Measurement of the right and left crank torque to improve the rehabilitative effects of FES cycling on stroke patients

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Abstract
The FES cycling is an interesting method in the rehabilitation of stroke patients. This study takes advantage of an instrumented and motorized cycle-ergometer, able to measure the torque at the right and left crank.

Some trials on healthy subjects were carried out to test the sensors during voluntary asymmetric pedaling. Then, an experimental FES cycling protocol was defined: each muscle was stimulated individually during isokinetic trials. The difference between the right and left torque produced during the active phases and those produced during the passive ones, was computed. Finally, a feasibility test was performed on a post-acute stroke patient at the beginning of his rehabilitation.

The developed sensors allowed to distinguish the effect on the right and left torque produced by each muscle individually; a result was that gluteus and tibialis anterior produced a negligible contribution while the role of the hamstring and quadriceps was apparent and repeatable.

The measured signals in a post-acute stroke patient showed clearly the asymmetry of pedaling during a FES cycling protocol. Therefore, these sensors could be used in the design of an automatic controller able to change the stimulation parameters of the involved muscles in order to assure a symmetrical movement on stroke patients.

1 Introduction
The use of functional electrical stimulation (FES) is a well established method in the rehabilitation of grasping and walking for stroke patients [1, 2]. Just a few studies exist on the application of FES to induce cycling movement in stroke patients [3]. The FES cycling could be a good rehabilitative movement for this pathology because it involves many muscles of the lower limb and it can be carried out in a very comfortable position for the patient. In addition, FES cycling provides the complete afference of the task to the patient enhancing the synaptic controls needed to produce a well organized movement. Therefore, the patient can re-learn the activation sequence of the muscles involved. In a previous study [3], the feasibility of using FES cycling on stroke patients was analysed and encouraging results were reached. In this previous study, the symmetry of the movement was given by a stimulation strategy which was exactly the same for both the legs and the patient was asked not to voluntary contribute to the motor task. But, if the two legs were acting differently because of a diverse effect of fatigue in the two sides, there was not the possibility to adjust the stimulation parameters in order to compensate the problem.

This study can be seen as a step forward in the improvement of the application of FES cycling on stroke individuals. In fact the aim of this study was to develop and test sensors able to measure the torque at the right and left crank in order to provide a starting point in the design of an automatic controller for symmetry.

2 Methods
2.1 Experimental Setup
A current–controlled 8-channel stimulator and a motorized cycle-ergometer were used for the experiments. It was possible to control the cycle-ergometer by changing the resistant torque and the angular velocity or by directly setting the motor voltage with pulse width modulation.
As shown in Figure 1, the cycle-ergometer was equipped with instruments able to measure the bending moments and the radial forces at the right and left crank, so that the torque can be computed. The sensors were electrical resistance strain gauges, connected on a Wheatstone full-bridge. The strain gauges were conditioned by a four-channel wireless device, which allowed the real-time transmission of the
signals from the rotating shaft to the acquisition system. The metrological chain was calibrated by means of static tests with standard masses. An internal optical encoder was used to measure the angular crank position. A more detailed explanation of the setup can be found in [4].

2.2 Experimental Protocol

Some trials on able-bodied subjects (AB) were carried out to test the developed sensors during voluntary asymmetric pedaling.

Once tested the sensors, a specific FES cycling experimental protocol was performed on an AB. The subject was asked not to voluntary pedal. Each trial lasted 10 minutes: during the initial and final 60 s, the subject was not stimulated at all and so he cycled passively. In the intermediate part of the test, each muscle group (quadriceps, hamstrings, gluteus maximus and tibialis anterior) was individually stimulated for 60 s each. Passive cycling was guaranteed by a motor and the angular velocity was maintained at a constant value of 30 rpm during all the trials. The range of stimulation of each muscle in respect to the crank angle was set following [3]. The crank angle was set at 0° in correspondence to the point of maximum flexion of the left hip. An ON-OFF pulse width profile was used. The pulse width value was fixed at 400 µs for all the muscles. The stimulation currents were set at a value that produced a tetanic contraction. A stimulation frequency of 20 Hz was used and all the signals were sampled at 500 Hz.

Finally, a feasibility test was carried out on a post-acute stroke patient at the beginning of his rehabilitation. In the trial eight muscles was stimulated following [3].

Written informed consent was obtained from all subjects.

2.3 Data analysis

The bending moments and the radial forces measured were used to compute the torque at the right and left crank. After re-phasing the torque data on an angular constant scale, the median and the 5th-95th percentiles were computed: the result was the torque as a function of the crank angle, in each test condition of the trials. Then the left and right active torque were computed as the difference between the torque produced during the active phases and the one generated during passive pedaling.

3 Results

Figure 2 shows the median active torque produced by an AB pedaling actively only with the right leg. The asymmetry of the movement can be clearly noticed: the left active torque was quite zero among all the revolution, instead, there was a significant peak in the right active torque when the right quadriceps was pushing. This agrees with the assumption that during a voluntary pedaling the quadriceps muscle gives the greatest contribution to the movement.

Figure 3 shows two examples of the results obtained by the AB during the FES protocol when only the right quadriceps (panel (a)) or only the right hamstrings (panel (b)) were stimulated. These signals were obtained imposing the cycle-ergometer resistant torque at a value of 1.2 Nm. In both the panels, a positive peak of the right active torque can be noticed exactly in correspondence to the muscular

Figure 1. The instrumented cycle-ergometer, the wireless device is in the box on the crank.
stimulation range, shown in light grey. This confirms that the muscles were stimulated in their functional range, i.e. when they were assisting the cycling motion.

On the other side, the left active torque was nearly zero during all the revolution. This is the result to expect because the left leg should be pedaling passively.

The effect on the right and left active torque, obtained when the tibialis anterior and the gluteus were stimulated, were quite negligible.

4 Discussion and Conclusions

The use of FES cycling in the rehabilitation of stroke patients is a valid method to investigate. The development of a neuroprosthesis able to assure a symmetrical movement could be a crucial goal for the recovery of stroke patients. This study takes advantage of custom designed sensors able to measure independently the torque produced by the right and the left leg during cycling. To understand the effect of each muscle on the signals, a protocol was developed and provided the stimulation of each muscle individually in the proper crank angle range.

The developed sensors allowed to distinguish the effect of the stimulation of the quadriceps and hamstrings during the movement. Instead, the active torque produced by the gluteus maximus and by the tibialis anterior were quite negligible. Such a result was expected because the gluteus, as a proximal muscle acting only on the hip, can transfer a low contribution to the crank, while the effect of the tibialis anterior is limited by the use of the ankle foot orthosis.

The obtained results represent a starting point for the development of a closed loop controller aiming at the maximization of the symmetry during the movement. The achieved results also suggest that a simplified first version of the controller could act only on the stimulation of the hamstrings and quadriceps and not on the gluteus maximus and tibialis anterior, which shown a quite negligible effect on the right and left torque.

References


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