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ORIGINAL REPORT

FEASIBILITY OF FUNCTIONAL ELECTRICAL STIMULATED CYCLING IN SUBJECTS WITH SPINAL CORD INJURY: AN ENERGETICS ASSESSMENT

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Objective: **To determine the functional electrical stimulated (FES) cycling volume necessary to reach the recommended weekly exercise caloric expenditure of 1000–2200 kcal in FES-trained subjects with paraplegia.**
Subjects: **Eight (7 males, 1 female) FES-trained subjects with traumatic motor and sensory complete paraplegia (AIS A, lesion level between Th3 and Th9) of at least 3 years duration were included.**
Methods: **Subjects performed an FES-training session at the highest workload they were able to sustain for 60 min. During the training session respiratory gas exchange was measured, which allowed the calculation of mean fat and carbohydrate oxidation rates, and of total energy expenditure by means of indirect calorimetry.**
Results: **Subjects revealed a mean energy expenditure of 288 (standard deviation 104) kcal/h. This corresponded to a mean oxidation rate of 49.5 (standard deviation 35.2) g/h for carbohydrate and 8.5 (standard deviation 8.4) g/hour for fat. Thus, 4–8 hours of FES-cycling are necessary to reach the recommended weekly exercise caloric expenditure of 1000–2200 kcal.**
Conclusion: **FES-cycling appears to be a feasible and promising training alternative to upper body exercise for subjects with spinal cord injury. Four to 8 h of FES-cycling are necessary to reach the recommended weekly exercise caloric expenditure that seems to be essential to induce persistent health benefits.**

Key words: spinal cord injury; energy expenditure; exercise; indirect calorimetry.

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INTRODUCTION

Individuals with a complete spinal cord injury (SCI) exhibit reduced physical activity due to a paralysis-based loss of motor function (1, 2). As a consequence, low cardiorespiratory fitness levels are common in subjects with SCI and lead to inactivity-related co-morbidities, such as hyperlipidaemia, obesity, diabetes and cardiovascular disease (3). In fact, during the past years cardiovascular disease has been one of the leading causes of mortality in people with chronic SCI (4). Thus, regular physical activity appears to play a key role in reducing health-related risk factors and complications in this population (5).

Physical activity in people with complete SCI is limited and is restricted mainly to upper body exercise, where only a small muscle mass is involved. In addition, up to 64% of subjects with paraplegia (6, 7) reported upper extremity (mainly shoulder) pain, which may impact on upper body exercise performance. Functional electrical stimulated (FES) cycling may provide a suitable alternative involving a large muscle group, and concurrently prevent additional exercise-induced loads being imposed on the upper extremities.

The effect of FES-cycling on the cardiovascular system of subjects with SCI has been investigated in several studies (e.g. 1, 8–11). Although beneficial effects of FES-cycling on cardiopulmonary fitness are undisputable, the precise frequency, intensity and duration of FES-cycle training required to minimize health risks remains unclear, and training regimes have varied widely (12). However, commonly accepted recommendations to reduce health risks are for at least 30 min of moderate daily activity (3, 13). Some studies (13–15) recommend a minimal weekly training volume, with energy expenditures of approximately 1000–2200 kcal, whereas others suggest that more benefits may be expected with higher caloric expenditure (15, 16).

The aim of the present study was to determine the FES-cycling volume necessary to reach the generally recommended weekly exercise caloric expenditure of 1000–2200 kcal (13, 15) in FES-trained subjects with paraplegia and to estimate how feasible and realistic such a training regime might be for a broader population with SCI.

METHODS

Subjects

Eight (7 males, 1 female) healthy FES-trained subjects with traumatic motor and sensory complete paraplegia (AIS A) of at least 3 years duration participated in the study. Detailed information about anthropometrical data and impairment are presented in Table I. Subjects

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were all part of a multicentre FES-cycling study described in detail elsewhere (12) and gave their written informed consent to participate in the study, which was approved by their respective ethics committee: the ethics committees of the Southern General Hospital and the Faculty of Biomedical and Life Sciences at the University of Glasgow, UK (for subjects tested in Glasgow) and the ethics commission of Kanton Luzern, Switzerland (for subjects tested in Nottwil). Ethics approval was obtained prior to the start of the study.

Equipment and experimental procedure

At the end of a 12-month high-volume FES-cycling programme described by Berry et al. (12) a 60-min home-training session performed by each subject was monitored. For this purpose, subjects were sitting on an individually adapted recumbent tricycle (Inspired Cycle Engineering Ltd, Cornwall, UK) mounted on a training roller (Flow Ergotrainer Tacx, Wassenaar, The Netherlands) and performed their habitual training at the highest workload they were able to sustain for 60 mins. In order to provide muscle contraction for cycling, quadriceps, gluteal and hamstring muscles were stimulated bilaterally via surface electrodes by means of a Stanmore Stimulator (17). During the whole training session oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were recorded breath by breath with a portable ergospirometric system (Metamax, Cortex Biophysic GmbH, Leipzig, Germany), which was calibrated according to the manufacturers' instructions prior to each test.

Carbohydrate and fat oxidation rates were calculated based on VO_2 and VCO_2 data according to the formulae of Péronnet and Massicotte (18). Energy expenditure from fat and carbohydrates were converted to kilocalories per h (kcal/h) by multiplying the oxidation rate of fat by 9.75 (18) and the oxidation rate of carbohydrate by 4.15 (19).

Statistics

Data are presented as means and standard deviations (SD).

RESULTS

Subjects had a mean energy expenditure for 60 min FES-cycling exercise of 288 (SD 104) kcal/h. Seventy-one percent of the total amount of energy was delivered by carbohydrate oxidation and 29% by fat oxidation. This corresponded to oxidation rates of 49.5 (SD 35.2) g/h for carbohydrates and 8.5 (SD 8.4) g/h for fat. Thus, approximately 4–8 hs of FES-cycling are necessary to reach an energy expenditure of 1000–2200 kcal.

Table I. *Subjects' characteristics*

Sex/age (years)	Height (cm)	Weight (kg)	Time post-injury (years)	Lesion level	AIS
M/43	186	67	26	T9	A
M/39	177	83	9	T3	A
M/40	184	70	11	T4/5	A
F/35	162	64	16	T7	A
M/57	173	85	9	T4	A
M/44	170	76	4	T4	A
M/38	183	73	12	T5	A
M/44	173	75	20	T7	A
Mean (SD) 42.5 (6.7)	176.0 (8.1)	74.1 (7.3)	13.4 (7.0)		

SD: standard deviation; T: thoracic; AIS: American Spinal Injury Association (ASIA) impairment scale.

DISCUSSION

The results of the present study show that for FES-trained subjects with paraplegia between 4 and 8 h of intense FES-cycling are necessary to reach the postulated minimal weekly energy expenditure of 1000–2200 kcal in order to reduce health risks (14, 15). Interestingly, the calculated 4 hours per week seems to correspond closely to the 30 min of moderate daily activity proposed in former studies for older able-bodied persons (13) as well as for subjects with SCI (3). In other words, FES-cycling appears to be a feasible and promising training alternative to upper body exercise for subjects with a SCI. FES-cycling may help to reduce training induced overload of upper extremities and concomitant shoulder pain (6, 7). In addition, FES-cycling exercise is also possible in subjects with tetraplegia (20), where, dependent on lesion level, upper body exercise is not possible or is extremely limited.

Moreover, FES-cycling of the lower limbs involves large muscle groups and creates a higher cardiorespiratory and musculoskeletal stress compared with isolated arm exercise. Although the absolute cycling power output of FES-cycling was found to be very low in untrained (21) and trained FES cyclists (12), the metabolic cost is approximately 3.5 times higher than for cycling exercise in able-bodied persons (22). In terms of energy expenditure this is advantageous, although a higher level of work efficiency for mobility and recreation purposes would be desirable.

Despite the numerous potential health benefits of FES-cycling, including improved cardiopulmonary fitness (12), enhanced insulin sensitivity (23) and positive effects on bone loss (24), one should bear in mind that FES-cycling is quite time-consuming and requires some fundamental skills. Before transferring to the FES-cycle, electrodes have to be placed and connected to a power source, and after the training session have to be disconnected, which, depending on the person's motor skills, may make the presence of a caregiver necessary. Such circumstances may negatively influence training compliance. However, in a recently published FES-cycling study (12) mean compliance was reported to range between 75% and 91% (corresponding to a mean of 3.7 training sessions per week of 58 min duration each) over a one-year training period. It is of interest that these data accurately correspond to the 4 h calculated in the present study and seem to cover the basic requirements to reduce health-related risk factors and complications. As more benefits may be expected with higher caloric expenditure (15, 16), it would be desirable for training duration and intensity to be increased further. Given that preparation (attaching and removing electrodes, etc.) is quite time-consuming it may be advantageous and less time-consuming to exercise less frequently but for longer durations (e.g. 3 times 90 min instead of 6 times 45 min per week). In addition, it was postulated by Kraus et al. (25) that for positive effects on, for example, plasma lipid and lipoprotein concentrations, exercise volume rather than exercise intensity seems to be more important. Beside the practical considerations, this finding additionally supports the recommendation of fewer but more prolonged training sessions in order to achieve a higher training volume.

A promising alternative to further enhance energy expenditure and cardiorespiratory fitness in subjects with SCI might be a combination of voluntary upper body and FES-induced leg exercise, such as FES-rowing. A review (26) reported average peak VO_2 values for FES-rowing of 1.98 l/min compared with 1.05 l/min during FES-cycling, which underlines the higher physical and caloric demands of FES-rowing compared with FES-cycling. However, excessive FES-rowing exercise may lead to overuse and concomitant pain of the upper extremities (mainly the shoulder), which was found to be a major problem in subjects with SCI (6, 7).

For the future it might also be worthwhile considering a broader application of FES-cycling in patients with incomplete SCI or in subjects with tetraplegia (20) as an alternative training mode in order to enhance physical fitness and energy expenditure in this population, which is especially at risk for overweight and obesity (27). Moreover, beyond the scope of this paper, the application of FES also seems to be gaining a more important role in rehabilitation and regeneration after SCI (28).

In conclusion, FES-cycling appears to be a feasible and promising training alternative to upper body exercise for subjects with SCI. Four to 8 h of FES-cycling are necessary to reach the recommended weekly exercise caloric expenditure of 1000–2200 kcal, which seems to be essential to induce persistent health benefits.

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