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# The Influence of Functional Electrical Stimulation during Cycling Exercise on Cardiorespiratoric Response in Order of Cadence at Increasing and Persistent Exercise in Healthy Adults

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## Abstract

**Introduction:** Functional electrical stimulation during cycling (FES Cycling) exercise is seen to improve cardiorespiratoric performance for maintaining health in patients with spinal cord injury. The relationship between widely varying stimulation pattern, functional movement and effects on cardiorespiratory response is not yet sufficiently studied. While different muscle activation patterns during the FES Cycling may increase metabolic consumption, the influence of different cycling cadences is controversial. The aim of this study was to investigate the acute effect of functional electrical stimulation and different cadences on cardiorespiratoric responses in passive cycling movement in healthy volunteers.

**Methodology:** 26 healthy subjects assigned in two groups, performed stepwise increased tests with and without functional electrical stimulation with cycling cadence increased from 20-60 rpm, 10 rpm every five minutes and two 25 minutes lasting, persistent tests with functional electrical simulation at cadences of 20 and 60 rpm. Passive cycling exercise was performed adding functional electrical stimulation on musculus quadriceps femoris, biceps femoris, tibialis anterior and gastrocnemius. Subjects were obliged to perform no voluntary movement. Heart rate, oxygen uptake and respiratory exchange ratio was recorded.

**Results:** No significant changes between heart rate and oxygen uptake at different cadences during stepwise increased tests were found ($p>0.05$). Respiratory exchange ratio was different between beginning and end of the test ($p<0.05$). There was no Influence of electrical stimulation in any of measured parameters ($p>0.05$). Mean oxygen uptake within persistent 60 rpm test increased significantly, compared to 20 rpm. No differences of heart rate and respiratory exchange ratio were detected ($p>0.05$).

**Discussion:** Acute cardiorespiratoric responses during passive cycling caused by functional electrical stimulation are only tendential, but not significant. By increasing the current and the cadence of FES Cycling metabolic consumption could be increased. A significant increase in cardiorespiratoric consumption is apparently only possible by combining exercises using FES Cycling and active arm exercise.

## Introduction

Functional electrical stimulation is been used for about 50 years in treatment and rehabilitation of patients with stroke and spinal cord injury. Numerous studies could show positive effects of functional electrical stimulation (FES) combined with cycling movement (FES Cycling) [1,2]. Main improvements in stroke patients are motor changes, such as improving walking ability, balance and spasticity [3-5]. Increase of residual muscle strength, prevention of contractures and sense of well-being are described as important therapeutic goals in paraplegia [6,7]. Improvement of cardiorespiratory performance seems to be a considerable component for maintaining health [8], especially in patients with spinal cord injury. FES Cycling exercises interventions show significant improvements in cardiorespiratory parameters [9,10]. Investigations with simple electromyostimulation (EMS) without functional movement on cardiac patients with very low cardiac levels also show an increase in cardiorespiratory capacity [2,11]. The relationship between stimulation parameters, functional movement and effects on cardiorespiratory parameters is not yet sufficiently studied.

In numerous investigations exercise protocols, stimulation frequencies and strength of electric current varies widely. It is known that rectangular pulses for FES are suitable [12,13]. Basically in both, healthy and paralyzed muscles with increased amperage, more motor units are recruited [14]. While different muscle activation patterns during FES Cycling may increase the cardiorespiratory load, the influence of different cycling cadences is discussed controversial

**Table 1:** Mean and standard deviation of subject characteristics.

| | Persistent test group | Stepwise increased test group |
|---|---|---|
| n | 14 | 12 |
| age [a] | 25.6±1.6 | 24.1±0.9 |
| height [m] | 1.78±0.1 | 1.82±0.1 |
| weight [kg] | 75.14±13.7 | 83.8±19.5 |
| test spacing [d] | 6.1±4.2 | 4.3±2.6 |

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**Table 2:** Mean and standard deviation of the current of FES during persistent- and stepwise increased test.

| Strength of the electric current [mA] | Mean±SD | | |
|---|---|---|---|
| **Muscles** | **Persistent test 20 rpm** | **Persistent test 60 rpm** | **Stepwise increased Test** |
| QF left | 20.6±8.6 | 21.3±8.2 | 21.8±5.1 |
| QF right | 20.4±7.0 | 20.4±6.4 | 25.2±6.8 |
| BF left | 20.6±7.1 | 22.3±7.4 | 23.3±5.9 |
| BF right | 23.0±6.9 | 22.7±7.3 | 25.5±6.8 |
| TA left | 20.3±7.3 | 21.0±7.8 | 23.2±4.5 |
| TA right | 21.6±5.8 | 20.1±6.7 | 23.9±6.8 |
| GA left | 19.3±5.8 | 20.3±5.7 | 24.7±6.0 |
| GA right | 20.3±6.4 | 20.4±6.2 | 24.0±6.1 |

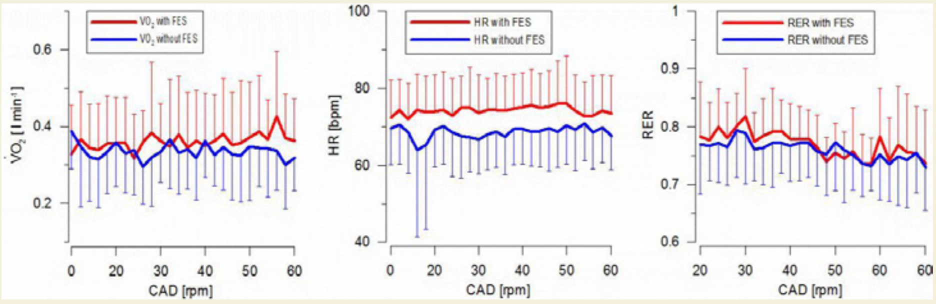


**Figure 1:** Mean and standard deviation of respiratoric exchange ratio (RER), heart rate (HR) and oxygen uptake ($VO_2$) during tests with stepwise increased cadence (CAD), with and without functional electrical stimulation (FES).

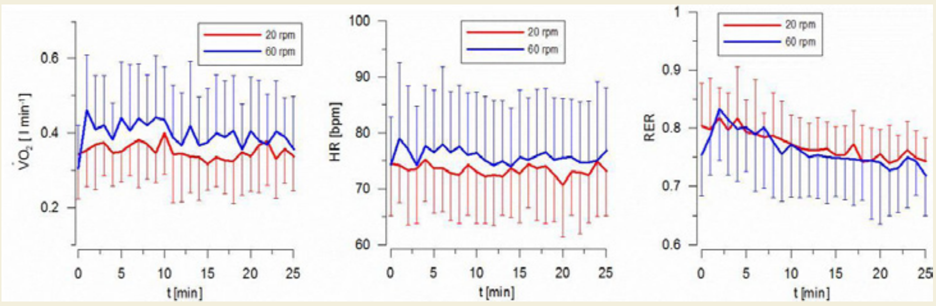


**Figure 2:** Mean and standard deviation of respiratoric exchange ratio (RER), heart rate (HR) and oxygen uptake ($VO_2$) during persistent tests at 20 and 60 rpm with functional electrical stimulation (FES).

[15,16].

The aim of this study was to investigate the acute effect of functional electrical stimulation and different cadences on cardiorespiratoric responses in passive cycling movement in healthy volunteers.

## Methodology

26 healthy volunteers (25±1.5 years, 180±10 cm, 78.8±16.5 kg) were divided into two groups (stepwise increased test group=ST/ persistent test group=PT) (Table 1).

The subjects performed two exercise tests at Reck MOTOmed viva2 Bewegungstrainer with a lag of 5.3±3.6 days. During passive cycling exercise, the subjects were instructed to perform no voluntary movement. ST group cycling cadence increased stepwise 10 rounds per minute (rpm) every 5 minutes from 20 to 60 rpm. Tests were carried out one with FES and one without in randomized order. Persistent tests (25 min) were done with FES each, randomized at a cadence of 20 and 60 rpm. Functional electrical stimulation was applied by Hasomed RehaStim2 stimulation device via biphasic rectangular pulses (300 µs, 30 Hz) by both sides with adhesive electrodes on musculus (M.) quadriceps femoris, biceps femoris, tibialis anterior and gastrocnemius. Current intensity was set to a visible contraction of the muscles, tolerated by the subjects. Intensity of electric current was approximately reproduced at the second test (Table 2).

Heart rate (HR), oxygen uptake ($VO_2$) and respiratory exchange ratio (RER) were recorded continuously during the exercise tests via Cortex Metamax 3b portable device. Final minute measurements of the stepwise increasing cadence periods and measurements of every minute in the persistent test were used for evaluation. Statistical analysis was performed using SPSS 23.0 software program. All data were examined for normality of variance and distribution by Shapiro-Wilk and Levene test for homogeneity of variances. To test the effect of stimulation and cadence on the physiological variables a two factor ANOVA was used. Differences between the physiological data in the persistent test were examined by t-test for dependent means. Level of significance was 5%. For graphical representation Grapher 4.0 was used.

## Results

### Stepwise increased tests (ST)

Rest value before the test with FES was recorded 73.1±9.9 beats per minute (bpm) (HR), 0.328±0.129 l $min^{-1}$ ($VO_2$) and 0.78±0.09 (RER). Before the test without FES the value showed a 2.5±0.20 bpm lower heart rate and a 0.03±0.02 lower RER. Oxygen uptake showed about 0.061±0.029 l $min^{-1}$ higher values.

Mean value of heart rate, $VO_2$ and RER during measurement with FES was 75.03±9.49 bpm, 0.362±0.131 l $min^{-1}$ and 0.77±0.07. Without FES the values decreased about 4.95±0.76 bpm, 0.029±0.020 l $min^{-1}$ and 0.02±0.00. The minimal differences seen in the graphs of HR and $VO_2$ between varying cycling cadences showed no statistical significance ($p>0.05$) (Figure 1). Only the RER was significantly different between the beginning and end of the stepwise increased tests ($p<0.05$). No influence of electrical stimulation could be detected in any of the three parameters ($p>0.05$).

### Persistent tests (PT)

Mean resting data at 20 rpm was 74.5±9.3 bpm (HR), $VO_2$ of 0.344±0.122 l $min^{-1}$ and RER about 0.80±0.07. Before 60 rpm rest value of heart rate was amounted to 74.3±8.6 bpm, oxygen uptake 0.303±0.118 l min-1 and RER 0.75±0.07. During the persistent test at 20 rpm a mean value of 73.3±8.5 bpm (HR), 0.351±0.102 l $min^{-1}$ ($VO_2$) and a RER of 0.77±0.06 was determined. At 60 rpm the mean HR was higher than at 20 rpm by 2.5±2.6 bpm. $VO_2$ increased about 0.047±0.039 l $min^{-1}$. RER was lower by 0.01±0.02. $VO_2$ at 60 rpm was statistical significantly higher than 20 rpm ($p<0.05$). For heart rate and RER no significant differences were detected (Figure 2).

## Discussion

FES currently appears to be an important potential therapy in neurological disorders. Therefore neuromuscular electrical stimulation is coupled with a functional movement like cycling or running. Recent findings show effects of interventions with FES Cycling [17]. Adjustments of the neuromuscular system are affected by the specific stimulation of the muscle fibers. Furthermore, changes in the muscle cells are stimulated by influence of the cell metabolism, whereby the utilization of oxygen and the ATP consumption plays an important role.

The aim of the study was to investigate the energy metabolism during exercise with and without FES and different duration of the lower extremities.

It was shown that cardiorespiratory stress during passive cycling through FES learns only tendential not significant changes. Also stepwise increasing cycling cadence shows no effect on the cardiovascular stress. In contrast, significant change of $VO_2$ could be observed by increasing the cadence at persistent FES Cycling exercise. This is in contrast to a previous study, which showed no cadence effect on $VO_2$ during endurance tests, but at the same time significant changes between passive cycling and FES Cycling [17]. Other studies also show an acute effect of FES on the $VO_2$ [18]. Amount of the electric current appears to play a crucial role in the cardiovascular stress. The strength of the current in the present study was, because of the sensibility of the healthy participants; by up to 5 times lower than in interventions with spinal cord injured patients [17,18]. While recruitment of motor units is rising in a randomized non-physiological sequence with increased amperage, both in healthy and paralyzed muscles, the different muscle fiber composition in healthy subjects and spinal injured patient is not important [14,19]. A different muscle recruitment at different cadences, as of Fornusek and Davis suspected, may therefore have no significant impact on the metabolic parameters [15].

In summary it can be stated, that the metabolic stress during FES can be customized by both, the current as well as a modulation of the cadence. Unlike voluntarily controlled movements [20], absolute values of the reachable physiological load between different movement speeds at FES are low, which is also reflected in lower differences with and without FES. Causes of cardiovascular changes are therefore more likely to be linked with adaptation phenomena in muscle physiology. Comparative studies of muscle metabolism between FES and movement without electrical stimulation support this assumption [21]. A significant increase in cardiorespiratory parameters, such as the $VO_2$, to achieve adaptations of the cardiovascular capacity, is effective only by a combined load using FES Cycling and active arm exercise [18]. In addition to the intensity (amperage), the duration and extent of the FES seems to be crucial factors to induce adaptations of the cardiorespiratory capacity [9,22,23].

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