Virtual Reality and Robotics for Neuro-Motor Rehabilitation of Ischemic Stroke Patients

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Abstract— **It is well known that patients undergoing a cerebrovascular attack often experience a partial recovery of the motor function of the upper limbs, despite the application of manual motor therapy. Therefore, several research studies have recently focused on improving the rehabilitation process by using robotic devices and virtual reality. Robot-aided therapy may be capable of overcoming some of the limitations of manual therapy, such as the lack of exact repeatability of the movements and the objective measurement of training progresses. On the other hand, embedding the patient in a virtual environment, which might be personalized not only to his spared abilities but also to his interests, could be more motivating and could provide online bio-feedback about his performance, hence reinforcing the effect of the therapy. Although the preliminary results of those studies are encouraging, they have been limited to small groups of chronic patients. In this project, robot-aided rehabilitation in combination with virtual environments will be used on sub-acute and chronic stroke patients for the first time. This allows not only the evaluation of effectiveness of the advanced treatment and comparison to traditional motor therapy, but will also supply information about the retention of benefits over time. In order to explore the temporal evolution of cortical activity in relation to the degree of functional recovery, functional Magnetic Resonance Imaging (fMRI) will be conducted before, during and after the new rehabilitation therapy. Combined with Electroencephalography (EEG) and Electromyography (EMG) studies, which will be recorded online during treatment, the collected data will provide a basis for a better understanding of the neurobiological and neurophysiological mechanisms that underlie the changes in brain pattern activation after stroke.**

Keywords— **Virtual Reality, Robotics, Rehabilitation, Ischemic Stroke.**

I. Introduction

Stroke is a leading cause of permanent disability in the industrialized countries. In Italy about 30% of persons who undergo a cerebrovascular attack report disabling outcomes, mainly disability of the upper limbs (UL). Functional recovery of motor abilities is fundamental for enhancing the patients quality of life. Unfortunately, despite the continuous exercise required by conventional therapies, recovery of the motor function is often only partial.

Several research studies have recently focused on the development of novel robotic interfaces and on the use of Virtual Reality (VR) for more efficient rehabilitation of stroke patients. The combination of these advanced technologies seems to be a promising way to improve the effectiveness of the stroke patient's training and recovery.

The use of haptic devices may overcome some of the major limitations related to manually assisted movement training, such as the lack of repeatability, the high dependence on the availability of specialized therapists and the lack of objective estimation of the rehabilitation progress.

On the other hand, a unique feature of VR is that the patient is embedded in an evocative virtual environment that is more stimulating than a traditional rehabilitation therapy setting. Virtual environments tailored to the patient's preferences can be produced and adjusted to his needs and spared abilities. Moreover, a typical VR set up may permit to provide the patient with online feedback about his performance, enhancing his awareness of deficits and improvements, hence maximizing the effectiveness of the rehabilitative process.

II. What is already known?

The current evidence on the effectiveness of robotic interfaces and VR environments for the upper limbs rehabilitation in stroke patients is limited to small groups of chronic patients, where an improved recovery has been observed in tasks of reaching of visual targets with the arm [1] and of object manipulation with the hand [2]. Although preliminary, those results are sufficiently promising to justify additional clinical trials on chronic stroke patients' population, and new studies on acute and/or sub-acute stroke patients. Until present, no study has been performed on these patients for a number of reasons, mainly practical, despite the importance of assessing the effectiveness of the robots & VR therapy when administered from the very early stages after stroke.

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Furthermore, cross-sectional and longitudinal neurophysiological studies have demonstrated that the damaged adult brain is able to reorganize in order to compensate for motor deficits. To date, the most common pattern of functional reorganization observed in patients with focal injury is a dynamical reorganization of the topography of task-related functional responses. Involvement of non-motor and contra-lesional motor areas has been consistently reported, but the emerging notion is that the greater the involvement of the ipsi-lesional motor network, the better is the recovery [3]. Recently, a strong and task-specific increase of sensorimotor cortical activity after robot-based therapy combined with VR games has been described [2].

Besides task-related functional activation, more recent measures of intrinsic functional connectivity (FC) between cortical regions during resting wakefulness are providing important clues on the large-scale functional reorganization that the injured brain undergoes during recovery from stroke. However, changes in FC during motor recovery following rehabilitation have not been explored yet.

III. Description of the Project

In this project the conjoint use of robotic interfaces and non-immersive Virtual Reality scenarios, successfully employed in few studies on chronic stroke patients, will be employed for the first time in sub-acute patients. The same treatment will be used on a larger population of chronic patients than before, in order to verify the validity of positive results already obtained by the few studies present in the clinical literature. Both sub-acute and chronic stroke patients' groups will be also administered traditional rehabilitation therapy. In this manner, we will be able to compare the effectiveness of the innovative treatment in two different populations of stroke patients (sub-acute and chronic), we will be able to evaluate the retention of benefits over time, and we will also gather information sufficient to perform a comparative study on the outcomes of rehabilitation therapy when it is administered following a traditional procedure only, or when it is accompanied with treatments based on the use of technologically advanced systems.

Another important feature of this project is that it will provide new information on the neurophysiological correlates of motor recovery and rehabilitation training. The neural correlates of robot-based therapy combined with Virtual Reality have been explored only by a recent study restricted to chronic patients and to manipulation of objects with the hand [2]. A high temporal resolution EEG and functional neuroimaging data will be used to significantly improve current knowledge because they will be collected before, during and after a treatment based on robot-aided rehabilitation and VR, involving the arm during movements of reaching, not only at chronic stage but also on sub-acute stage. Moreover, the longitudinal study will allow to collect missing information on the dynamic temporal evolution of the neural reorganization following the innovative treatments. Furthermore, we will study the functional connectivity in stroke patients suffering from motor deficits of the upper limbs.

Collected data will also provide useful information for reproduction and generalization of previous findings. These are important issues, given that primarily very small patient samples have been studied, which furthermore may not represent the entire spectrum of deficit and recovery.

The present project will provide also missing information on the comparison between simple motor tasks, used in the literature on motor recovery, and more elaborate paradigms employed in cognitive neuroscience, including reaching, action observation and action imagination.

Finally the project will add new insights on the effects of VR environment manipulation on the motivation and psychological well-being of stroke patients affected by disability of the upper limbs.

IV. Project Aims

The main purpose of the present research project is to evaluate the effectiveness of new motor rehabilitation treatments for the upper limbs of hemiparetic patients affected by ischemic stroke. The treatments will make use of VR systems and dedicated robots (haptic devices) to exploit the combination of robot-aided rehabilitation and VR at the sub-acute and chronic stage. The treatment will be administered in addition to traditional motor therapy (MT), and the obtained motor functional outcome will be compared with that of patients being administered only MT.

The second aim is to assess if the positive effects of innovative therapies on motor recovery are more persistent in time compared to those deriving from traditional MT, and if the repetition of such treatments from sub-acute to chronic stage can reinforce the initial effects.

The third aim of the research project is to achieve a better understanding of the neurobiological and neurophysiological mechanisms underlying the changes in brain activation patterns after stroke. Indeed, to devise better therapeutic strategies for the rehabilitation of patients with hemiparetic stroke, it is important to understand the mechanisms that underlie the neuroplasticity induced by skills training and exercise programs. This will be achieved by combining high temporal resolution techniques such as electroencephalography (EEG) with functional imaging. High-resolution

EEG studies, together with EMG measures, will be conducted online during the innovative rehabilitation treatments. In addition functional magnetic resonance (fMRI) studies will be conducted at the beginning, after 3 weeks and at the end of the same rehabilitation training, exploring the temporal evolution of cortical activity and functional connectivity between cortical regions in relation to the degree of functional recovery.

A further aim of the project is to increase the patients' motivation and well-being by creating different virtual environments and scenarios which may be of particular interest for them. Personal scenarios may be presented ad hoc according to the patient, following an interview with each of them, in order to introduce familiar elements in the scene. Motivation and positive disposition are critical aspects to maintain a constant exercise and to obtain the maximal final motor outcome.

V. Potential impact of results

Task-oriented repetitive movements can improve muscular strength and movement coordination in patients with movement disabilities due to neurological impairment. Particularly in stroke patients, several studies prove that movement therapy of the upper limbs has positive effects on the rehabilitation progress, which include the recovery of motor function along with the prevention of muscle atrophy, and also a large-scale functional reorganization of the brain.

However, manually assisted movement training is labor-intensive and therefore, the training duration is usually limited by personnel shortage and fatigue of the therapist and patient. The disadvantageous consequence is that the training sessions are shorter than required to gain optimal therapeutic outcome.

In contrast, new therapies for upper limb rehabilitation that are based on robot-assisted devices and VR environments have several advantages, such as the fact that they can be used in an either active or passive manner, hence reducing patient's and therapist's fatigue and consequently permitting to afford longer sessions, or that they allow an objective estimation of rehabilitation progress. Therefore, robot-assisted and VR therapies permit to envisage an intensive and controlled training program without increasing the time dedicated by the therapist to each patient.

If the outcome of this research project will confirm the expected effectiveness and advantages of these novel rehabilitation treatments, five potential and highly important impacts can be foreseen:

1. an increase of the number and duration of training sessions per patient
2. the possibility to objectively document and evaluate the rehabilitation process through quantitative measures
3. an overall improvement of upper limb rehabilitation and a better restoration of the related brain functions, also in patients for whom traditional movement therapy is ineffective
4. a reduction of the therapist-hours devoted to each patient
5. an overall decrease of the costs for specialized personnel

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