World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:7, No:2, 2013

Effect of FES Cycling Training on Spasticity in Spinal Cord Injured Subjects

Werner Reichenfelser, Harald Hackl, Josef Hufgard, Karin Gstaltner, and Margit Gfoehler

***Abstract*—**Training with Functional Electrical Stimulation (FES) has both physiological and psychological benefits for spinal cord injured subjects. Commonly used methods for quantification of spasticity have shown controversial reliability. In this study we propose a method for quick determination of spasticity in spinal cord injured subjects on a cycling and measurement system. 23 patients did training sessions on an instrumented mobile FES cycle three times a week over two months as part of their clinical rehabilitation program. Spasticity (MAS) and the legs resistance to the pedaling motion were assessed before and after the FES training and measurements were done on the subjects ability to pedal with our without motor assistance. Measurements with test persons with incomplete spastic paraplegia have shown that spasticity is decreased after a 30 min cycling training with functional electrical stimulation (FES).

***Keywords*—**Spasticity, paraplegia, spinal cord injury, functional electrical stimulation.

I. Introduction

THE activation of lower limb muscles through FES is an important supporting therapy for persons with complete or incomplete paraplegia. The contraction of the paralysed leg muscles increases perfusion of the lower limbs and improves the cardiovascular condition and the pulmonary system [1, 2]. Additionally, muscle mass [3] and bone density increase when FES is performed continuously [4,5]. Spasticity is a common problem among paraplegic subjects that can cause pain, lead to unwanted movements or prevent intended movements. Lance [6] defined spasticity as a motor disorder that is characterised by a velocity dependent increase in the tonic stretch reflex with exaggerated tendon reflexes. For quantification of spasticity manual scales, biomechanical techniques, or neurophysiological methods have been applied. Manual scales as the Ashworth Scale/Modified Ashworth Scale (MAS) are most commonly used but have shown little reliability [7]. Krause et al [8] found that FES cycling training reduced spasticity (determined by MAS and pendulum test) in spinal cord injured (SCI) subjects.

The aim of this study was the assessment of spasticity in the lower extremities using the pedaling mechanism of a cycling system for paraplegics [9] and the influence of cycling training with Functional Electrical Stimulation (FES) on spasticity in SCI subjects.

W. Reichenfelser, H. Hackl and M. Gfoehler are with the Dept of Engineering Design & Logistics Engineering, Vienna University of Technology, Vienna, Austria, (margit.gfoehler@tuwien.ac.at).

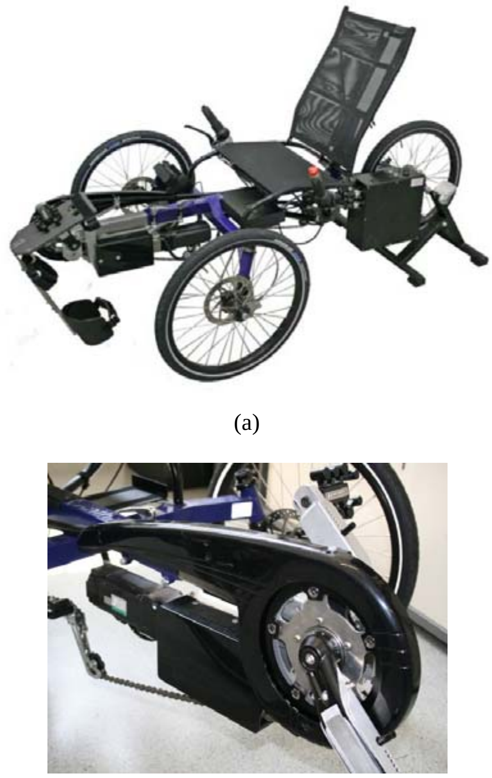
J. Hufgard and K Gstaltner are with the AUVA Rehabilitation Centre Weisser Hof, Austria.

This study was sponsored by the General Accident Insurance Company Allgemeine Unfallversicherungsanstalt AUVA Vienna, Austria.

II. Methods

A. The Cycling and Measurement System

The cycling and measurement system is based on a tricycle that was especially adapted for the FES training of paraplegic subjects. As the basic frame for the described FES- cycling system a standard tricycle (AnthroTech) was adapted (see Fig. 1a). For easier transfer from a wheelchair to the tricycle the right steering handle can be dismounted by opening a quick clamp. Additionally a transfer board can be hugged on to the frame. A motor that is mounted underneath the crank beam can move the cranks at a given angular velocity or hold the cranks at a defined position (Fig. 1b). Orthoses support the legs and fix the ankle joints (Fig. 2).



(a)

(b)

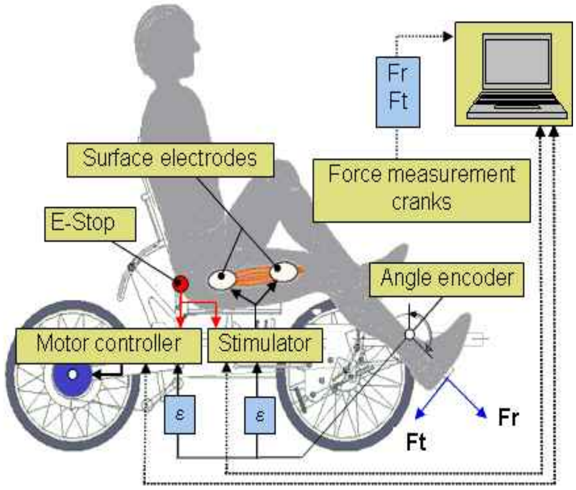
Fig. 1 (a) Trainings- and measurement system for FES-cycling (b) drive unit at the cranks

Fig. 2 Orthoses for leg stabilization on the pedals

A ten-channel current controlled stimulator stimulates three muscles/muscle groups of each leg (Quadriceps, Hamstring, and Gluteus Maximus) via attached surface electrodes. The motor current is measured that is needed for the control of the movement of the cranks and is in relation to the resistance of the legs against the movement.

Fig. 3 shows the cycling and measurement system during a test session and a schematic of the control.

(a)



(b)

Fig. 3 The cycling and measurement system during measurements (a) and schematic of control (b) [10]

B. Measurements

Each therapy session followed the training protocol as llustrated in Fig. 4. The pre-training phase starts with the spasticity assessment according to the Modified Ashworth Scale (MAS) carried out by the therapist. After the transfer from wheelchair to the training system and the attaching and connecting of the surface electrodes (Axelgaard CF5090, 2 x 9cm) the therapy phase is started with the spasticity test routine. This is a three minute test where the legs of the patient are passively propelled at 6 isokinetic cadences. The system performs eight crank turns at 10, 20, 30, 40, 50 and 60 rpm and records the induced drive current. The peak value of the joint angular velocity at the knee joint is 30 °/s at 10 rpm and 200 °/s at 60 rpm at the hip joint 24°/s and 140 °/s, respectively. A program written in LabView 7.0 (National Instruments, Texas) processes the data and gives a mean resistance value for each crank angular velocity.

After 5 minutes of warm up where the cranks are moved with 30 rpm and low density stimulation (amplitude 20 mA) is applied to the leg muscles the training is continued with 5 minutes of isokinetic training. There the patient is asked to propel actively and a supporting stimulation is added in a pattern as pictured for the right leg in Fig. 3. The applied stimulation consists of rectangular biphasic pulses with a frequency of 50 Hz and pulse duration of 600µs. The amplitude is set to a level were the stimulation is not uncomfortable for the patient but a contraction of the stimulated muscle group occurs.

Subsequently the patient is asked to pedal as strong as possible during 10 isokinetic crank revolutions without stimulation and the averaged power output generated by the active muscle forces is calculated. The pedals are moved at constant angular velocity by the motor. Performed at 30 rpm this power output test mainly gives evidence of the patient's muscular strength and at 60 rpm the additional coordinative aspect is accented. Regular performance of the tests over the time period of 2 months allows monitoring the rehabilitation progress of each individual patient.

Next a 5 minute training with constant motor torque and FES is performed (constant torque training), where the motor supports or brakes the system with constant torque depending on the physical abilities of the patient. The motor support or motor resistance is set by the therapist in a current range of +/- 1000 mA to enable the patient a smooth pedaling. Before the concluding spasticity test, the isokinetic training is repeated for 5 min.

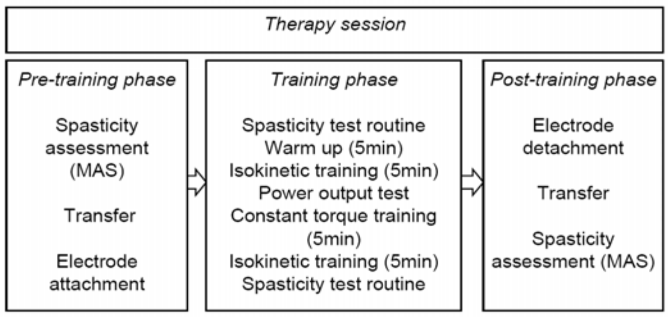
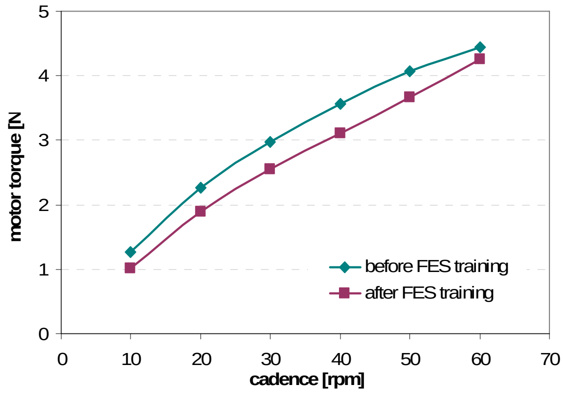


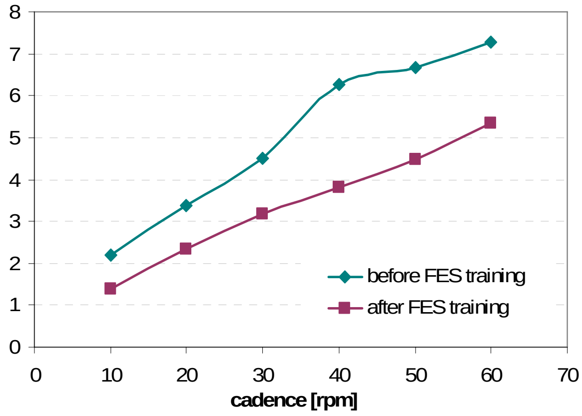
Fig. 4 The three phases of the therapy session [10]

III. Results

Nine test persons with incomplete spastic paraplegia volunteered for the study and gave informed consent. The results of 7 to 14 training sessions were averaged for each patient. Fig. 5 shows a comparison of the averaged results of a non-spastic test person (MAS 0) and a test person with an average MAS of 1.5 that dropped to 1.2 after the FES training. For non-spastic subjects resistance was usually slightly decreased after the FES training over the whole range of velocities, the curves run in parallel (Fig. 5a). Basically, the increase due to inertia is the same before and after the FES training. Consequently, if the difference between the two curves increases at higher velocities as in Fig. 5b, it can be assumed that the ‘increase in difference’, meaning the difference at 60 rpm minus the difference at 10 rpm originates from the spasticity that increases with velocity.



(a)



(b)

Fig. 5 Comparison of averaged results of a non-spastic test person P1 (a) and test person P3 with MAS 1.5 (b) on average before the FES training

Fig. 6 shows the reduction of spasticity for all nine test persons, that was calculated as the reduction of necessary drive power by the motor for control of the crank speed due to the lower resistance torque. Test person P3 reaches the highest value, 7 W, for the non-spastic test person P1 the value is 0. It can be seen that the reduction of resistance significantly increases with cadence for the subjects with spastic SCI, whereas there is only a slight increase in the healthy subjects and subjects with nonspastic SCI.

IV. Conclusion

The introduced system offers multifunctional equipment for FES-cycling therapy. Used in rehabilitation centres it should provide an additional attractive therapy tool. Due to the force measurement and the automated data processing the therapy progress can be well monitored. The proposed method of spasticity assessment has the advantage, that the spasticity of both hip and knee joints is included. Angular velocities at both hip and knee have a cyclic pattern, what is similar to natural movements as walking. The results of the spasticity assessment show that the resistance of the legs to the passive pedaling movement is decreased in the spastic group after the FES training. The relaxation increases with velocity, what indicates that spasticity may be decreased. These results agree with the findings of Krause et al. [8]. The result of the able-bodied group showed slightly higher values than the non spastic patient group which may be caused by the difficulty to relax completely when being pedaled during the assessment. To quantitatively assess spasticity with the described approach and to find related long term effects of FES cycling on spasticity further research will be necessary.

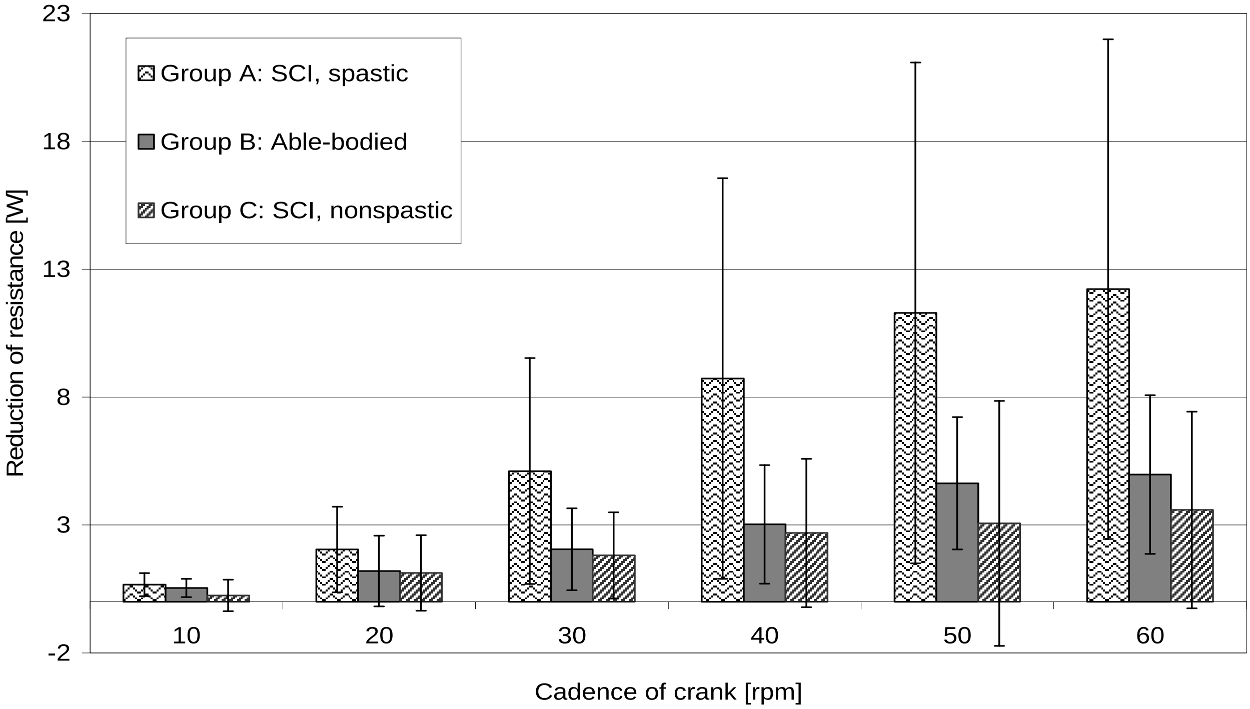


Fig. 6 Bar chart of the reduction of resistance [W] over the crank cadence [rpm] for three groups of subjects. Group A: SCI with MAS ≥1 (spastic), able-bodied group (B) and SCI group (C) with MAS <1 (non-spastic)

ACKNOWLEDGMENT

The authors thank the test persons for taking part in the study and Mrs. Julia Wiedner for collecting the data.

REFERENCES

[1] Janssen T.W.J., Glaser R.M., and Shuster D.B.: “Clinical efficacy of electrical stimulation exercise training: effects on health, fitness, and function.” Top Spinal Cord. Inj. Rehabil., (1998), 3, 33-49.

[2] Figoni S.F., Rodgers M.M., Glaser R.M., Hooker S.P., Faghri P.D., Ezenwa B.N., Mathews T., Suryaprasad A.G. and Gupta S.C.: “Physiologic responses of paraplegics and quadriplegics to passive and active leg cycle ergometry.” J.Am.Paraplegia Soc., (1990) 7, 33-39.

[3] Heesterbeek P.J.C., Berkelmans H.W.A, Thijssen D.H.J., Kuppevelt van H.J.M., Hopman M.T.E. and Duysens J., ”Increased physical fitness after 4-week training on a new hybrid FES-cycle in persons with spinal cord injuries”; Technology and Disability, 17 (2005),103-110.

[4] Frotzler A., Coupaud S., Kakebeeke T.H., Hunt K.J., Allan D.B., Donaldson N., and Eser P., “Effects of high volume FES-cycling training on bone parameters of subjects with chronic spinal cord injury,” in Proc. 45th ISCoS Annual Scientific Meeting, (Boston, USA), June 2006.

[5] Hunt K.J., McLean A.N., and Fraser M.H., “The health benefits of cycling exercise in paraplegia using functional electrical stimulation”, Proc. 42nd Ann. Sci. Mtg. Int. Spinal Cord Soc., (Beijing, China), 2003.

[6] J. W. Lance, Symposium synopsis, in Spasticity: Disordered Motor Control, R. G. Feldman, R. R. Young, and W. P. Koella, Eds. Miami: Symposia Specialist, (1980), 485-495.

[7] A. D. Pandyan, G. R. Johnson, C. I. M. Price, R. H. Curless, M. P. Barnes, and H. Rodgers, "A review of the properties and limitations of the Ashworth and modified Ashworth Scales as measures of spasticity," Clinical Rehabilitation, 13 (1999), 373-383.

[8] P Krause, J Szecsi, A Straube,Changes in spastic muscle tone increase in patients with spinal cord injury using functional electrical stimulation and passive leg movements Clin Rehabil. 22 (2008), 627-34.

[9] W.Reichenfelser, H.Hackl, S.Mina, S.Hanke, P.Lugner, M.Gföhler, Trainings- and Measurement- System for FES- Cycling, Proc. IFESS 2008.

[10] Reichenfelser W, Hackl H, Hufgard J, Kastner J, Gstaltner K, Gföhler M. Monitoring of spasticity and functional ability in individuals with incomplete spinal cord injury with a functional electrical stimulation cycling system. J Rebahil Med 2012; 44: 444–449.