Bioengineering activities in proprioceptive and robotic rehabilitation at Salvatore Maugeri Foundation

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Abstract—Over the last decades, numerous and extensive research programs have been conducted in the field of robotic and proprioceptive rehabilitation. Robotic rehabilitation allows to record quantitative data about movement patterns that can help clinicians to better address the rehabilitation protocols providing information not captured using clinical measures, but the biomechanical parameters proposed until today, to evaluate the quality of the movement are not yet standardized.

Equally, the proprioception rehabilitation is known to play important roles in the planning and control of limb posture and movement. The Russian Academy of Sciences has recently developed the “Regent Suit” (RS), an experimental medical device derived from a suit worn by astronauts for therapeutical purposes after space flights. Although preliminary studies describe rehabilitation outcome of the RS in stroke, EMG changes induced by the suit are not known.

The purpose of this paper is to review the rehabilitation activities employed at Salvatore Maugeri Foundation in the last two years, showing the main robotic and proprioceptive rehabilitation protocol developed to carefully analyse the motor strategies of the movement and of the gait in pathological conditions.

Keywords—reaching movement, submovements, gaussian mixture, regent suit, rehabilitation

I. INTRODUCTION

Neurological or orthopedic impairments frequently lead to hemiparesis or partial paralysis of one side of the body that affects the patient’s ability to perform activities of daily living such as walking and eating. Physical therapy, involving rehabilitation, helps to improve the lost functions [1; 2]. The aim of conventional rehabilitation is to recover the motor function using therapeutic exercises guided by a therapist who moves the patient’s body. An early and repetitive rehabilitation can substantially improve the long-term mobility of the both upper and lower limbs and minimize functional deficits.

In the last decades, numerous research programs have been conducted in the field of robotic and proprioceptive rehabilitation [3; 4] with the purpose to recover the motor functions. Recent studies have focused on the development of mechatronic and robotic systems for rehabilitation which make able the patient to perform repetitive and goal-oriented movements. These systems permit to make a safe, repeatable and intensive training that can be done in combination with other kinds of rehabilitative treatments. Another useful advantage of the robotic technology is the possibility to evaluate kinematic and dynamic parameters during the movement of the limb, while clinical scales permit only qualitative and potentially disagreeing evaluations, often carried out by different therapists [5; 6]. Although the robotic systems are widely applied in the rehabilitation programs of patients affected by different congenital or acquired brain injuries [7], they show several limits. Further, many of the developed systems have been designed from an engineering perspective rather than based on therapy demands and most rehabilitation paradigms are based on the repetition of stereotypical movements instead of applying more advanced principles of motor control and motor learning [8]. Finally, the biomechanical parameters proposed until today in the scientific literature, to evaluate the quality of the movement, are related to the specific robot used and to the type of exercise performed and are still far to be considered as viable alternatives to the clinical scales.

Along with these systems, other rehabilitation strategies take advantage of the basic role played by sensorial and proprioceptive stimulations which can influence patient’s postural control and ambulation recovery [9]. In fact, the correct proprioceptive inputs can adjust the timing and the activity of the muscles to the speed of locomotion, to keep the body upright, while at the same time moving around in an orderly, stable and symmetrical manner. In this scenario the Institute of Biomedical Problems of the Russian Academy of Sciences in Moscow developed a special Regent Suit (RS). Originally designed for therapeutic purposes for astronauts after space flights, this suit is currently employed also for neurological patients’ rehabilitation. It has been shown that a rehabilitation program using the RS is more effective than usual care in improving locomotion and daily living activities in patients with sub-acute stroke [10; 11]. However, the understanding of the changes induced by the proprioceptive inputs of the RS in combination with a treadmill training on the Electromyographic (EMG) patterns in chronic stroke is not well-known.

The purpose of this paper is to review, at first, our attempts to overcome the limitations of the robotic rehabilitation protocols of upper arms; particularly, we have proposed a quantitative kinematic assessment of robot assisted upper arm reaching movements to study the smoothness and the motor composition of visually-guided reaching movements from people with Parkinson’s disease (PD), applying the minimum jerk theory and a submovements decomposition method based on a mixture of Gaussian pulses. The “Gaussian mixture” has been also ap-
plied to describe the effects of RS on lower limb EMG patterns in hemiparetic subjects.

II. MATERIALS AND METHODS

A. Robotic Rehabilitation Program

The experiment has involved 5 subjects with Parkinson’s disease (55±5 year old, males, pathological subjects, PS) tested after not having taken medication for at least 12 h (OFF state) and 5 age-matched controls (healthy subjects, HS). Kinematic exercise has consisted on visually-guided two horizontal reaching tasks of four movements performed by the their dominant arm at 30° of amplitude. All reaching movements have been performed by a shoulder rehabilitation device, the Multi-Joint-System (MJS) of the Tecno-body (Figure 1). The motor composition of visually-guided reaching movements of people with PD and the kinematic quality have been investigate applying respectively, to the envelope, a submovements decomposition method based on a mixture of Gaussian pulses and a new kinematic index to evaluate the smoothness of the movements based on the minimum-jerk theory.

The quality of the movement, based on the minimum jerk theory, has been evaluated introducing the kinematic index Level of Smoothness (SL) defined as follows:

$$SL = \frac{J_m - J_i}{J_i}$$

where $J_m$ (m for measured) is the smoothness, normalized with respect to time and amplitude of the movement, measured on the subject’s movement while $J_i$ (i for ideal) is the normalized smoothness reported in previous works [12-16]. The lower the relative error, SL, the greater the quality of the movement.

The velocity profile of each movement has been modeled as the summation of different Gaussian pulses (submovements), in mathematical terms according to the expression (Eq. 1):

$$y(x) = \sum_{i=1}^{M} \frac{\alpha_i}{\sqrt{2\pi}\sigma_i^2} \exp\left[-\frac{(x - \mu_i)^2}{2\sigma_i^2}\right]$$

where $\alpha_i$ is the amplitude of the basis function, $\mu_i$ and $\sigma_i$ are respectively the mean and standard deviation of each Gaussian base function, M is the number of pulses. The decomposition has been obtained with a method based on an expectation maximization (EM) constrained algorithm and a scale-space approach. To analyze the motor strategy of the subjects we have considered several indexes, such as the number and the inter peak distances among the submovements, as reported in a previous work [17].

B. Rehabilitation with the Regent Suit

Concerning the gait rehabilitation program, we have studied 5 hemiparetic patients. (3 males, 2 female, mean age 41 yo). All subjects underwent a session divided in two phases, each consisting of four recordings of a straight walk of 10 steps. In the first phase, subjects have been instrumented by surface EMG electrodes and footswitches. Four EMG channels have been acquired, according to SENIAM recommendation, by the main muscles involved in walking, such as the Soleus, anterior Tibialis, Semitendinosus and Vastus Lateralis. With a fifth wireless channel, the gait cycle was recorded. In a second phase, each patient has been assisted by nursing staff (physiotherapists and occupational therapists) in the wearing of the suit. The EMG analysis has been offline performed by LEG-Lab, a Matlab software package developed by the authors and specifically designed for EMG gait analysis [18-19], providing both the measured and the that performed by healthy subjects, which are very close to the expected, we found that the movements of the pathological subjects are more fragmented and less continuous compared to the that performed by healthy subjects, which are very close to the uni-modal and bell-shaped profile predicted by the minimum jerk model (Figure 3).

Relating to the rehabilitation with RS, results have shown that the proprioceptive stimulation of the RS involves a general improvement of the muscle activities, bringing them more closer to that exhibited by healthy subjects (Figure 4).
Preliminary results obtained in this work indicate that the decomposition method proposed in addition to the use of a smoothness index to quantify the quality of a reaching movement allows us to meaningfully investigate the motor strategy of movement produced by subjects with Parkinson’s Disease. Moreover, the postural correction through its elastic strap system aligns the patients’ body as close to normal as possible creating a muscle framework by dynamic proprioceptive patterns of movement thus improving gait pattern. This restoration of the posture and proper function of both distal and proximal muscles allows the patients to learn proper patterns of movement thus improving gait pattern. 

**IV. DISCUSSIONS**

REFERENCE


