Archives of Physical Medicine and Rehabilitation

journal homepage: www.archives-pmr.org

Archives of Physical Medicine and Rehabilitation 2013;94:990-3

BRIEF REPORT

Pilot Study of the Effect of Low-Cadence Functional Electrical Stimulation Cycling After Spinal Cord Injury on Thigh Girth and Strength

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Abstract

Objective: To investigate the long-term effects of functional electrical stimulation (FES)-evoked cycle training cadence on leg muscle hypertrophy and electrically evoked strength.

Design: Open intervention study.

Setting: Laboratory setting.

Participants: Untrained individuals with chronic spinal cord injury (N=8).

Interventions: Six weeks (3d/wk) of training on an isokinetic FES cycle ergometer. For each subject, 1 leg was randomly allocated to cycling at 10 revolutions per minute (rpm) (LOW) for 30min/d, and the other cycling at 50rpm (HIGH) for 30min/d.

Main Outcome Measures: Pre- and posttraining measurements of lower limb circumference were performed at the distal and middle position of each thigh. Electrically evoked quadriceps muscle torque during an isometric contraction was also assessed.

Results: Six weeks of FES cycle training significantly increased thigh girth in both LOW and HIGH groups. At midthigh, girth increases induced by LOW (6.6%±1.2%) were significantly greater than those by HIGH (3.6%±0.8%). LOW also produced greater gains in electrically evoked isometric torque than HIGH after training.

Conclusions: These results suggest that lower pedaling cadences evoke greater muscle hypertrophy and electrically stimulated muscle strength compared with higher cadences.

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Functional electrical stimulation (FES)-evoked cycling is an exercise modality that allows persons with paralysis to exercise their paretic or paralyzed leg muscles.[1] Regular FES cycling results in increased muscle mass, augmented blood flow, reduced spasticity, and improved muscle oxidative capacity in the paralyzed legs.[2] These peripheral adaptations can be beneficial, for example, in improving glucose metabolism or offering a protective effect against the development of pressure sores.[3]

Compared with other FES exercise modes, FES cycling produces only modest gains of leg strength or muscle hypertrophy,[4,5] which is likely because of the lower muscle forces evoked. FES cycling is usually performed at cadences of 50 revolutions per minute (rpm), but research has shown that lower cadences (eg, 10rpm) produce greater muscle forces.[6] This study compares changes of muscle strength and thigh girth induced by 6 weeks of FES cycle training at LOW and HIGH pedaling cadences. We hypothesized that LOW FES cycling would confer greater gains in electrically elicited leg strength and thigh girth.

Methods

Participants

Eight subjects (mean age ± SD, 39±14y) with spinal cord injury (SCI) (C7−T11; 7 American Spinal Injury Association [ASIA]-A, 1 ASIA-C) recruited from the community provided written informed consent before participating. Their inclusion criteria were as follows: age between 18 and 65 years, at least 1 year post-SCI,

Supported by a University of Sydney Faculty of Health Sciences postdoctoral fellowship.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

0003-9993/13/$36 - see front matter © 2013 by the American Congress of Rehabilitation Medicine

http://dx.doi.org/10.1016/j.apmr.2012.10.010

had not performed FES exercise in the 6 months before this study, and leg muscles responsive to FES. The protocol (12578) was approved by the university's human ethics committee.

FES cycling training protocol

The exercise regimen involved FES cycle training 3 times per week over 6 weeks. For each participant, 1 leg was randomly allocated to be trained at 10rpm (LOW) and the other at 50rpm (HIGH). Each leg performed 30-minute FES cycling while the other leg was moved passively at the same cadence. The order of leg training (eg, LOW then HIGH) was alternated each session. During each 30-minute cycling session, the stimulation amplitude was linearly ramped from 40mA to 140mA over 10 minutes and then held constant. This ensured that almost identical stimulation was delivered to the 2 legs.

FES cycling equipment

Leg exercise training was performed on a custom-designed isokinetic FES cycle ergometer.[7] Stimulation (250μs, 35Hz) was delivered via gel-backed self-adhesive surface electrodes that were placed on the quadriceps, hamstrings, and glutei muscles. Electrode positions were kept consistent between testing and training sessions to ensure similar muscle fiber recruitment.

Thigh circumference and isometric quadriceps torque

The primary outcome measures were thigh circumference (10cm and 20cm above the superior patella border) and electrically evoked isometric quadriceps torque. Thigh circumference was obtained by averaging 3 measurements at each site using a cloth measuring tape.

Electrically evoked isometric quadriceps strength was tested on a Biodex muscle testing system 2[a] with the knee positioned at 50° from full extension. Three 7-second isometric contractions with a 2-second stimulation amplitude ramp were elicited by the stimulator for each quadriceps muscle; a 10-second rest was given between each contraction. The average stimulation amplitude used was 99±18mA. The stimulation amplitude was kept consistent for each subject during pre- and posttraining assessments. The quadriceps torque measured was corrected for the weight of the leg and averaged over the 3 contractions to give the average net torque generated by each quadriceps muscle.

Cycling performance and crank torque

The average power outputs that could be produced during 30 minutes of FES cycling exercise were assessed for each leg at both pedal cadences by using a stimulation protocol similar to that used during the training sessions (described previously). Additionally, the torque applied to the motorized ergometer (over 1 revolution) by the stimulated leg muscles was measured during the training sessions. This torque allowed us to estimate the relative magnitudes of the muscle forces exerted by LOW and HIGH. The average torque (across 30min) was extracted from the motor torque data for sessions 1 and 18.

List of abbreviations:

ASIA	**American Spinal Injury Association**
FES	**functional electrical stimulation**
HIGH	**cycling at 50rpm**
LOW	**cycling at 10rpm**
rpm	**revolutions per minute**
SCI	**spinal cord injury**

Statistical analysis

Nonparametric testing was employed in all statistical analyses using a Wilcoxon signed-rank test for paired samples. Baseline data for thigh girth, FES isometric quadriceps torque, and FES cycling power output were compared between the LOW and HIGH training groups. Pretesting versus posttesting comparisons were performed to determine statistically significant changes in thigh circumference, FES isometric quadriceps torque, and power output over the training period. We also tested whether the changes in thigh circumference and isometric quadriceps torque attributable to LOW and HIGH were statistically different. A P value of less than .05 was considered statistically significant. SPSS 17.0[b] was used for statistical analyses.

Results

Baseline values

Before the training program there were no statistically significant differences between the LOW and HIGH groups for thigh girth, FES-elicited isometric quadriceps torque, or cycling performance (table 1).

Thigh circumference

FES-evoked cycle training resulted in gains of thigh circumference at both training cadences (see table 1). The gains in thigh circumference were statistically significant at both measurement sites for both LOW and HIGH. The circumference of the thighs trained at LOW ($\Delta Girth_{10cm}$, +5.3%; $\Delta Girth_{20cm}$, +6.6%) increased more than those trained with HIGH ($\Delta Girth_{10cm}$, +4.0%; $\Delta Girth_{20cm}$, +3.6%). The circumference increase 20cm above the suprapatellar border was significantly greater from LOW.

Electrically stimulated quadriceps isometric torque

After the training program the quadriceps produced greater extension torque during electrical stimulation (see table 1). The average torque generated by the legs trained at LOW cadence increased by 87%, whereas the legs trained at HIGH cadence increased only 20%. The postassessment torques generated were significantly greater for LOW when compared with pretest values.

Average power output

The power outputs recorded during FES cycling (see table 1) were typical of persons with SCI. Pretraining, there was no difference in cycling ability between the legs trained at 10 and 50rpm. Training with FES cycling resulted in significant improvement in FES cycling performance. After training, the power outputs produced at 10 or 50rpm were not affected by the training cadence. Higher crank torques were observed during LOW than HIGH for both training sessions 1 (3.5Nm vs 1.1Nm) and 18 (4.2Nm vs 1.4Nm), indicating that greater muscle forces were being applied to the pedals.