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► **To cite this version:**

Jovana Jovic, Christine Azevedo Coste, Philippe Fraise, Charles Fattal. Decreasing the Arm Participation in Complete Paraplegic FES-Assisted Sit to Stand. IFESS: International Functional Electrical Stimulation Society, Sep 2011, São Paulo, Brazil. <lirmm-00644067>

**HAL Id: lirmm-00644067**

**<https://hal-lirmm.ccsd.cnrs.fr/lirmm-00644067v1>**

Submitted on 23 Nov 2011

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# Decreasing the arm participation in complete paraplegic FES-assisted sit to stand

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## Abstract

*We have developed a method aiming at improving Functional Electrical Stimulation (FES) – assisted sit to stand transfer in people with paraplegia. The approach is based on the coordination of upper and lower parts of the body with final objective to reduce arm participation during the rising motion. The proposed approach is based on the observation of trunk acceleration during rising phase and a detection algorithm, which triggers leg stimulation at a desired time instant. The objective of this study is to present preliminary experimental results obtained in one complete paraplegic subject showing that the delay between leg stimulation onset and maximum trunk acceleration event is related to the arm support applied during sit-to-stand motion.*

**Keywords:** FES, sit-to-stand, paraplegia, closed-loop system.

## Introduction

The ability to rise from a sitting to a standing posture would be of major importance for people with paraplegia in order to achieve minimal mobility and independence. The majority of the FES systems which assist paraplegic subjects rising from a seated position are based on open-loop stimulation of lower leg muscles. Although, this method is useful, there are still a lot of issues, such as muscle fatigue and excessive upper body support, which needs to be solved before FES-assisted standing up, becomes functional enough to be part of subject's everyday life. Therefore some closed-loop controls of standing up have been proposed [1]-[2]. It has been shown that orientation and acceleration of the healthy human trunk during rising motion have low intra and inter-variability, so those signals could be good indicators of the evolution of sit to stand movement [3]. Also, comparing rising motion in healthy and paraplegic subjects it has been demonstrated that one main difference between them is the onset of leg movement in regards to trunk bending [3]. We have shown that in order to be efficient in terms of consumed energy and applied hand forces during the motion, trunk bending forward should start before and last during knee and ankle movement [3]-[4]. Therefore, a closed-loop FES system for sit-to-stand transfer, based on the observation of trunk movement has been developed [5].

The goal of this study is to show the results from an experiments in which we used this closed-loop system with one T6 paraplegic patient. This system should automatically trigger leg stimulation in optimal moment with respect to the trunk motion in order to decrease arms participation during the motion.

## Material and Methods

### *Approach*

The approach we propose is based on the observation of trunk acceleration in the sagittal plane during rising motion and a detection algorithm which triggers a pre-programmed stimulation pattern. The detection algorithm is similar to the one described in [5]: a reference pattern is built based on averaged trunk acceleration signals from different trials. The detection algorithm consists in comparing ongoing motion with the reference pattern. When the correlation coefficient exceeds a defined threshold the sit-to-stand signature is recognized. Figure 1 presents typical trunk acceleration signal observed in healthy subjects and an example of a reference pattern build from this acceleration signal. Within this strategy, subjects should lean their trunk forward before sit off moment in order to use trunk inertia during the motion [3]. The approach intrinsically imposes that subjects are able to repeat a same trunk pattern trial after trial. The ability of proposed closed-loop system to recognize sit-to-stand motion and to trigger

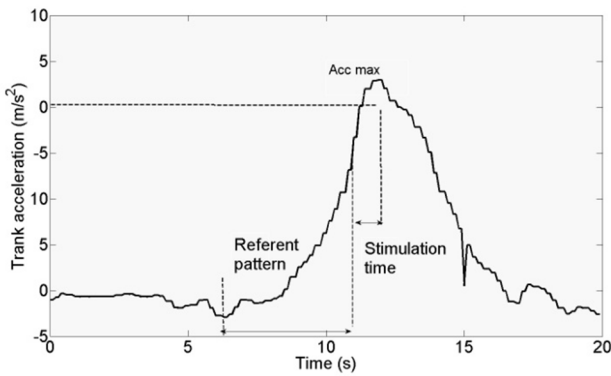


Fig. 1. Trunk acceleration signal and reference signal in the sagittal plane.  $Acc_{max}$  is maximum value of acceleration signal. Stimulation time is moment when stimulator was triggered with respect to  $Acc_{max}$ .

stimulation in desired time instant has been successfully tested in healthy subjects [5]-[6]. The goal of the study presented here is to analyze the impact of the leg stimulation onset on the arm efforts involved during sit-to-stand transfer in one complete paraplegic subject.

### Subjects

One complete T6 paraplegic subject (age 40 years, height 1.71m, weight 70kg, post injury period 25 years) participated in this study. Subject had experience in FES usage. Approval from local ethical committee was obtained to run those tests.

### Protocol

Stimulated muscles were quadriceps (vastus medialis and vastus lateralis) and biceps femoris. PROSTIM<sup>TM</sup> stimulator was used. Stimulation parameters were pulse width (PW) of 300 $\mu$ s and frequency of 30Hz. Maximal current amplitude ( $I_{max}$ ) which would be capable of inducing muscle contraction and ensuring joints locking was experimentally defined (120mA for right quadriceps, right biceps femoris and left biceps femoris, 130mA for left quadriceps). To ensure smoother and safer sit-to-stand transfer, ramping of stimulation train was used. Duration of the ramp was set to 300ms. Subject went through: 1) one muscle mapping session during which we tested the condition of the muscles, 2) two training sessions during which subject get used to the experimental setup and “trained” his muscles and 3) two measurement sessions during which data were recorded.

### Measurement session

The kinematics data were acquired by one-axis wireless accelerometer positioned between shoulder blades of the subject. The wireless system is described in [7]. Six degrees of freedom force

sensors were mounted on handles on parallel bars in order to record arm efforts. Sampling frequency of accelerometer and force sensors was 100Hz. The stimulation current amplitude was set to  $I_{max}$ . At the beginning, subject was sitting on the chair with arms rested on the handles. The positions of the handles were adjusted according to the subject’s height and preferences. Subject performed rising motion using our system by bending his trunk forward before sit off phase at the signal given by experimenter. Each measurement lasted until the subject reached a visually correct standing posture. Each experiment session lasted until subject was able to repeat sit-to-stand trials.

### Results

On Fig. 2. typical trial of the sum of left and right hand forces measured during the experiment is shown. Mean and maximal values of the sum of left and right measured resultant hand forces for all sit-to-stand trials are presented on Fig. 3. Stimulation time in seconds with respect to the maximal trunk acceleration is presented on the x-axis. Negative values indicate that stimulator was triggered before  $Acc_{max}$ . In the same way, positive values mean that stimulation started after  $Acc_{max}$ , i.e. after sit off (see Fig. 1). Figure 4 shows duration of rising phase of each sit-to-stand trial. X-axis is labeled in the same way as described.

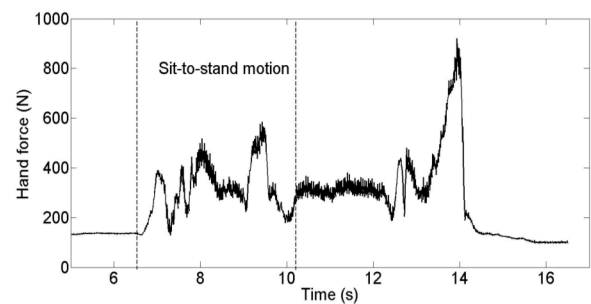


Fig. 2. Typical trial of hand forces recorded during the experiments.

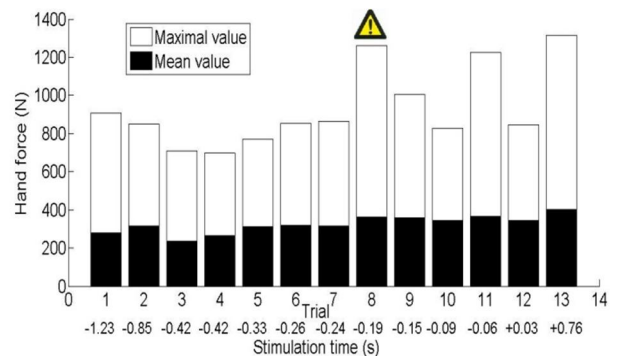


Fig. 3. Mean and maximal value of sum of the left and right hand forces measured during experiments.

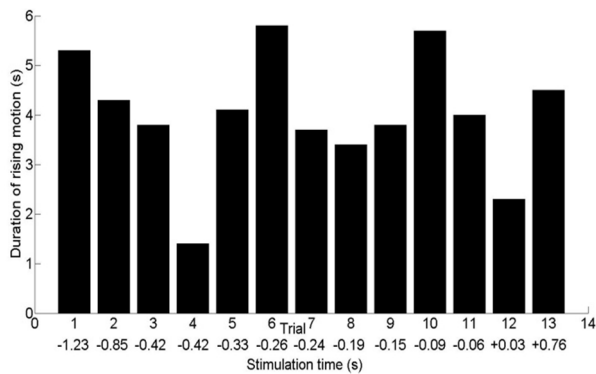


Fig. 4. Duration of rising phase for sit-to-stand trials measured during experiments.

## Discussion

This study aimed to reduce two main quantities during rising motion of paraplegic subjects, the overall effort to decrease fatigue and the maximal peak effort to preserve shoulder joints. Observing Fig. 3., it seems that there is an influence of the timing of stimulation application and upper limb support forces. As expected, the highest mean and maximal value of hand forces were achieved for trial 13, when command signal was sent to stimulator 0.76s after maximal trunk acceleration occurrence ( $Acc_{max}$ ), i.e. after sit off phase. On the other hand, the lowest mean and maximal values of the hand forces were achieved for trials 3 and 4, when command signal was sent to stimulator 0.42s before  $Acc_{max}$ . More specifically, in trial 3 the recorded mean and maximal forces were respectively reduced by 58.5% and 53.8% of the ones measured in trial 13. Concerning trial 4, these values were reduced by 65.6% and 53.1%. Taking duration of the stimulation ramp into consideration and adding muscle contraction delay, rising motions with the lowest arm support was similar to the one of the healthy subjects in terms of onset of the legs motion with respect to the motion of the trunk [3]. Note that during the trial corresponding to stimulation instant of -0.19s before  $Acc_{max}$ , the subject had strong spastic contractions of the legs' muscles. In this condition, this trial should not be taken into account. Fig. 4. presents the duration time of the rising motion of all sit-to-stand trials. One can see, by comparing Fig. 3 and 4, that the applied arm force values are not linked with the duration of the trial. For example, the force values of trials 3 and 4 were similar while their respective duration was 3.8s and 1.4s. Finally, the standard deviation of the mean duration for rising part of sit-to-stand trials was high ( $4.007 \pm 1.236$ s). From these observations, we can conclude that, duration of the rising motion does not play an important role in applied arm forces during the motion.

## Conclusion

Using the described system enables us to get preliminary evidence of the existence of an optimal

time instant for triggering the stimulator. Our closed-loop controller appears to be a good solution to observe trunk motion and triggering stimulation at the appropriate timing [8]. Further study will involve more paraplegic subjects in order to evaluate the closed-loop controller and to generalize the conclusions of this paper. Ability to transfer with minimal participation of upper limbs would preserve shoulder integrity and improve daily life of individuals with paraplegia.

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## Acknowledgements

Authors would like to acknowledge subject L.T. who participated in this study.

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