Experimental Results and Design Considerations for FES-Assisted Transfer for People with Spinal Cord Injury

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Abstract. Sitting Pivot Transfers (SPT) are key factors for enabling independence of individuals with paraplegia. However, repetitive instances of SPT may lead to overload of upper limbs, possibly causing pain and injury. In this work, we explore the use of electrical stimulation during the lift pivot phase in order to reduce the overload on upper limbs. First, an experimental set-up was developed to investigate the use of multiple interface modalities for controlling the applied electrical stimuli. Then, the set-up was used in a study involving 5 subjects with paraplegia. The results indicate the load reduction on upper limbs.

1 Introduction

Mobility and autonomy of individuals with Spinal Cord Injury (SCI) is highly dependent of her ability to transfer. However, an increasing quantity of transfer throughout the day and over the years may lead to joint and muscle overload [1–4]. The most common type of transfer performed on a daily basis by persons with paraplegia is sitting pivot transfer (SPT) [5,6]. Indeed, SPTs are performed 15 to 20 times a day on average [5].

Functional Electrical Stimulation (FES) is a technique used to activate neural pathways through the application of low-energy electric pulses. Such technology may be used to activate lower limb coordinated with upper body and upper limb movement, in order to provide an auxiliary force that may assist individuals while transferring.

In this work, our long-term goal is to evaluate the possibility to employ FES within an assistive device to aid persons with paraplegia to perform SPTs. The

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present experimental investigation aimed at validating the necessary interface technology and obtaining initial results to demonstrate the approach.

2 Materials and Methods

2.1 Subjects

Five subjects with paraplegia have taken part in the study. They present lesions between T2 and T11 and have been diagnosed as AIS A (American Spinal Injury Association Impairment Scale) . All subjects provided informed consent, which, along with this work, was approved by an ethical committee (CAAE: 54748116.9.0000.0022)

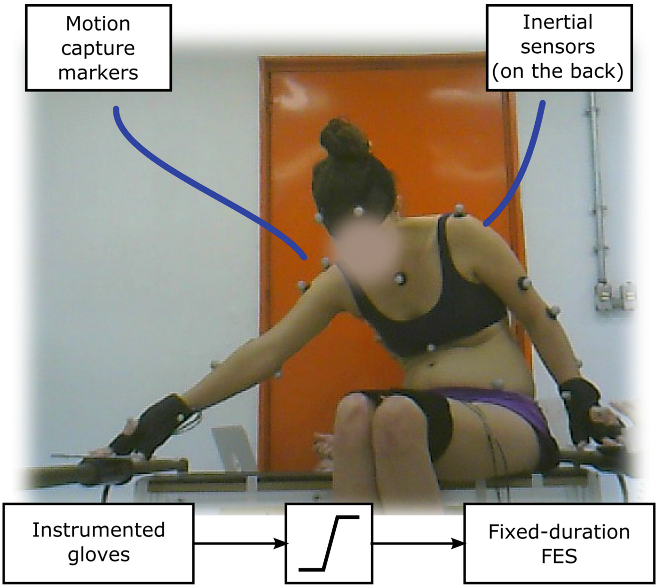

Fig. 1. A participating subject before starting a new trial. The figure also illustrates the control interface for triggering FES using gloves that embed pressure sensors (bottom). Other sensor modalities employed (a motion capture system and inertial sensors) are also depicted (top). The benches are positioned with a 10^o angle between them. The legs are constrained to prevent them from falling to the sides.

2.2 Experimental Set-Up

An experimental environment was built especially for investigating SPT (Fig. 1). It consists of a multichannel electrical stimulator (Rehastim 2, Hasomed, Germany), force platforms (Bertec, USA), benches, support bars, and eight infrared cameras (Qualisys, Sweden). Furthermore, inertial sensors (3-space, Yost Labs, USA) and instrumented gloves are either placed or used by the participating subject.

Data from additional sensors are recorded for off-line analysis. One wireless inertial sensor is placed over the subject's C7 vertebrae. Orientation with respect to the orientation at the beginning of the trial is sampled at 170 Hz. Also, an optical motion capture system is used, providing position estimates of 31 markers representing upper body motion at 200 Hz. Data from force plates is also sampled using this system.

2.3 Control Strategy

Both quadriceps are stimulated in order to provide sufficient knee extension torque to assist the user while performing the SPT. FES is applied at 50 Hz and 450 μs. The stimulation amplitude is determined immediately before starting the trial based on each subject's individual response to achieve leg extension for 10 s.

During the trials, the control of movement initiation is provided to the subject. The stimulation system is controlled in real-time based on input received from instrumented gloves used by the subject. Pressure sensors are embedded within the glove, enabling establishing a pressure threshold that may be used to trigger the open-loop stimulation pattern (1 s duration) that assists the user during her SPT.

Based on the synchronized acquisition of pressure, motion capture, and inertial sensing data, we may then evaluate if the wireless IMU may be used as the singular interface modality for such device in the future. This is a potentially significant feature, since the resulting system would be more transparent to the user, enabling free use of hands without any attached sensor.

3 Results and Discussion

The results obtained from the study are diverse. From the one hand, we have observed that the trunk angle estimated using an IMU can be used as the interface modality for FES-aided SPT. Indeed, as described in detail in [7], trunk angle correlation obtained from first day of experimentation for all subjects presented correlation greater than 0.75. These results, concerning both the motion capture system and the IMU indicate that the wearable sensor may be user as an interface for controlling the FES system.

Furthermore, we have been able to confirm, based on data obtained from an heterogeneous sample of individuals with paraplegia, that quadriceps stimulation throughout the lift pivot phase may indeed decrease the load on the upper limb on SPTs. Considering 5 subjects, 4 presented significant increase on lower limb support, while no significant alteration on kinematics was observed for all subjects. These results not only confirm the predictions from previous simulation [8] and experimental studies [9,10], but also provides more details on types of transfer strategies employed by individuals with paraplegia [11,12] and which profile would found great benefit in using the technology.

4 Conclusion

This work aimed at evaluating the use of FES to reduce the overload on upper limbs during SPTs performed by individuals with paraplegia. An initial result obtained from the study regards the development of an integrated experimental set-up where data from different sensing systems may be acquired to investigate which sensor interface could be more appropriate to control the assisting knee extensor torque provided. For instance, an IMU used to estimate trunk angle may provide a reliable control signal.

Using this setup, a study conducted with 5 persons with paraplegia have obtained positive results regarding the reduction of upper limb overload. Nevertheless, the level of injury, and other factors could have affected some of other factors investigated in the study.

Future works may focus on using a simpler version of the set-up in order to evaluate how a training protocol to use the system might help improving the obtained performance or, more importantly, aid those individuals that lower performance.

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