virtual Reality in Neurorehabilitation

VR environments can provide realistic training for the patient in different scenarios and phases of the neurorehabilitation. By using VR in conjunction with Human Computer Interfaces (HCI) the training of daily life activities can be much improved in terms of time and quality. This approach permits a realistic and ergonomic training in a safe, interactive and immersive environment.

Examples of interfaces able to interact with VR are mice, joystick, haptic interfaces with force feedback and motion tracking systems.

Repetition is crucial for the re-learning of motor functions and for the training of the cortical activity. This task has to be connected with the sensorial feedback on every single exercise. Then again the patient motivation is fundamental and can be improved by assigning a video game format to the therapy. In this way the training activity becomes more attractive and interesting [54, 17]. Moreover, VR shows another advantage: the possibility to be precisely adapted to the patient's therapy and to be specific for each rehabilitation phase. In addition, it represents a precise tool for the assessment of the therapy during each session. The (tracked/saved) data can be used by the rehabilitators for monitoring and managing the telerehabilitation [7]. Several researches have shown that, during VR rehabilitation, the movements are very similar to those used in the traditional therapy. Although they appear a bit slower and less accurate, [40, 52] they are appropriate for rehabilitation. Finally, [48, 22, 58, 41, 49, 12] have proven good results in executing the movements trained in VR in reality.

Some of the significant studies on the application of robotics in conjunction with VR for rehabilitation purposes shall be introduced briefly. The Rutgers Arm [24] is one of the first prototypes composed of a PC, a motion tracking system and a low-friction table for the upper extremity rehabilitation. The system has been tested on a chronic stroke subject and showed improvements in arm motor control and shoulder range of motion (Fugl-Meyer [13] test scores). The same group has developed the Rutgers Ankle [4] for the lower extremity rehabilitation. It is a haptic/robotic platform, which works with six degrees of freedom, driving the patient's feet movements (Fig. 6, left). In [32], the Rutgers Ankle system has been tested. As a result, the group of patients trained with the robotic device coupled with the VR demonstrated greater changes in velocity and distance than the group trained with the robot alone.

The InMotion system is a complete robotic system for the rehabilitation of the upper extremity [7]: arm, shoulder, wrist, and hand. It allows multiple degrees of movement: pronation, supination, flexion and extension, radial and ulnar deviation (Fig. 7 left).

In [40], the MOTEK Medical's V-Gait System is described as a tool for clinical analysis, rehabilitation and research. This system combines a self-paced instrumented treadmill capable of comprehensive measurements of ground reaction force with a real-time motion capture system and a 3D virtual environment (Fig. 7 right).

The state-of-art in rehabilitation using virtual reality (VR) and robotics is provided by Lokomat and Armeo (from Hocoma) for the lower and the upper extremity, respectively (Fig. 6 center and left). These two systems are validated by the medical community and used in several rehabilitation centers [23].

Lokomat [18] offers a driven orthosis (gait robot) with electrical drives in knee and hip joints. The orthosis is adaptable to subjects with femur lengths and an additional body weight support is included. The Armeo [1] provides support to reacquire and improve motor control for the affected arm and hand. This support counteracts the effects of gravity. There are three types of subproducts in the Armeo line: i) the ArmeoPower is a robotic arm exoskeleton, with an electric lifting column for comfortable height and weight adjustment;

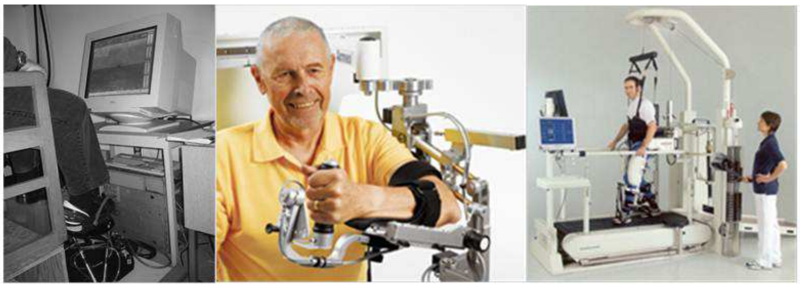

Fig. 6. Successful application of robotics in rehabilitation. From left to right: Rutgers Ankle (Courtesy of Rutgers University), Armeo and Lokomat (Courtesy of Hocoma)

Fig. 7. Examples of products for rehabilitation including VR concepts. On the left: InMotion Arm Robot. On the right: rehabilitation with MOTEK Medical.

ii) the ArmeoSpring is an instrumented arm orthosis with a spring mechanism for adjustable arm weight support; and iii) the ArmeoBoom is a simple arm weight support system with low inertia to facilitate functional movements.

All the previous products commercialized from Hocoma are completed by an augmented feedback module which extend the conventional hardware with a computer and a large monitor with acoustic stereo feedback together with a software with interactive training tasks. This option provides various engaging virtual environments to motivate the patients, adjustable level of difficulty and intensity according to the cognitive abilities and the specific needs of each patient.

3 The HYPER Project

3.1 Project concepts

None of the systems described in the previous section proposes VR in conjunction with an hybrid and wearable MNP-NR system. With the HYPER project

(Hybrid Neuroprosthetic and Neurorobotic devices for Functional Compensation and Rehabilitation of Motor Disorders) the authors aim at a breakthrough in the research of neurorobotic and neuroprosthetic devices for rehabilitation and functional compensation. The project focuses its activities on new wearable hybrid systems that will combine biological and artificial structures in order to overcome the major limitations of the current rehabilitation solutions to Cerebrovascular Accident (CVA) and Spinal Cord Injury (SCI). The main objectives of the project are: i) to restore motor functions in SCI patients through functional compensation, and ii) to promote the re-learning of motor control in patients suffering from CVA.

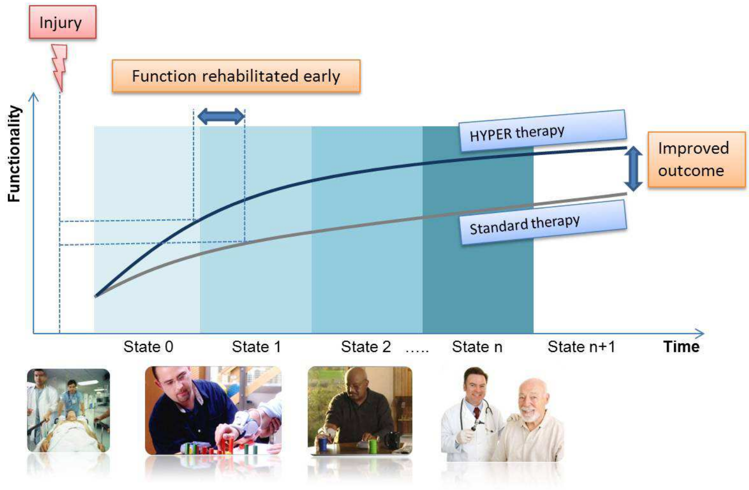

Fig. 8. Rehabilitation using the HYPER system: the therapy is specific for different states. Functions are regained faster and the outcome is improved.

The specific rehabilitation targets of the HYPER project are, on the one hand, to speed up the rehabilitation procedures and, on the other hand, to improve the outcome of the therapy using new paradigms and technologies, as depicted in Fig. 8. This shall be achieved by an integrated use of different interventions comprising multimodal sensing and actuation. Both upper and lower parts of the patient body are assisted. The main emphasis is put on restoring daily life activities, i.e. walking, standing, reaching and grasping. The therapy is subdivided in several states from the state 0 in which the injury happens until the state N in which the patient is fully rehabilitated. The ranges of movements that are significant in the rehabilitation for CVA or SCI patients have been identified by medical doctors. Any of the daily life functions constitutes a combination of these defined movements. In the specific, the upper body joints (and related movements) are:

- shoulder (flexion, extension, abduction, adduction, outward medial rotation, inward medial rotation);
- elbow (flexion, extension, pronation, supination);
- wrist (flexion, extension, abduction, adduction).

Similarly, the lower body joints (and related movements) are:

- hip (flexion, extension, abduction, adduction, medial and lateral rotation);
- knee (flexion, extension);
- ankle (plantar flexion, dorsal flexion, inversion and eversion).

For each of them, both degrees and ranges of movement have been specified in order to assess the patient's skills during the rehabilitation process and to parameterize the rehabilitation training.

Users' groups have been identified in order to adjust therapy and system components to the various therapy needs. Diverse scenarios have been developed and elaborated in detail. Each of them includes a specific configuration of components (MNP, NR, and VR). Some of the components integrated into the HYPER system are presented in Fig. 9.

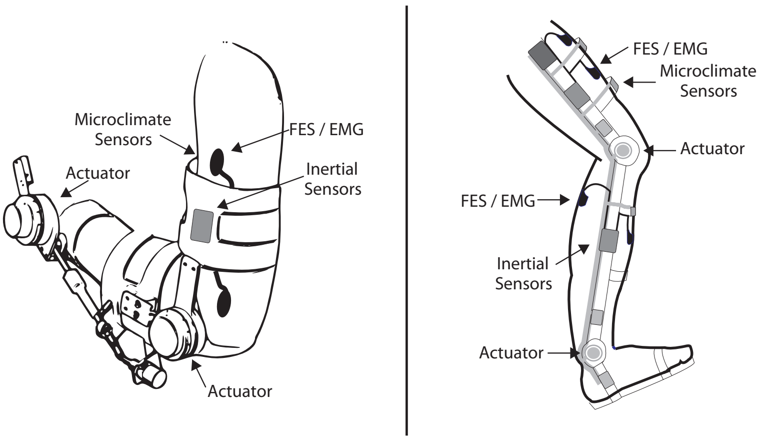

Fig. 9. Components of the HYPER system.

Fig. 10 shows how the inputs and outputs of both actors (human and hybrid device) are interconnected through a multimodal interaction platform. Using a multi-channel acquisition approach, the user's outputs (EEG, EMG, kinetic and kinematic information) serve as inputs to the controller of the hybrid platform. The controller, as in the natural human control system, (re)presents a feed-forward component based on predetermined motion and

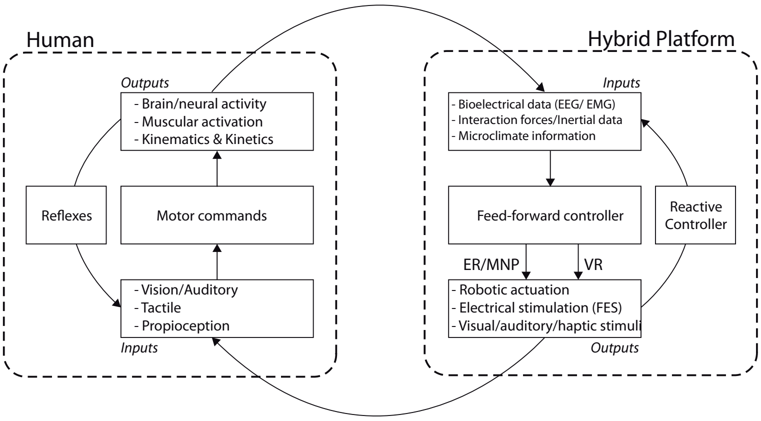

Fig. 10. HYPER human-machine interaction scheme.

biomechanical models, and a reactive controller that mimics human neuro-motor mechanisms and reflexes. In addition to the limb actuation systems (NR/MNP), a virtual reality system generates visual/auditory feedback to increase the user's involvement and immersion, potentiating the cognitive interaction. A Brain Neural Machine Interface (BNMI) is applied to potentiate the cognitive interaction and to drive the hybrid system. BNMIs are able to extract and interpret the volitional commands generated by the humans neural system, by relying on: (1) direct brain activity monitoring, which might assess users motor intention; (2) measurement of the peripheral nervous activity, e.g reflexes, that might involuntarily trigger muscle activity; and (3) indirect monitoring of neural activity through EMG, to estimate the fine motor effects of nervous activity. Due to this capacity of extracting relevant information about human motor control mechanism, apt to be fed back to the machine, BNMI might also contribute to new means of improving user-centered strategies (e.g. AAN paradigm).

3.2 The role of Virtual Reality in HYPER

Virtual reality has the ability to simulate real-life tasks and provides several evident benefits for the new rehabilitation therapy proposed in the HYPER project:

1. specificity and adaptability to each patient and phase of the therapy;
2. repeatability (repetition is crucial for the re-learning of motor functions and for the training of the cortical activity);
3. ability to provide patient engagement (active cooperation of the patient is needed to achieve a more functional outcome of the therapy);
4. capability for precise assessment (data can be used by the rehabilitation specialists for monitoring and managing the therapy);

5. safety (VR provides the user with the possibility to perform tasks with a degree of safety which is normally not possible in the traditional rehabilitation).

We are currently working on providing a VR rehabilitation platform for the HYPER project. The interactive VR environment, an important part of the complex system, was initially based on Radio Frequency (RF) tracking technology. Patients movements in the execution of the different tasks were initially tracked using RF transmitters positioned on each joint of the patient body (upper/lower part). This solution offers good tracking performances but it suffers from the use of many cables. Considering the patients needs it has to be considered as a not optimal solution. Therefore we are now exploring a new wireless and inexpensive technology: Kinect [3]. First results are very promising and even if the accuracy of the tracking has to be measured exactly it seems that for this type of application the needs in terms of accuracy are not highly demanding. Additionally the tracking system appears to be robust enough to track the patient and the related neurorobotic exoskeleton or neuroprosthetic devices on both upper and lower part of the body. A limitation to be considered is that the Kinect IR camera suffers when the subject is illuminated strongly by the sun light. This is, however, a merely technological limitation which can be overridden.

In order to validate the VR concepts and system accuracy we are currently comparing the two trackers used (RF and Kinect) with the Armeo measuring the performances in the execution of simple tasks of the upper part of the body. In a similar way, we plan to compare the system with Lokomat for the lower part of the patient. Finally, a further part of our research concerns the conjunction between a Brain Computer Interface and virtual reality in order to create a good diagnostic and personalized environment in which it is possible to study the brain signals as answers to external (VR) stimuli or to assess the progress of the patient in the rehabilitation therapy. Several researches [26, 36] have shown how brain-computer interfaces can become a communications medium for VR applications in the range from basic neuroscience studies to developing optimal mental interfaces and more efficient brain-signal processing techniques. Since the engagement and collaboration of the patient is a must in order to obtain good results, an important role can be played by VR during brain signals analysis. A snapshots of simple VR scenes (reaching, moving and grasping a virtual object) is shown in Fig. 11.

4 Conclusions

In this chapter we have introduced the main concepts, and the state of the art in the field of neurorehabilitation. In particular we have presented a review of the concepts, advantages and perspectives of robot-assisted therapy, hybrid wearable technology, bio-inspired systems used in CVA and SCI therapies.

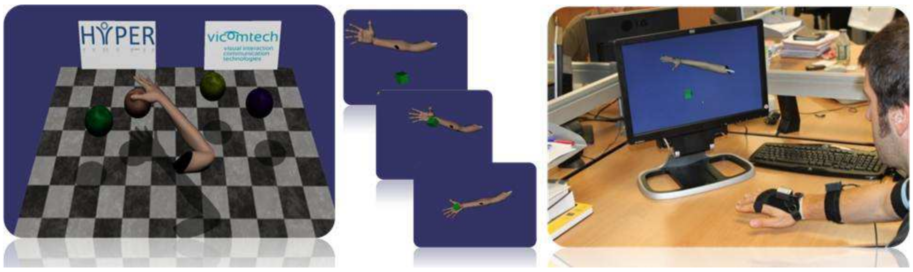

Fig. 11. Snapshots of simple VR scenes: reaching, moving and grasping a virtual object.

Additionally, an analysis of the state of art of Virtual Reality based applications in the field of the rehabilitation from motor disorders has been presented focusing the discussion on the potential benefits of the virtual therapy and new available technologies. We have described, as a case study, the first system that combines NR, MNP and VR for neurorehabilitation and functional compensation. The development of the system is still in the preliminary stage, but the application of a new generation of wearable compensational devices together with the integration of the virtual reality environment promises the evolution of (modern/novel) rehabilitation therapies for people suffering from motor disorders.

We believe that this interdisciplinar approach combined with advanced technology will help patients suffering from CVA and SCI in fast re-learning of the skill required to perform autonomously the daily live activities.

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