Effect of FES Cycle Training Cadence on Velocity-specific Power Outputs in Individuals with SCI

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Abstract

This study investigated the effects of FES-cycle training cadence upon the power outputs produced during either fast or slow cycling velocities. Seven untrained individuals with spinal cord injury (C7-T11) performed six weeks (18 sessions, 30-min each leg) of training on an isokinetic FES cycle ergometer. One leg was trained at 10 rev•min^{-1} and the other at 50 rev•min^{-1}. The cycling performance of each leg was measured before and after training during 30-min of exercise at both pedalling cadences. Power outputs were calculated as the highest peak power (W) achieved, whenever these occurred during the 30-min pre-training and post-training assessment and average power output (W) over 30-min. Both peak and average powers were significantly increased following FES-cycle training (peak power by 30%-51%; average power by 41%-62%). Percent changes after training were greater for average power than for peak power. However, neither training cadence (50 rev•min^{-1} or 10 rev•min^{-1}), nor the cycling velocity that each trained leg was assessed at, had any effect upon training-induced gains of leg power. These data suggest that for a prolonged aerobic activity such as prolonged FES cycling, training at either slow or fast cadence produces equivalent gains of leg power output.

Keywords: *FES cycling, velocity, cadence, power output, exercise training.*

Introduction

Exercise is beneficial not only for the able-bodied population, but also for people affected by spinal cord injury (SCI). SCI can lead to numerous negative sequelae including moderate-severe muscle weakness or paralysis, as well as loss of lower limb functionality. However, SCI almost always results in lower levels of cardiorespiratory fitness for the individual compared to an able-bodied person. Consequently, these individuals display significant reductions in both their fitness and general health due to a restricted movement capacity as a wheelchair user – frequently leading to higher levels of cardiovascular risk [1].

Regular FES cycling can be used for both health benefits and recreation [2]. The health benefits bestowed to the paralysed limbs by FES cycle training include increased muscle strength and mass, augmented blood flow, and improved muscle oxidative capacity [3]. Yet, one limitation of FES cycling is that the muscle forces produced are quite low resulting in only modest strength and hypertrophy gains compared to other FES exercises [3, 4]. Furthermore, little previous research has investigated the effect of FES training cadence on muscle power production, most likely because the majority of FES cycles have been based on mechanical braking systems with a restricted cadence range (i.e. 35-50 rev•min^{-1}).

More recent FES cycle ergometers can produce isokinetic ("constant-velocity, variable cadence") cycling over a wide range of pedal cadences (from 5-60 rev•min^{-1}) [5]. One study has shown that low-cadence FES cycling can produce larger muscle forces than traditional cadences [6]. Fornusek et al [7], demonstrated that slow cadence cycle training over 6 weeks induced greater muscle hypertrophy and isometric strength compared to cycling training at a faster cadence.

The purpose of this study was to compare cycle power outputs before versus after FES-training at a slow (10 rev•min^{-1}) versus fast (50 rev•min^{-1}) cadence. Secondarily, we sought to determine whether cycle training at a slow or fast cadence over 6 weeks resulted in velocity-specific increases of peak and average cycling power output.

Material and Methods

Subjects:

Seven subjects with spinal cord injury (C7-T11 lesions; AIS A-C) participated in this study. All were sedentary and none of the subjects had performed FES exercise within the last six months. Their gender, age, time since injury and body mass are shown in Table 1.

Table 1: Subject Characteristics

Subjects	Age (y)	TSI (y)	Body Mass (kg)
6 ♂, 1♀	37 ± 10.5	6.1 ± 4.4	84.6 ± 11.6

Training protocol:

The training volume comprised 540 min of light-moderate intensity FES cycling exercise (6 weeks, 3 times per week at 30-min per session). Exercise heart rates were not recorded since the goal of the training program was strength development and leg muscle power production, not cardiorespiratory fitness. One leg was randomized to train at 10 rev•min^{-1} and the other at 50 rev•min^{-1}. Each leg was trained separately and the order of training was reversed each day. Muscle stimulation angles for FES-cycling at 50 rev•min^{-1} were adjusted to be 30° earlier than during cycling at 10 rev•min^{-1} to account for the delayed force rise at the higher cadence.

FES cycling training and testing equipment:

A custom-designed FES cycle was used [5]. The components of the cycle included a motorised isokinetic ergometer (Reck MOTOmed Viva2), a laboratory-constructed neuromuscular stimulator (DS2005, University of Sydney), and a laptop computer running purpose-built FES timing and control software. The neuromuscular stimulator delivered 250 μs pulses at a frequency of 35 Hz. Stimulation amplitude was initially set to 70 mA and linearly ramped to reach 140 mA after 10 min. Stimulation was held at 140 mA for rest of training session. Stimulation was delivered via pre-gelled self-adhesive electrodes over quadriceps, hamstrings and gluteal muscles.

Pre and post training measurements:

The peak power output and average power outputs that could be produced during 30-min of FES cycling exercise was assessed for each leg at both pedal cadences (10 and 50 rev•min^{-1}). For one subject, only the left quadriceps was stimulated during the cycling test. The stimulation protocol used during testing sessions was similar to that used during their training sessions, whereby muscle stimulation amplitude was ramped from an initial value of ~70 mA up to 140 mA over the first 10-min, and was maintained at 140 mA thereafter.

Statistical Analyses:

Changes of peak and average power outputs pre- versus post-training were analysed by paired t-test. To determine whether FES-cycle training at fast and slow cadences had velocity-specific outcomes at 10 and 50 rev•min^{-1} assessments, regression analyses were perfomed using the pre-test score with training cadence and testing velocity dummy-coded to predict post-test score. All data are expressed as mean ± S.E. Training-induced changes were considered significant at $p<0.05$.

Results

Six weeks of FES cycle training significantly increased the peak and average power outputs of both legs. Average power over 30-min increased by 42% - 64% following FES-cycle training, but there were no differences between training at 10 rev•min^{-1} or at 50 rev•min^{-1} (Table 2). Peak power outputs observed during the 30-min exercise period increased by 29% -54%, but both legs increased their peak powers by similar amounts (Figure 1).

Table 2: Average Power Output over 30-min (W)

Training Cadence (rev•min^{-1}) ⇨	**10**		**50**	
	Pre	Post (%Δ)	Pre	Post (%Δ)
Testing Cadence				
10	2.4 ±0.5	3.8 ±0.8	2.6 ±0.7	3.7 ±0.9
		58% *		**42% ***
50	3.3 ±0.8	5.4 ±0.7	3.7 ±0.5	5.8 ±1.0
		64% *		**57% ***

* denotes pre- training to post-training p <0.05

Stepwise linear regression did not find any velocity-specific effects between training at fast versus slow pedal cadences, or pre-post assessments performed at 10 and 50 rev•min^{-1}. The strongest predictor of post-training leg powers or percent change of leg powers was the pre-training score.

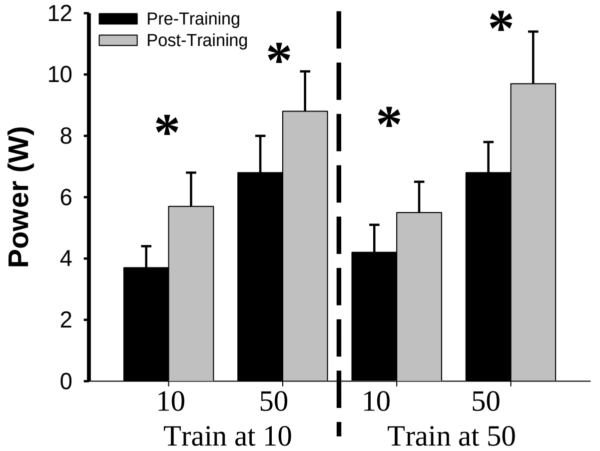

Figure 1: Peak Power Output (W)

Discussion

These data suggested that slow cadence cycle training (at 10 rev•min^{-1}) produced equivalent increases of power output as training at a faster cadence (e.g. 50 rev•min^{-1}). Cycling training improved performance at the trained cadence but also demonstrated a marked ‘crossover effect’ by improving performance at the untrained cadence.

Cycling performance was increased by both cadences, but there was no trend to suggest that training at 10 rev•min^{-1} may have enhanced performance more than at 50 rev•min^{-1}. Indeed, training at 50 rev•min^{-1} resulted in increased peak and average powers of 43% and 57%, respectively when the legs were assessed at their training-specific velocity. However training at the faster pedal cadence also incremented peak and average powers at the slow pedal cadence by 31% and 42%, respectively. Similarly, training at 10 rev•min^{-1} resulted in augmented peak and average powers of 54% and 58%, respectively when the legs were assessed at the slow training-specific velocity, but training at the slower pedal cadence also incremented peak and average powers at the higher pedal velocity by 29% and 64%, respectively.

This ‘cross transfer of training’ effect (a.k.a. cross-training) suggests that since either pedal cadence may be appropriate to augment power outputs during prolonged cycling, then the slow cadence might be the preferred option if the outcome desired are both muscle power and strength. Fornusek and colleagues [7], in a pilot study of only three individuals, suggested that slow cadence cycle training induced greater muscle hypertrophy and augmented isometric strength than did training at a faster cadence. In light of the current findings, it seems likely that training at either pedal cadence (or both) will improve muscle power outputs during exercise of prolonged duration that requires aerobic metabolism to generate the ATP needed for exercise - especially if the individual's legs are initially untrained.

Clinical applications

Traditionally, FES cycling has been employed at high cadences (eg 35-50 rev•min^{-1}). [3] The drawback of using high cadence cycle training is that muscles forces become low due to a high fatigue rate [6]. Lower cadence training should assist with improving and accelerating gains from FES-evoked leg exercise, particularly if there are no differences of power output using either one.

At 50 rev•min^{-1} the rapid intermittent stimulation results in rapid fatigue [4]. It is possible that a portion of the performance improvements for the leg trained at 50 rev•min^{-1} could be due to greater fatigue resistance to intermittent stimulation. If this was the case, then training with a combination of slow and fast cadences could result in the greatest improvements at 50 rev•min^{-1}.

Conclusions

These data demonstrated that slow cadence cycle training (at 10 rev•min^{-1}) produced equivalent increases of power output as did training at a faster pedal cadence (e.g. 50 rev•min^{-1}). Furthermore a clear ‘cross transfer of training’ effect was observed whereby there was no velocity-specific benefits at training at either pedal cadence. Depending on the training goals, slow cadence FES cycling could play an important role in optimising FES training for a particular individual.

References

[1] Myers J, Lee M, Kiratli J. Cardiovascular disease in spinal cord injury: an overview of prevalence, risk, evaluation, and management. Am J Phys Med Rehabil. 86:142-52, 2007

[2] Raymond J, Crameri R. Electrical Stimulation for Individuals with Spinal Cord Injury. Am J Med Sports, 228:209-222, 2001.

[3] Hamzaid NA and Davis GM. Health and fitness benefits of Functional Electrical Stimulation-evoked leg exercise for spinal cord injured individuals: A position review. TSCIR 14:88-121, 2009.

[4] Crameri RM, Cooper P, Sinclair PJ et al. Effect of load during electrical stimulation training in spinal cord injury. Muscle Nerve, 29:104-11, 2004.

[5] Fornusek C, Davis GM, Sinclair P, Milthorpe B. Development of an isokinetic functional electrical stimulation cycle ergometer. Neuromodulation, 7:56-64, 2004.

[6] Fornusek C, Davis GM. Maximizing muscle force via low-cadence FES cycling. J Rehabil Med, 36:232-237, 2004.

[7] Fornusek, C. and G. Davis (2010). Effect of FES Cycling Cadence on Muscle Girth and Strength after SCI. Proc Austral and New Zealand Spinal Cord Society (ANZSCoS), 34.

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