FES-assisted leg cycling after incomplete spinal cord injury: what role do the arms play in rehabilitation?

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Abstract

The purpose of this study was to determine the retained effects on over ground ambulation 6 to 24 months after completing 12 weeks of functional electrical stimulation (FES)-assisted arm and leg cycling. FES-assisted arm and leg cycling may be an effective method of improving walking in people with incomplete spinal cord injury (iSCI). This study also examined the effects of FES-assisted leg cycling without the arms on improving walking in people with iSCI. Improvements from FES-assisted leg cycling were compared to results obtained from FES-assisted arm and leg cycling. Results 6 months post FES-assisted arm and leg cycling compared to pre-training baseline measures showed retained improvements in: a) ASIA sensory (up to 13 points) and motor function (up to 7 points); b) balance using the Berg balance scale (up to 5 points); c) speed in a 10 meter walk test (up to 0.25 m/s); d) endurance in a 6 minute walk test (up to 64.80 m); and e) decreases in soleus mean Hoffman (H-) reflex peak to peak amplitudes (up to 4.1 mV). FES-assisted leg cycling without the arms also showed improvements after 6 weeks of training in: a) sensory (up to 4 points) and motor function (up to 3 points); b) balance (up to 6 points); c) walking speed (up to 0.02 m/s); d) walking endurance (up to 306 m); and e) H-reflex peak to peak amplitudes (up to 1.2 mV). However, when compared to similar duration of the FES-assisted arm and leg cycling training intervention, overall differences were found not to be as effective. These results suggest that the arms play an important role over the course of FES-assisted cycling training and the benefits are retained over the long term.

Keywords: Spinal cord injury, Functional electrical stimulation, Arm and leg cycling, Training, Walking

Introduction

One of the most debilitating results after spinal cord injury (SCI) is the impairment of walking. Walking is a complex task that involves the integration of several mechanisms, one of these being the ability to coordinate muscle activation between two legs [1]. Coordination is also seen between the upper and lower limbs and appears to influence the modulation of reflexes within the spinal cord [2]. Dietz [1] has hypothesized that functional, task-dependent neural pathways exist between the neural circuits that coordinate upper and lower limb muscles. These pathways play a role in regulating Hoffman (H-) reflexes and cutaneous reflexes during walking. [3]

In Canada, it is estimated that 85,556 [4] people live with SCI. Contusion, compression, or transection to the spinal cord can result in a loss of sensory and motor function, paralysis, and even loss of autonomic function [5, 6]. Depending on the severity of the damage, SCI can be classified into complete and incomplete [7].

It has also been suggested that the central pattern generator (CPG) within the spinal cord plays a primary role in generating the rhythmic movement of the lower limbs seen during walking [8]. Yang et al. [9] provided evidence of this innate mechanism (i.e., CPG) in infants, in which the underdeveloped corticospinal pathways can be compared to the impairments of sensorimotor pathways in individuals with SCI.

Considering the rhythmic movements generated by the CPG and intralimb coordination within the spinal cord, various treatment techniques have been used to improve walking after SCI. In particular, Alvarado Pacheco et al. [10] were the first to use a combination of functional electrical stimulation (FES)-assisted arm and leg cycling and achieved encouraging results, demonstrating improvements in over ground walking speed, balance, changes in leg muscle activation, and reduced hyperactivity of the H-reflex.

The goal of this study was to: 1) determine the retained effects of FES-assisted arm and leg cycling 6 months or more after 12 weeks of daily 1 hour training sessions; and 2) to determine the effects that FES-assisted leg cycling without the arms have on improving sensory and motor function, over ground walking speed, balance, and reduction in hyperactivity of the soleus H-reflex in volunteers who have sustained incomplete SCI (iSCI). It was hypothesized that participants would show retained improvements in over ground walking > 6 months post FES-assisted arm and leg cycling and that upper limb cycling would better enhance over ground walking when combined with leg cycling compared to leg cycling alone.
Materials and Methods

Three adult males and 1 adult female participated in the 6–24 month post FES-assisted arm and leg training follow up assessments. To date, two adult male volunteers out of the anticipated total of 6 have fulfilled the FES-assisted leg cycling without the arms study inclusion criteria. These participants were also part of the FES-assisted arm and leg cycling study 12 to 24 months earlier. All participants had a chronic iSCI sustained more than 2 years before the study. Participants provided written, informed consent to the study protocol approved by the University of Alberta Human Research Ethics Board.

A FES leg ergometer (ERGYS 2, Therapeutic Alliances, Inc. Fairborn OH, USA) was used for one hour of training, 5 days a week, for 6 weeks. The quadriceps, gluteus maximus, and hamstring muscles were electrically stimulated via 2 surface electrodes on each muscle. Quadriceps were stimulated at the proximal end towards the lateral side and distally, slightly medial of the patella to produce knee extension. Gluteus maximus were simulated lateral to the posterior superior iliac spine and medially of the greater trochanter on the distal aspect to aid in hip extension. The hamstrings were stimulated proximally on the medial aspect and distally at the midline on the posterior aspect of the thigh to assist in knee flexion. A target speed was held constant throughout the training period and was selected to be one level higher than the participant was able to pedal. Cycling resistance was then increased on the ergometer manually as the training period advanced in order to further challenge the participants. The results collected from clinical and electrophysiological assessments were used to monitor changes throughout the study. The results after 6 weeks of training were used to analyze the significant role of arm involvement in FES-assisted leg cycling training in comparison to FES-assisted arm and leg cycling.

To assess the retention of gains obtained by 12 weeks of FES-assisted arm and leg cycling, sensory and motor scores were obtained using the ASIA Impairment Scale before the initiation of training (baseline), after 12 weeks of training, and > 6 months post training [12]. Balance measurements were recorded using the Berg Balance Scale and were conducted at the same assessment dates as the ASIA scores [13]. For FES-assisted leg training, these assessments were conducted pre-training and 6 weeks after training.

Walking speed and endurance were assessed using the 10 meter straight pathway and 6 minute walk along an 18.54 meter oblong track respectively [14].

All participants required hand held walking aids to safely support themselves during ambulation. The same walking aids used during daily activities were also used during assessments.

All statistical analyses of >6 months post FES-assisted arm and leg cycling were conducted using SPSS Statistics Version 20 (IBM Corp, NY, USA, 2011). Nonparametric Wilcoxon Signed Ranks tests were conducted to determine significance of sensory, motor, and balance scores at 95% confidence intervals. One-way analysis of variance (ANOVA) tests were performed on the walking tests and soleus H-reflex means at 95% confidence intervals.

For FES-assisted leg cycling participants, differences between each assessment from baseline were used to compare measurements. Due to the small sample size, the results were qualitatively compared to the same volunteers’ results obtained with FES-assisted arm and leg intervention after 6 weeks of training.

Results

Sensory evaluations >6 months post FES-assisted arm and leg cycling training was completed showed a range of -18 point (losses) to +13 point (improvements) in sensory function according to the ASIA Impairment Scale compared to pre-training. Wilcoxon Signed Ranks Tests showed changes from baseline to >6 months post training (p=0.715) to not be statistically significant (see Fig. 1).

Motor function assessments at > 6 month follow up compared to pre-training indicated losses of 3 points in motor function and improvements up to 7 points. Wilcoxon Signed Ranks Tests showed that differences from baseline to the > 6 month follow up assessments (p=0.273) were not statistically significant.

Balance scores >6 months post training had completed showed differences compared to baseline ranging from losses in balance of 2 points to improvements up to 15 points. After performing Wilcoxon Signed Ranks Tests, >6 month follow up differences from baseline (p=1.00) were shown not to be statistically significant.
Ten meter walking speed assessments >6 months post training had completed had a mean of 0.72±0.28m/s, compared to 0.55±0.21m/s at baseline. Six months post training assessments showed improvement differences ranging from 0.02 to 0.25m/s in walking speed from baseline. These changes were not statistically significant (ANOVA, p=0.483).

Six minute walking speed assessments >6 months post training had a mean of 193.66±61.31m, compared to 231.28±47.00m after 12 weeks of training and 190.19±61.32m at baseline. Six months post FES-assisted arm and leg training completed showed retained improvements ranging from 64.62m to 65.15m compared to baseline. A one-way ANOVA found these differences were not statistically significant (p=0.518; table 1)

Six months after completion of FES-assisted arm and leg cycling, the mean peak to peak amplitudes of the soleus H-reflex at 10% of the maximal stimulation intensity were 2.1mV at rest and 2.3mV at 20% MVC. Compared to baseline, >6 month follow up differences ranged from 0.1mV to 3.0mV. A one-way ANOVA showed differences at rest (p=0.771) and those with 20% MVC facilitation (p=0.637) not to be statistically significant.

Sensory evaluation scores of FES-assisted leg cycling without the arms 6 weeks after training showed improvements in both subjects with improvement differences of 0 and 4 compared to baseline. When compared to improvements attained from baseline to 6 week assessments after arm and leg cycling, improvement differences were 0 and 12.

Motor function assessments for FES-assisted leg cycling without arms showed improvement differences of 2 and 3 from baseline to the 6 week assessments. Arm and leg cycling from baseline to 6 weeks after training showed differences of 0 and 1.

Balance scores from baseline to 6 weeks after leg cycling without arms showed improvements of 2 and 6 points. When compared to arm and leg cycling training, improvements from baseline to 6 week assessments showed differences of 0 and 8.

Ten meter walking speed assessments after FES-leg cycling without the arms showed a mean of 0.72±0.37m/s after 6 weeks of training compared to 0.72±0.40m/s at baseline. Compared to FES-assisted arm and leg cycling, 6 week differences to baseline showed improvements ranging from 0.05 to 0.08m/s and a mean of 0.67±0.24m/s.

Six minute walking speed assessments for FES-leg cycling without the arms showed a mean of 220.00±56.34m after 6 weeks of training compared to 165.79±18.11m at baseline. Compared to FES-assisted arm and leg cycling, 6 week differences to baseline showed improvements ranging from 3.14 to 19.79m and a mean of 203.00±48.15m.

Soleus H-reflex assessments for FES-assisted leg cycling without arms showed a mean of 0.2mV at rest and 0.3mV with 20% facilitation after 6 weeks of training compared to 0.5mV at rest and 0.7mV at facilitation during baseline testing. When compared to arm and leg cycling, 6 week differences to baseline
showed differences ranging from 0.2 to 0.4mV at rest and 0.7 to 1.4mV at 20% facilitation.

Discussion

The goal of this study was to determine the retained effects of FES-assisted arm and leg cycling >6 months after a 12 week training program. In addition, this study attempted to determine the significance of incorporating arm cycling with leg cycling to improve over ground walking. It was hypothesized that gained benefits would be retained after training was completed. It was also hypothesized that the effects gained during leg cycling without the arms would not be as significant when compared to arm and leg cycling.

Overall, retained effects were seen >6 months after training was complete compared to pre-training baseline measurements. Although FES-assisted leg cycling without the arms was shown to improve motor scores, balance, walking speeds and endurance, and decrease soleus H-reflex excitability in both participants, these outcomes were not as substantial when compared to FES-assisted arm and leg cycling. FES-assisted arm and leg cycling may enhance ascending and descending motor and sensory neural coupling between the upper and lower limbs leading to the greater improvements and retained gains after this particular training paradigm [1,10, 11].

Conclusions

These results demonstrate the effects of arm cycling on improving the clinical and electrophysiological outcomes of iSCI individuals when combined with FES and leg cycling. These effects can be retained even after at least 6 months post training. Although further investigation is necessary, these preliminary findings suggest that active arm involvement plays a role in the rehabilitation of walking after iSCI. If the significance of arm involvement in FES-assisted leg cycling can be determined with enrollment of more participants, results can be compared to the improvements seen after treadmill locomotor training in the future.

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References


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