Changes in active cycling time and distance during FES assisted cycling before and after the pandemic closure – a case study

Lilla Botzheim, David M. Ernyey, Mariann Mravcsik, Laszlo Varaljai, Andras Klauber, Peter Cserhati and Jozsef Laczko

***Abstract*— We investigated the efficiency of FES cycling trainings of a paraplegic patient. Our patient performed FES assisted cycling on a BerkelBike tricycle, while active cycling time, distance and the cadence was measured during the trainings. Due to the pandemic, we had to keep a three months long break in the serial of trainings when the patient had to stay away from the rehabilitation center. We compared the changes in the measured parameters before and after this three months. The break caused a significant relapse in each measured parameter. Nevertheless, the improvement in the parameters after restarting the trainings was higher than before the absence from the trainings and the patient reached the same performance level what he had before pausing the trainings. This suggests that during the preparation for a FES cycling competition a pause in the serial of trainings may not prevent a pilot from reaching proper performance.**

I. Introduction

Physical and sport activities are essential for healthy lifestyle and it is an important part of spinal cord injured (SCI) patients' therapy. Functional Electrical Stimulation (FES) driven cycling is an efficient way to do this. With the FES technology, paralyzed muscles can exert active muscle forces to perform cyclic limb movements and the physiological and psychological benefits of this have been investigated in several studies [1], [2]. A new approach of FES cycling is hybrid FES, when the paraplegic SCI patients are cycling with their arms voluntarily and leg cycling is controlled by FES. This method is also beneficial for the physiological conditions of these patients [3]–[5].

FES cycling is used not only for therapy but also as one of the events in the Cybathlon competition [6]. The inclusion criteria for the pilot is spinal cord injury, paraplegia, complete loss of motor function (AIS A or B). The tricycle must meet the conditions of the race. Several research teams developed their own tricycle for the race [6]–[8]. Some of these tricycles are also commercially available, one of the well-known of these is the BerkelBike (BerkelBike B.V., Netherlands) that is a hybrid tricycle equipped with a 6 channel electrical stimulator [9].

Research teams prepare their pilots for the race in a variety of ways, yet each preparation is unique [6], [10].

In our study, we present the improvement in performance of a spinal cord injured patient who performed trainings on a BerkelBike and his resumption after a 3-month pause of the trainings which had to take place due to the pandemic. We have adjusted the training protocol to the needs of the patient and our future goal is to participate in the Cybathlon competition.

II. Methods

A. Patient

Our patient is a 52 years old male who suffered traumatic spinal cord injury in 2012. After surgical stabilization of the broken thoracic VII and X vertebrae, he started rehabilitation. Throughout the years after the accident he become relatively independent considering the Activity of Daily Living, including maintaining continence and using urinary catheter. According to ASIA score level A, his symptoms are anaesthesia and paraplegia under level ThVII. The patient had spasms, but it did not hinder him in the cycling movement. Because of a former anterior cruciate ligament (ACL) tear, he has no ACL in the left knee. He is highly motivated and cooperative. He had several FES cycling trainings on a MotoMed ergometer and some test trainings on the Berkelbike. After watching the Cybathlon 2020 FES cycling race he became even more motivated and enthusiastic and we started his trainings on the Berkelbike in late 2020 with a new protocol. He had usually one or two trainings per week until the beginning of March 2021. At that time, we had to stop these trainings and could restart only in late May 2021.

B. Experimental setup

Due to the claim of our patient we payed special attention on the training and measurement protocol. The most essential parts are the proper seat position and the stimulation pattern. The patient's left leg had to be adjusted to minimize lateral knee oscillation. Another criterion was not to swing out his leg when reaching the most extended position. The stimulation electrodes were placed on Quadriceps, Hamstrings and Gluteus maximus muscles on both legs. The stimulation pattern was adjusted to the patient's movement. First, we asked a physiotherapist to be a subject in a test training. He identified which of his leg muscles play a significant role in cycling on the tricycle, and at which crank angle these muscles exert active muscle forces. Based on these, we defined a stimulation pattern that was tested on our patient. The stimulation pattern was then modified and optimized based on test trainings and this was adjusted to the patient (Fig. 1.).

Lilla Botzheim is with the University of Pecs and the Department of Computational Sciences, Wigner Research Centre for Physics, H-1121 Budapest, Hungary. (e-mail: botzheim.lilla@wigner.hu)

David M Ernyey is with the Semmelweis University, Budapest, Hungary (e-mail: davidmarcell.ernyey@gmail.com)

Mariann Mravcsik is with the University of Pecs and the Department of Computational Sciences, Wigner Research Centre for Physics, Budapest, Hungary. (e-mail: percze-mravcsik.mariann@wigner.hu)

László Váraljai is with the National Institute for Medical Rehabilitation, Budapest, Hungary (e-mail: Varaljai.Laszlo@omint.hu)

András Klauber is with the National Institute for Medical Rehabilitation, Budapest, Hungary (e-mail: Aklauber@rehabint.hu)

Péter Cserhati is with the National Institute for Medical Rehabilitation, Budapest, and Department of Rehabilitation and Physical Medicine, University of Pecs, Hungary (e-mail: Cserhati.Peter@omint.hu)

Jozsef Laczko is with the University of Pecs, and Wigner Research Centre for Physics, and Pazmany Peter Catholic University, Hungary and also with the Dept. of Physiology, Feinberg School of Medicine Northwestern University Chicago IL60611, IL USA (e-mail: laczko.jozsef@wigner.hu).

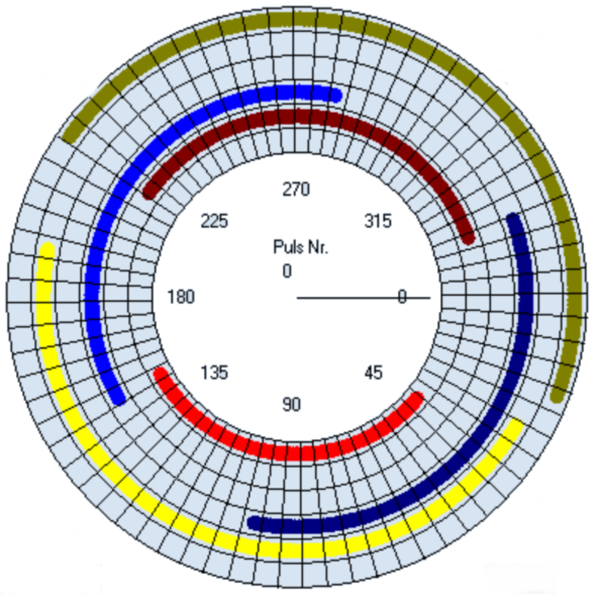

Figure 1. The stimulation pattern. The red arc denotes the range of crank angles where the left Quadriceps was stimulated, the light blue arc denotes the range where the left Hamstrings, the yellow arc denotes the range where the left Gluteus maximus was stimulated. The brown, dark blue, and olive arcs show the range where the right Quadriceps, right Hamstrings and the right Gluteus maximus was stimulated. Crank angle is zero when the right crank is directed horizontally forward.

This basic stimulation pattern was modified to allow the patient to perform the cycling task without his arms. In the meantime, we changed the initial protocol as our patient progressed. Before the measurement, the patient was seated on the BerkelBike and we set his position and his legs. During the training, the front wheel of the bicycle was placed in a stand and it was rotated without friction.

One training comprised several sessions. The patient had two warm up sessions, first without current, and the second with 30mA. Each warm up session lasted for 5 minutes. During the trainings we measured the cycling time with active muscle movement per training, the cadence, the distance, the number of sessions and the duration of the longest session.

After the warm up sessions, in the first protocol, we began the stimulation by increasing the current amplitude from 0 mA, and started the measurement when the patient was able to perform the cycling only with his legs. When his cadence decreased to almost zero, we increased the current amplitude always in 6mA steps until 120mA. As soon as his legs were not able to drive the bike further, we stopped the session and the measurement. The length of the pause between the sessions depended on the duration of the previous session. One training lasted a total of one and a half hours (including installation and resolution of the training setup), and the active cycling time in one session was maximized in 25 minutes.

When the patient was able to exceed the 25 minutes in one session, the protocol was changed. We employed a second protocol in which we set the gear in the highest position. Due to the limitation of total active cycling time, we had to specify (increase) the required minimum cadence to ensure further progression of the patient. In this second protocol, the patient himself could increase the current intensity, if he felt slowdown, or if the cadence fall below 50 rpm. The active cycling time in one session was maximized in 30 minutes. We used the second protocol only when we restarted the trainings after the pandemic closure.

III. RESULTS

In the series of trainings our measurements showed increase in each measured parameter. Unfortunately, because of the pandemic, we had to stop the project for three months. During this pause the patient had neither electrical stimulation nor any other type of physical training. Our results show that the break caused a significant relapse in the measured parameters, however, soon after the restart of the trainings we experienced an increase in these parameters again.

A. Active cycling time

The active time during one training is the summation of the duration of all active sessions in one training (Fig. 2.). As we can see, the active cycling time during one training increased in the series of the trainings both before and after the pandemic closure, although the break (absence) caused a significant relapse. After the absence, the patient needed eleven trainings to reach almost the same level in this parameter.

B. Number of sessions

There is no interruption during one session, and the current intensity reaches 100% (according the BerkelBike software) always before the end of the session. In the series of the trainings the time of one cycling session with no interruption increased until the pandemic (Fig. 3.) and the number of sessions decreased. After the pandemic closure was suspended and the trainings started again, the patient was able to complete only shorter sessions. After 10 trainings, the time of one cycling session increased again and we reached longer sessions than before the break (which is a proof of the development.)

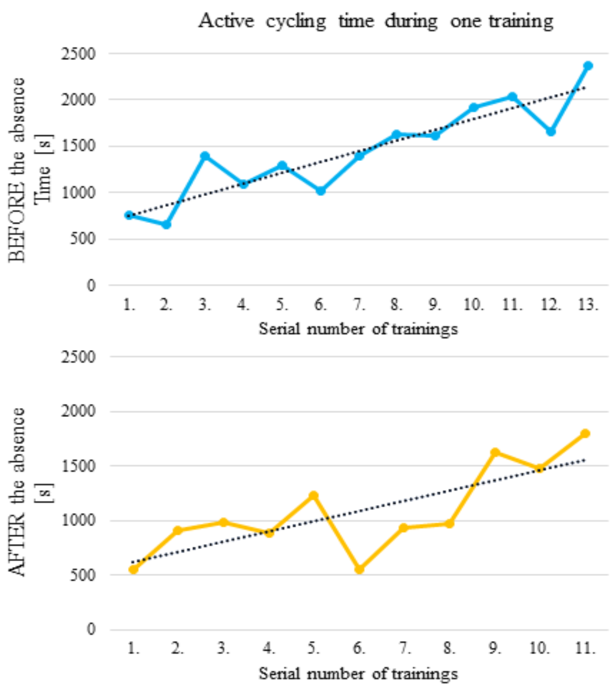

Figure 2. Total active cycling time in each training before and after the break (absence of the patient from the trainings due to the pandemic). Dotted line represents the trend of improvement.

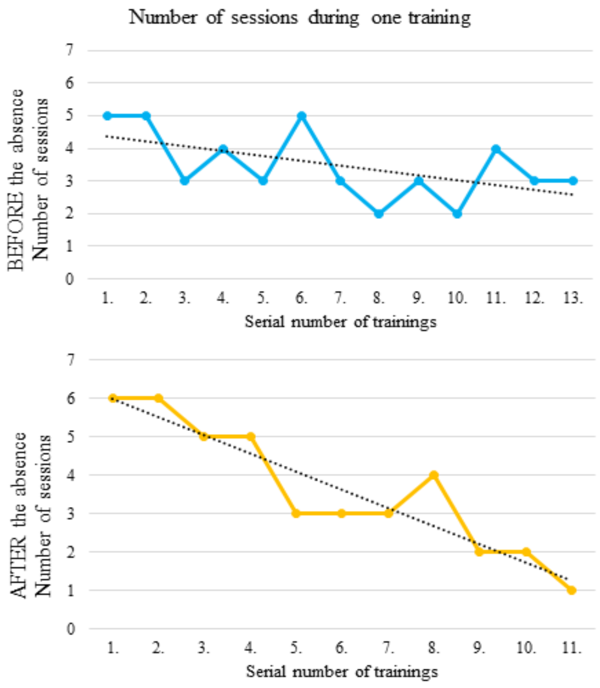

Figure 3. Number of sessions in each training before and after the absence due to the pandemic.

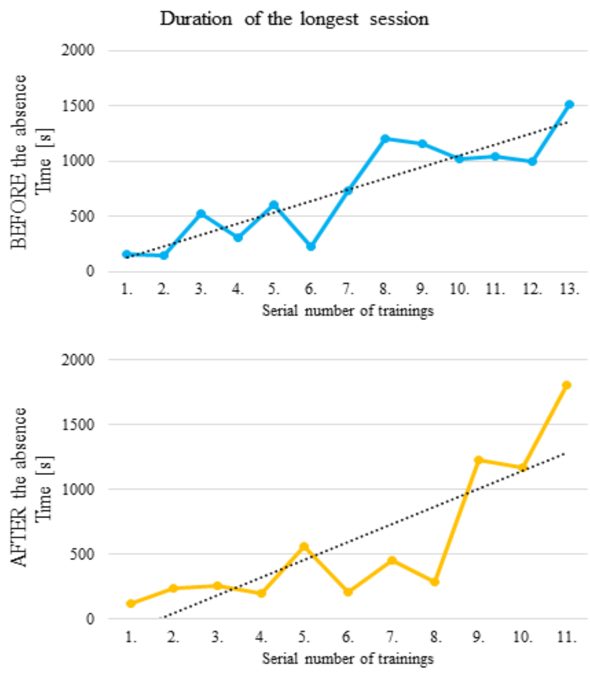

Figure 4. Duration of the longest session in each training before and after the absence due to the pandemic. Dotted line represents the trend of improvement.

C. *Duration of the longest session*

Based on our measurement, we found that the duration of the longest session within a training increased during the series of trainings (Fig. 4.). The patient was able to complete longer sessions and the number of the sessions in one training decreased. This is noticeable both before and after the absence. After the absence, we measured only shorter sessions, like at the first trainings of the patient at the beginning, later the duration of the sessions increased.

D. *Cadence*

Before the absence, the average cadence of one training was waving, but overall the average cadence increased during the thirteen trainings (Fig. 5.). After the pandemic absence, we used the second protocol, in which we minimized the average cadence in 50 rpm. Patient could hold this cadence during each training.

E. *Distance*

Based on our measurement, the total distance of each training was calculated. The distance depends on the active cycling time and the speed (cadence). In the second protocol, the required cadence was higher than in first protocol, therefore the total distance was longer in the trainings (Fig. 6.). In addition, the rate of increasing was faster after the absence.

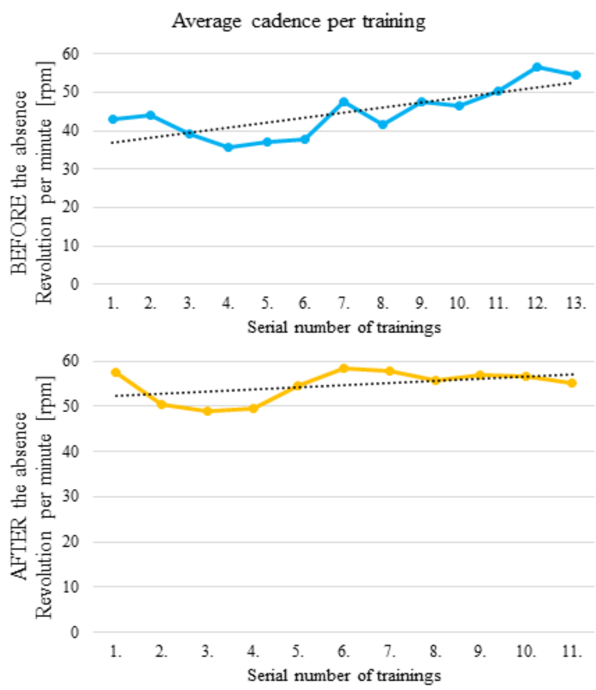

Figure 5. The average cadence across sessions was measured in each training before and after the absence due to the pandemic. Dotted line represents the trend of improvement.

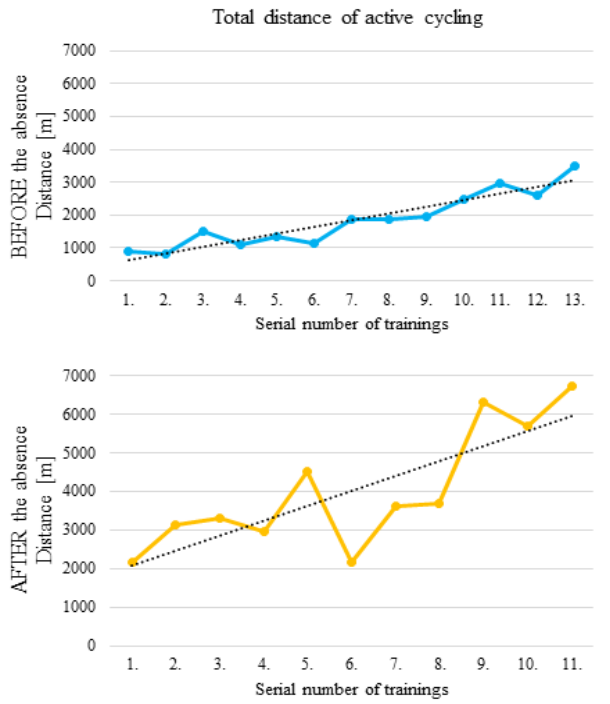

Figure 6. Total distance during active cycling time was computed in each training before and after the absence due to the pandemic. Dotted line represents the trend of improvement.

IV. Conclusion

In our study, we showed that the patient who participated in a sequence of trainings on a FES driven BerkelBike tricycle was able to improve the cycling time and cycling distance. The number of cycling sessions within one training decreased while the cycling time of the longest session increased. Thus, the duration of continuous FES driven tricycling increased even when the number of sessions decreased. The patient used less resting time in an entire training.

Interestingly, after the absence the patient started with a higher cadence compared to the training that he had in the last training before the pandemic. Due to the bigger and stronger spasms after the absence, he reached a higher cadence but the fatigue occurred earlier. Despite of his former experience in FES cycling, after the break he needed adaptation time to reach his previous achievements.

Our data shows that the long pause in sequence of trainings has temporarily unfavorable effect on the cycling performance of the patient.

After the introduction of a new training protocol in which the patient increased the intensity of the stimulating current, he was able to reach, in six weeks, the same performance what he had before the three months long break.

Our observation proves that directly before a competition there should not be any long pause in the trainings of the pilot. However, after restarting the sequence of trainings, the performance of the pilot improves quickly and the pause may not prevent him to reach expected performance in a FES cycling competition.

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