Reducing the upper body effort during FES-assisted arm-supported standing up in paraplegic patients

Seyedi A, Erfanian A

Neuromuscular Control Systems Lab., Iran Neural Technology Centre, Dept. of Biomed. Eng., Iran University of Science and Technology, Tehran, Iran

Abstract

In this work, the effects of the artificial ankle joint stiffness on the performance of sit-to-stand movement and upper body effort have been assessed during FES-assisted arm-supported standing up in paraplegic patients. An ankle-foot orthosis (AFO) was developed with the plantar-assisting spring. By changing the spring, the rigidity of the AFO could be adjusted. Experimental results on two complete paraplegic subjects indicated that by suitable selection of the stiffness in the plantar flexion direction, the paraplegic patient could stand up comfortably with less upper body effort. The results showed that the peak arm force was reduced from 67.2% to 44.3% of the body weight in subject RR and from 77.7% to 47.9% in subject MS.

Keywords: *Sit-to-stand, paraplegic, upper body effort, Functional Electrical Stimulation.*

Introduction

Sit-To-Stand (STS) maneuver is one of the repetitive movements in daily life and it is also a prerequisite for standing, walking, and reaching distant objects. It has been demonstrated that using Functional Electrical Stimulation (FES) on paraplegic's lower extremities they can complete the STS task [1]. One of the main issues in STS movement in paraplegic patients using FES is the amount of upper body effort during the task [2]. The long term effects of repetitive high transient loading of the arm during activities such as transfers and wheeling have been implicated in the high incidence of overuse syndromes in the spinal injured population [3]. Therefore it is essential to find a solution to minimize the patient's upper extremity efforts during movement.

Many STS aspects in healthy subjects and some issues in able-bodied young and elderly have been analyzed during past studies [4]-[8]. However, few studies exist on the FES-assisted STS movement in paraplegic subjects [9], [10]. Donaldson and Yu [9] measured the handle forces and the posture during open-loop FES-assisted standing up of two paraplegic subjects. The tests show that they use a strategy called *quick knee-locking* in which the hip extension occurs after the knees are locked and while a flexion deficit is being applied at the knees. The results shows that most of the forces needed to lift up the body in an upward position are provided by upper extremities. Bahrami et al. [10] analyzed the biomechanical aspects of STS transfer in healthy subjects with/without arm-support and in paraplegic patients with/without FES and suggested that some significant differences exist between the strategy used by the paraplegic patients to stand up and the strategies used by the healthy adults rising with arm-support.

In all FES-assisted arm-supported standing up [9], [10], only the knee joint or both the knee and hip joints were actively contributed to the STS movement by stimulating the quadriceps and gluteal muscles. Previous studies on STS movement in healthy subjects reveal that during seat off to standing posture the plantar flexion muscles are active and an extension torque is generated in the ankle joint [7], [8].

The aim of current study is to investigate the effect of ankle joint stiffness on the upper body efforts during FES-assisted standing up in paraplegic subjects.

Material and Methods

The experiments were conducted on two thoracic-level complete spinal cord injury subjects in different days. The paraplegic subjects were active participants in a rehabilitation research program involving daily electrically stimulated exercise of their lower limbs (either seated or during standing and walking) using ParaWalk neuroprosthesis [11]. The hip, knee, and ankle joint angles were measured by using the motion tracker system MTx (Xsens Technologies, B.V.) which is a small and accurate 3-DOF Orientation Tracker. A Kistler piezoelectric force plate type 9286AA (Winterthur, Switzerland) was used to measure the 3D ground reaction forces (GRF) under both feet (with an accuracy of ±0.5% of the full scale) and the corresponding CoP. The vertical forces on the arm support frame were measured by two Load cells (LRF350, Futek Advanced Sensor Technology, Inc, USA) mounted underneath the both walker handles (Fig. 1). An ankle-foot orthosis (AFO) was developed with the plantar-assisting spring. By changing the spring, the rigidity of the AFO could be adjusted.

The experiments were performed while the paraplegic subjects were seated in their wheelchair. Both feet were placed symmetrically and parallel to each other on a force plate. For rising, stimulation is voluntarily triggered by the patient wearing AFO, and the body is lifted upward from the initial to the extended upright position by the help of stimulating the quadriceps and gluteal muscles using an eight-channel computer-based FNS system [12] and arm support.

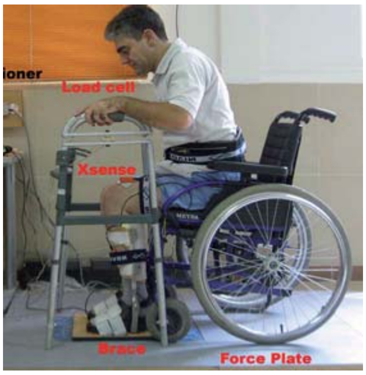

Fig. 1: Experimental Setup

Results

Fig. 2 shows the hip, knee, and ankle joint angles, hand and ground reaction forces, for different values of the stiffness controlling the plantar flexion for two paraplegic subjects. It is observed that the peak hand reaction forces (PHF's) are 48% (60%) and 52% (58%) of the body weight in subject RR (MS) when the stiffness values are 22.14 Nm/rad and 10.53 Nm/rad, respectively. The PHF's are 73% and 72% of the body weight with no spring in subjects MS and RR, respectively.

Fig. 3 shows the average of the hand reaction forces with different values of stiffness. Totally, 172 experimental trails were conducted on two subjects in different days. The results indicate that the mean hand reaction force is reduced form 48.2% of the body weight to 32.9% by applying 22.14 Nm/rad mechanical stiffness on the ankle joint in subject RR, and from 53.2% to 30.8% by applying 10.53 Nm/rad stiffness in subject MS.

Discussion and Conclusions

In this work, we investigate the effect of the ankle joint stiffness on the upper body efforts during FES-assisted standing up in paraplegic subjects. The results indicate that applying artificial stiffness in the plantar flexion direction could significantly reduce the upper body effort in paraplegic patients standing up using FES.

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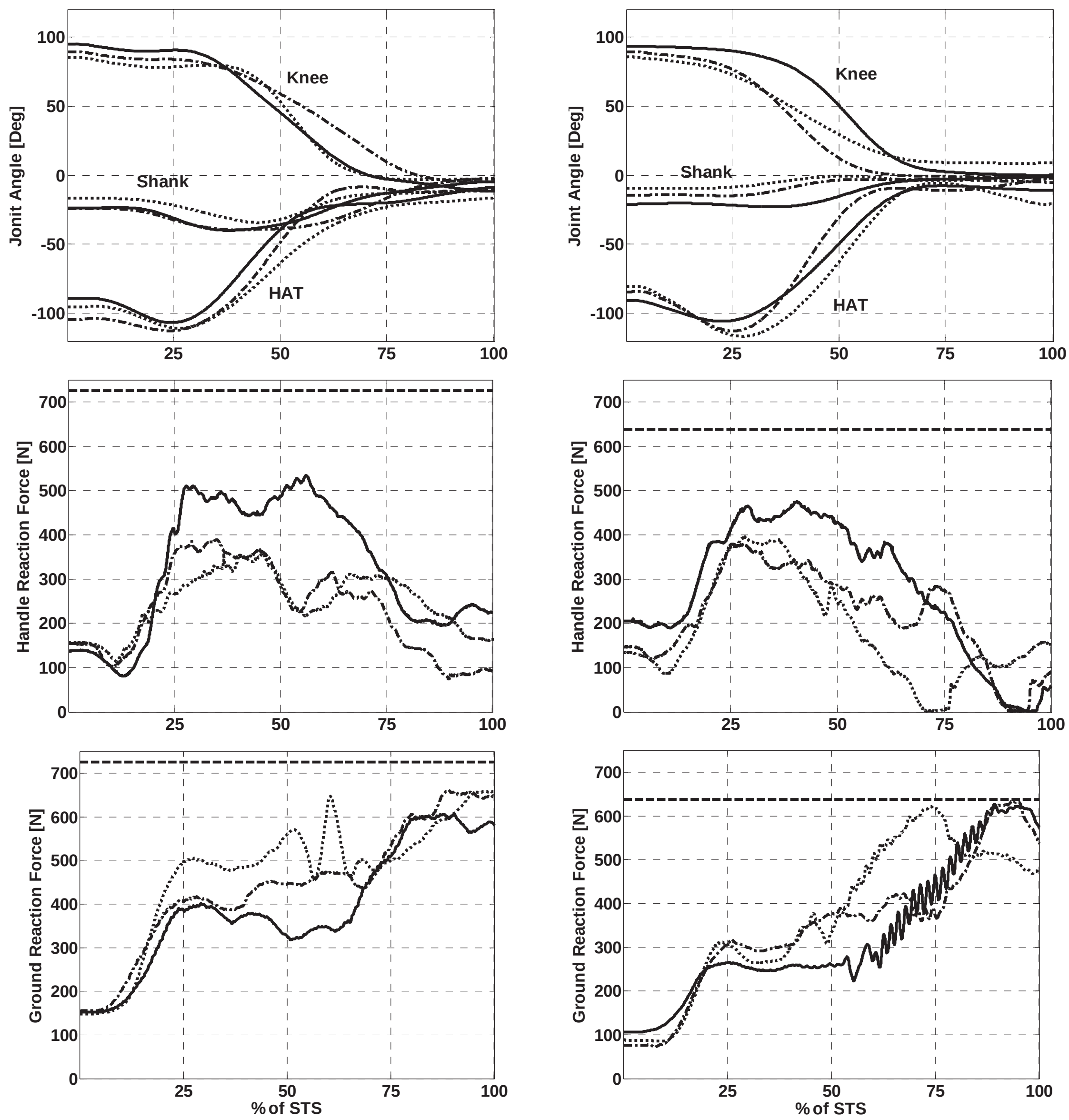

(a) (b)

Fig. 2: Joint angles, hand and ground reaction forces with different values of stiffness in the ankle joint for two paraplegic subjects RR (a) and MS (b): no spring (solid line), 10.53 Nm/rad (dashed line), and 22.14 Nm/rad (dotted line).

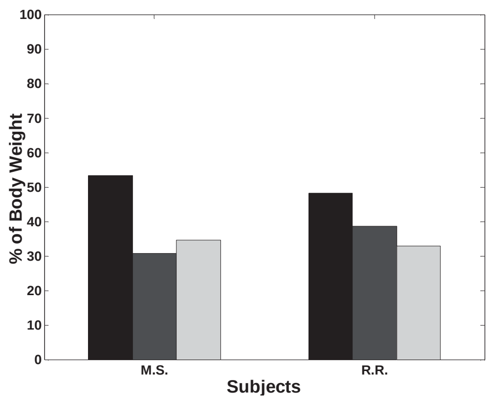

Fig. 3: Average of the hand reaction forces with different values of stiffness: no spring (black), 10.53 Nm/rad (dark gray), and 22.14 Nm/rad (light gray).

Acknowledgements

This work was supported by Iran Neural Technology Centre, Iran University of Science and Technology.

Author's Address

Seyedi A., Erfanian A.
Dept. of Biomedical Engineering,
Faculty of Electrical Engineering,
Iran University of Science and Technology,
Iran Neural Technology Centre,
Tehran, Iran.
erfanian@iust.ac.ir
aseyedi@ee.iust.ac.ir