FES DRIVEN CYCLING BY DENERVATED MUSCLES

Mravcsik M[1,2], Kast C[3], Vargas Luna JL[3], Aramphianlert W[3], Hofer C[4], Malik Sz[1], Putz M[5], Mayr W[3], Laczko J[1,2]

[1]Wigner Research Centre for Physics, Budapest, Hungary
[2]University of Pecs, Pecs, Hungary
[3] Medical University of Vienna, Wien, Austria
[4] Ludwig Boltzman Institute for Electrical Stimulation and Physical Rehabilitation, Vienna, Austria
[5] National Institute for Medical Rehabilitation, Budapest, Hungary

percze-mravcsik.mariann@wigner.mta.hu

Abstract: *Paraplegic individuals performed FES assisted lower limb cycling on a tricycle, which has been adapted for this purpose. Two persons with complete spinal cord injury and denervated muscles performed the trainings 2 times a week for 6 weeks. It was assumed that the trainings motivates them to reach higher cycling speed from training to training. Their cycling speed was monitored and compared during each training. The average speed increased during the 6 weeks period. Within trainings the speed was the highest in the first part of the training than decreased and slightly increased again. This was found for both participants. Results suggests that the quantitative difference between the participants, regarding cycling speed reflects more differences in their level of motivation and less their level of injury and muscle condition.*

Keywords: *Tricycle, Speed*

Introduction

It is known and reported that functional electrical stimulation (FES) helps to regenerate denervated muscles [1]. Denervated muscles after FES treatment show improvement in cross sectional area and in structure, and this treatment results in rescue of muscle mass and tetanic contractibility [2]. Recovery from muscle degeneration after denervation can be reached by appropriate FES training. FES is the only option for denervated muscles to have active contraction. [3]. FES trainings for lower limb muscles have been performed on stationary cycle ergometers and also on mobile tricycles [4, 5, 6]. Here we present that a sequence of FES trainings on a special tricycle for persons with flaccid paraplegia, make them able and motivated to propel it and increase cycling speed and distance over time.

Methods

Participants with complete spinal cord injury, lesion in the cauda equina, used a tricycle which has been adapted for this purpose (Reha-Funtrike, OVG, Munich, Germany). One participant (P1), 32 years old, level of injury T10, and a second participant (P2), 45 years old, level of injury T12, started the training 3 respectively 6 months post-injury. We examined whether the cycling speed increased during a period of 6 weeks, performed twice a week, and how speed changed within individual trainings.

The tricycle, was equipped with a custom build 4 channel electrical stimulator, capable of delivering biphasic rectangular long-duration pulses (15 - 100 ms per phase, +/- 80 V), as necessary for activating denervated muscles (Figure 1). Two channels and pairs of large size (200 cm^2) conductive rubber electrodes (Schuhfried Inc., Vienna Austria) with wetted foam pads were used to activate the quadriceps muscle groups on both legs for knee extension. Synchronous bilateral knee extension is used to actively pushing back the seat, coupled to the driving chain, and driving the bike forward; passive knee flexion is generated by pulling body and decoupled seat forward along gliding rails towards the firm steering bar by active arm flexion ("rowing mode"). The stimulation is activated and deactivated by a push button next to the left handle.

Each training was performed on flat surface of a straight corridor over a distance of about 50 meters, back and forth, with reversing zones at both ends. The subjects continued cycling in these loops for about 30 minutes.

Table 1: Basic data on both participants

	P1	P2
Gender	male	male
Age	32	45
Level of injury	T10	T12
	3 months	6 months
ASIA score	A	A
Avg Velocity	5 km/h	4 km/h
Avg Distance	2.51 km	2.01 km

Figure 2: Custom build 4-channel stimulator

Fig 2: Left: Bilateral knee extension starts and actively drives the tricycle as the quadriceps muscles are stimulated; Right: The end of quadriceps stimulation (start of "rowing mode").

Results

The speed was computed for 3 equal phases of the total cycling time. The speed in the first and third phases were similar but in the middle phase it appeared generally lower. Average speed for P1 in the 1st, 2nd and 3rd phase was 5.5 km/h, 4.4 km/h, 5.1 km/h respectively, the same values for P2: 4.4 km/h, 3.7km/h, 3.9km/h. The average cycling speed for a whole session (total cycling time) were 5.0 and 4.0 km/h for P1 and P2 (Figure 3.). The distances cycled in the 12 trainings are shown at Figure 4. The first participant achieved higher cycling speed and cycled longer distance (Figure 5.)

Average speed increased for both participants during the training period with slopes of 0.22 and 0.23 for P1 and P2 (Figure 6.).

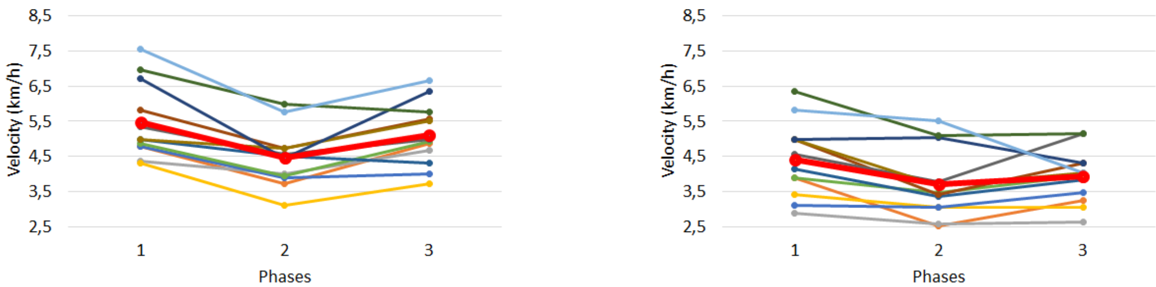
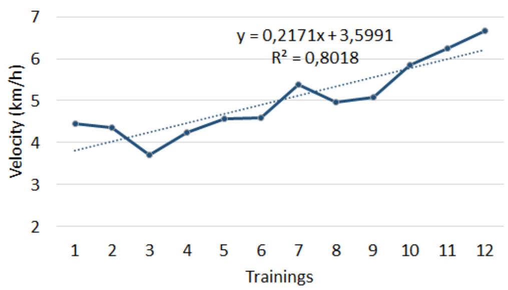


Fig 3: The average (across trainings) velocity is represented by large red dots representing the average of the first second and third phases of the training (dots connected by thick lines). Small dots and thin lines represent velocity values for 12 separate trainings for the participants P1 (left) and P2 (right).

Fig 4: The average (across trainings) cycling distance is represented by large red dots (dots connected with thick red lines). The small dots and thin lines represent twelve 12 separate trainings for P1 (left) and P2 (right).

Figure 5. Comparison of average cycling speed (left) and cycled distance (right) of the two participants.



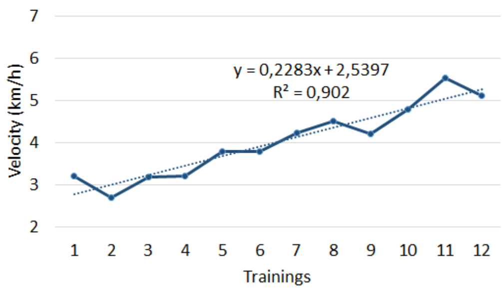


Figure 6. The speed in 12 consecutive trainings increased in both cases. left: P1, right P2.

Discussion

The speed increased during the series of trainings for both participants. Aware of all limitations of just preliminary observations in the 2 single cases we assume that the throughout higher values for participant P1 originate mainly from his higher motivation of using the tricycle to achieve as long cycling distance and as high cycling speed as possible. With T10 P1 had a higher level of injury (P2 had T12), but had a younger age and shorter time since injury. In both cases significant improvements were observed with progress of training, which is encouraging for further systematic studies with a higher number of participants.

Acknowledgement

Supported by grants GINOP 2.3.2-15-2016-00022 and OMAA 94öu7

References

[1] Mayr W, Hofer C, Bijak M, Rafolt D, Unger E, Sauermann S, Lanmueller H, Kern H. Functional electrical stimulation (FES) of denervated muscles: existing and prospective technological solutions. *Basic Appl Myol* 2002; (12): 287.

[2] Kern H, Carraro U, Adami N, Biral D, Hofer C, Forstner C; Moedlin M; Vogelauer M, Pond A, Boncompagni S, Polini C, Mayr W, Protasi F,Zampieri S. Home-Based Functional Electrical Stimulation Rescues Permanently Denervated Muscles in Paraplegic Patients With Complete Lower Motor Neuron Lesion. *Neurorehabilitation and Neural Repair*. vol. 24, pp. 709-721. 2010

[3] Kern H, Carraro U;Adami N; Hofer C, Loefler S, Vogelauer M; Mayr W, Rupp R; Zampieri S. One year of home-based daily FES in complete lower motor neuron paraplegia: recovery of tetanic contractility drives the structural improvements of denervated muscle. *Neurological Research*, vol. 32, pp. 5-12. 2010

[4] Szecsi J, Krause P, Krafczyk S, Brandt T, Straube A. Functional output improvement in FES cycling by means of forced smooth pedaling. *Medicine and Science in Sports and Exerc*. vol.39, pp.764-780. 2007

[5] Berkelmans R, Woods B, Strategies and performances of Functional Electrical Stimulation Cycling using the BerkelBike with Spinal Cord Injury in a competition context (CYBATHLON). *European J. of Translational Myology*. vol. 27, pp. 255-258. 2017.

[6] Mravcsik M, Kast Ch, Malik Sz, Mayr W, Laczko J. Cycling speed increases through Functional Electrical Stimulation (FES) assisted tricycling trainings of spinal cord injured individuals. *World Congress on Medical Physics & Biomedical Engineering, Prague 2018.*