Original Article

Interval training program on a wheelchair ergometer for paraplegic subjects

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Background: Various combinations of training intensity, duration and frequency are often proposed to people with spinal cord injuries in order to improve their fitness. However, no consensus about a specific training program has been reached for such a population.

Objective: This study investigated the effects of a short interval training program specifically designed for patients with spinal cord injuries.

Methods: Paraplegic men performed 30-min wheelchair ergometry three times per week, for 4 weeks. Maximal dynamic performance and endurance capacity were studied before and after the training program with an incremental test (10 W/2 min) until volitional fatigue and a constant work rate test, respectively. Cardiorespiratory responses were continuously studied during each of these tests.

Results: Training induced significant improvement in maximal tolerated power (+27.9%), and in peak oxygen consumption ($\dot{V}O_2$, +18.5%). After training the subjects were able to maintain the load applied during the constant test (total mechanical work +210.7%), for a significantly longer time. The heart rate, $\dot{V}O_2$ and ventilation values observed when the volunteers ended their first constant load test were significantly higher (+10%, +10%, +40% respectively) than those obtained after a similar time period during the second constant load test which was performed after the training program.

Conclusion: After this short training period, with an appropriate combination of different types of training, duration, intensity and frequency exercises, we observed a significant improvement in the fitness level and endurance capacity of paraplegic subjects.

Spinal Cord (2001) **39**, 532–537

Keywords: interval training; paraplegia; physical fitness and exercise prescription

Introduction

Upper limb exercise is of importance for disabled persons using a wheelchair in order to maintain an adequate level of fitness.¹ Due to their lesions and sedentary lifestyle these people are usually exposed to degenerative muscular processes and this mainly results in decreased lean body mass, lower aerobic capacity, and alters cardiorespiratory responses to physical exercise.² Exercise conditioning appears to be a good way to maintain and increase the physical fitness of such patients.¹ Several kinds of training programs for these persons have been investigated (for review eg³). It seems that the general endurance training guidelines for the able population are appropriate for the spinal cord injured (SCI) population. However, specific

recommendations about the type, intensity, and frequency of the training exercise for paraplegics are not established and there is a discrepancy among the training programs proposed to SCI persons. In the majority of cases, an arm-crank ergometer has been used.^{4–8} However, such training has a drawback because it does not reproduce the movements required for moving a wheelchair. In addition, the mechanical efficiency is higher for arm-crank ergometer than for wheelchair ergometer.^{9,10} In a few studies, a wheelchair ergometer was used to estimate the efficiency of specific endurance training protocols in disabled persons.^{11–14} According to these studies the exercise duration ranged from 4 to 24 weeks with a frequency of 2–3 sessions per week. Although the duration of exercise inversely varies with the intensity, the intensity threshold required to induce training benefits with wheelchair

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users was determined at 70% of the maximal heart rate¹¹ and for a minimal duration of 20 min.

Jimenez *et al*¹⁹ reported some interesting data using the Square Wave Endurance Exercise Test (SWEET) with able-bodied subjects. Six weeks of training with an exercise frequency of three times per week and with duration of 45 min for each session induced a significant increase both in $\dot{V}O_2\text{max}$ (+20 to +40%), and in endurance capacity (+34 to +75%). The SWEET concept has successfully been performed with patients suffering from chronic airway obstruction²⁷ and with patients after heart transplantation²⁸ but it has never been proposed to the SCI population. Recently, this training method has been studied with able-bodied subjects on a wheelchair ergometer,¹⁵ and the results showed significant improvements of the maximal power output (+63%), peak $\dot{V}O_2$ (+33%), O_2 pulse (+25%). Consequently, in order to prevent SCI persons from undergoing functional degeneration, an interval training program based on the SWEET was investigated. In order to respect the minimal training prescriptions and to maintain the subject's motivation the duration of the SWEET program was reduced to 4 weeks and 30 min per session. Too long a program might have been discouraging.

Therefore the purpose of the present study was to investigate the effects of specific interval training over a 4-week period in SCI persons. Physiological responses of incremental exercise tests to exhaustion and constant work rate tests on wheelchair were compared, before and after training, to examine the effectiveness of this interval training on wheelchair.

Materials and methods

Subjects

Five males (age = 27 ± 8.1 years (mean $\pm$ SD), weight = 65 ± 14.5 kg, and height = 178 ± 5.8 cm) participated in this study and gave their written informed consent. Our local ethical committee has approved this study. All of our volunteers have been paraplegics for almost 2 years with a stable lesion level between Th6 and L4. They were physically active without any specific upper-body training. According to the American Spinal Injury Association (ASIA) classification rules they were classified as ASIA A. Their characteristics are presented in Table 1.

Table 1 Characteristics of the subjects

Subject	Age (years)	Weight (kg)	Lesion level	Trouble
S1	18	50	Th6	spastic
S2	24	85	Th12	spastic
S3	40	52	Th12	spastic
S4	25	70	Th7	spastic
S5	28	70	L3-L4	spastic

Tests performed

Two different kinds of maximal tests were performed, before and after training, at the same time of the day on separate days with the subjects using their own wheelchair. There was a progressive test performed according to previous studies^{15,16} and a constant load test. The progressive wheelchair test started with a rest of 6 min on the wheelchair ergometer in order to stabilise the different cardiorespiratory variables. This was followed by a 2 min warm up, which was performed at a residual friction power of 15 W. The load was then increased by 10 W every 2 min until exhaustion. The highest load that could be maintained with a constant speed for 2 min was taken as maximal tolerated power (MTP).

Prior to the beginning of the constant load test, all subjects rested for 6 min and then performed a 2 min warm up at 50% of their MTP intensity. The load was then set at the MTP determined before training. The time to exhaustion was determined before and after the training period ('Tlim' and 'new Tlim', respectively) and the total mechanical work (TMW, kJ/kg) was then calculated. Exhaustion was reached when the subject was unable to maintain the speed imposed, despite strong verbal encouragement. The effects of training were estimated by comparing both TMW and the cardiorespiratory responses observed at Tlim during the post-training test.

All tests were performed at a constant speed corresponding to 1.25 ms^{-1} of linear displacement. The tests ended when the speed fell under 1.10 ms^{-1} for 15 s and could not be increased despite verbal encouragements.

Measurements

During each test, expired gases were sampled and analyzed with a breath-by-breath gas analyzer system (Medical Graphics type CPX/D, MSE, Strasbourg, France). The gas analyzer system was calibrated before each subject session using gases of known concentrations. All ventilatory variables were averaged every 15 s. The respiratory and metabolic parameters monitored included ventilation ($\dot{V}E$, l min^{-1}), respiratory rate (f , breaths min^{-1}), tidal volume (VT , l), oxygen uptake ($\dot{V}O_2$, ml min^{-1} and ml min kg^{-1}) and CO_2 production ($\dot{V}CO_2$, ml min^{-1}). Heart rate (HR, b min^{-1}) was continuously monitored during the test by telemetry (PE 4000 sport tester, Polar, Finland). Respiratory exchange ratio ($\dot{V}CO_2/\dot{V}O_2$), and oxygen pulse ($\dot{V}O_2/\text{HR}$, ml b^{-1}) were then calculated.

Peak oxygen uptake was determined according to the following criteria: (i) HR was maximal HR $\geq [(220 - \text{age}) - 10]^{17}$; (ii) when possible, the higher load was correctly performed without an increase of oxygen consumption; (iii) in all cases respiratory exchange ratio was above 1.0.

Both the training and tests were performed with the same ergometer (VP100H- HEF tecmachine, Andrezieux Boutheon, France) using the personal wheelchair

of each subject (Figure 1). This ergometer¹⁸ has a single motorised roller with enslaved braking, and an electromagnetic system. This system is controlled by specific software which allows the subject to work at a pre-determined speed and to record the resulting torque. The calculation of this torque simultaneously takes into account, the braking force really applied, the instantaneous speed of the roller and the positive variation of the speed. During the exercise the subject can see all the information concerning speed and power output through a control screen.

Training period

Each subject undertook 4 weeks of interval wheelchair training, three sessions per week and for 30 min per session. The training program based on the SWEET¹⁹ consisted of six successive workouts of 5 min each. During each workout, a 4-min period of moderate exercise, named 'base' level, was followed by a 1-min period of intense exercise, named 'peak' level. Initially, the base is set at 50% of the MTP and the peak at 80% of the MTP obtained at the maximal test before training. The intensity of each training period was determined to lead up to a maximal heart rate at the end of the sixth 'peak'. The peak and the base loads were alternately readjusted (+10% of the peak level) when the HR registered at the end of the session was at least 10 b min⁻¹ lower than peak HR. Hence, each training session corresponded to the maximal endurance intensity that the subject was able to maintain during 30 min.

TMW (in kJ kg⁻¹) after each of the training sessions and constant load tests was calculated. All tests, including the training session were performed under medical supervision.

Statistical analysis

All values are given as median and extreme values and are also expressed in per cent changes obtained after

training. The delta per cent ($\Delta\%$) changes are calculated as the mean of the individual variation ((value after training - value before training)/value before training)* 100). Training effects were analyzed with a Wilcoxon test. Statistical significance was set at the 0.05 level.

Results

Attendance of the volunteers at the training sessions was outstanding. All of our volunteers completed the training. The program was perfectly tolerated by the subjects without excessive fatigue or shoulder pain.

Comparisons of peak values obtained during maximal incremental tests before and after training are presented in Table 2. Wheelchair training produced a significant increase in MTP (+27.9%; $P<0.05$), in peak $\dot{V}O_2$ (+18.5%; $P<0.05$), peak $\dot{V}CO_2$ (+15.9%; $P<0.05$), O_{2p} (+23.9%; $P<0.05$). Peak heart rate was significantly lower after the training (results expressed as the median and extreme values in parenthesis: 191 (176–195) vs 183 (163–191) b min⁻¹, -4.3%). The per cent changes in VE (64 (47–78) vs 78 (56–86) l min⁻¹, +15.9%), and in VT (1.6 (0.9–2.1) vs 1.6 (1.1–2.1) l, +12.3%) were not significantly different. Respiratory rate was unchanged (43 (33–59) vs (34–53) breaths min⁻¹).

Table 3 shows the physiological responses observed during the constant load test before and after training. No significant differences were observed between Tlim and 'new Tlim' for the value of peak HR (181 (170–194) vs 189 (170–198) b min⁻¹), and O_{2p} (8.8 (6.2–10.5) vs 9.5 (6.4–10.9) ml b⁻¹). However, after training TMW (0.3 (0.10–0.33) vs 0.52 (0.18–0.85) kJ kg⁻¹, +210%) and peak values of $\dot{V}O_2$ (23.7 (20.2–32.1) vs 25.3 (21.5–36.2) ml min kg⁻¹, +9%), VE (71 (50–92) vs 84 (60–98) l min⁻¹, +15.5%) and the VT (1.6 (0.9–1.9) vs 2 (1.1–2.1) l, +13.3%) were

Figure 1 Wheelchair fixed on the ergometer used for the training and the testing sessions

Table 2 Maximal progressive test

	Pre-training	Post-training
$\dot{V}O_2$ peak (ml min kg ⁻¹)	21 (17–33)	24 (22–36) ^a
MTP (W)	45 (35–45)	55 (45–65) ^a
HR peak (b min ⁻¹)	191 (176–195)	183 (163–191) ^a
$\dot{V}E$ peak (l min ⁻¹)	64 (47–78)	78 (56–86)
O_{2p} (ml b ⁻¹)	7.9 (4.8–9.8)	9.9 (6–11.8) ^a

Results obtained at the end of the maximal progressive test concerning the following variables: pre- and post-training peak oxygen uptake ($\dot{V}O_2$ peak), maximal tolerated power (MTP), peak heart rate (HR peak), peak ventilation ($\dot{V}E$ peak), oxygen pulse (O_{2p}). Results are expressed as their median and extreme values in parenthesis. ^aSignificantly different ($P<0.05$) compared with the pre-training values

Table 3 Constant load test

	Pre-training Tlim	Post-training Tlim	New Tlim
Tlim (s)	187 (158–383)	187 (158–383)	600 (345–1320) ^b
$\dot{V}O_2$ (ml min kg ⁻¹)	23.7 (20.2–32.1)	21.5 (18.9–27.7) ^a	25.3 (21.5–36.2) ^{b,c}
HR (b min ⁻¹)	181 (170–194)	164 (159–176) ^a	189 (170–198) ^b
$\dot{V}E$ (l min ⁻¹)	71 (50–92)	52 (36–65) ^a	84 (60–98) ^{b,c}

Pre- and post-training oxygen uptake ($\dot{V}O_2$), heart rate (HR), ventilation ($\dot{V}E$), obtained at the end of the test at pre-training (Pre) performance time (Tlim), at the corresponding time (Tlim) during the post-training test (Post) and at the end (new Tlim) of the post-training test. ^aSignificantly different ($P < 0.05$) compared with the pretraining values. ^bSignificantly different ($P < 0.05$) compared with the posttraining values at Tlim. ^cSignificantly different ($P < 0.05$) compared with the pretraining values at Tlim

significantly higher ($P < 0.05$) at 'new Tlim' compared with the corresponding data registered at Tlim. The comparison of the cardiorespiratory data at Tlim before and after training showed significant ($P < 0.01$) decreases of HR (181 (170–194) vs 164 (159–176) b min⁻¹, -10%), $\dot{V}O_2$ (23.7 (20.2–32.1) vs 21.5 (18.9–27.7) ml min kg⁻¹, -13%), $\dot{V}E$ (71 (50–92) vs 52 (36–65) l min⁻¹, -34.5%). Only VT (1.6 (0.9–1.9) vs 1.7 (1.2–2.1) l, +13.3%) was significantly higher ($P < 0.05$) after training.

Between the first and the last training session TMW was improved by 32% (0.93 (0.76–1.25 vs 1.30 (0.95–1.56) kJ kg⁻¹, respectively; $P < 0.01$).

Discussion

A 4-week Square Wave Exercise Endurance Training program performed on wheelchair users induced significant improvements in maximal tolerated power, peak $\dot{V}O_2$, and physical working capacity. In addition, after training the cardiorespiratory and ventilatory responses observed during the constant load test at the pre-training performance time seem to indicate that the same exercise intensity is less stressful. These improvements are in accordance with the results of previous studies involving upper body training in disabled persons.^{11–13,20,21}

In such specific upper body training, many respiratory accessory muscles may play a role in the propulsion of the wheels. Moreover, it seems that training slowed down the development of respiratory fatigue. Therefore, the subjects were able to maintain a high ventilation rate for a longer time, as it was observed during the post training constant workload test.

Another central effect of training concerns the significant increase in O_2p . This could reflect an increase in stroke volume or in the capacity of oxygen

transport. During arm training, the exercise stimulus may not be strong enough to lead to central adaptations.²² In addition, spinal lesions disturbs sympathetic vasomotor tone and venous return.²³ This could limit stroke volume, cardiac output and the degree of stress placed upon the heart during the arm exercise. It can be speculated that the oxygen transport is improved by training.

Moreover, our results indicate significant improvement of propulsion efficiency. Such a phenomenon has previously been reported in lower-limb disabled persons who had followed a training program with little or no change in peak $\dot{V}O_2$.^{21,24,25} In both of these studies^{21,24} the decrease in submaximal heart rate was accompanied by a decrease in $\dot{V}O_2$ at the same power output. Because our subjects are experienced in wheeling, the significant decrease in $\dot{V}O_2$ observed at Tlim during the constant load test after training could be attributed to an improvement of muscular efficiency. This could be due to an improvement in oxidative metabolic capacity, oxygen extraction and muscle blood flow.²²

The main advantage of our training program is related to its specificity. Firstly, the ergometer used for training and testing has been specifically designed for the use of the volunteers personal wheelchair. This allowed us to respect the characteristics of wheelchair propulsion and the wheelchair adjustment of each subject. Hence, the subjects got quickly and easily accustomed to this type of exercise.

The usual training prescription for wheelchair users includes minimal exercise duration of 20 min and intensity corresponding to 70% of peak $\dot{V}O_2$. Below these levels the effect of training would be reduced.¹¹ Our sessions had the advantage of being planned over a short period of time. In order to assure effective exercise intensity, the sessions are organized to elicit the maximal endurance capacity of the subject at each training session. All the controls (HR, speed, work bout duration) conducted during each training session could also explain the efficiency of our training program.

Secondly, there are large inter-individual discrepancies in the SCI population, due to the level and completeness of the spinal cord lesion, the age and training status of the volunteers.²⁶ Such discrepancies may hamper the effectiveness of a standardised training program. Therefore the possibility to individualise the training program according to the subject's characteristics is crucial when working with the SCI population. This is especially true for subjects with a lesion above Th5 level who may exhibit a sudden episode of extremely high blood pressure due to an autonomic dysreflexia. Therefore, it is important to monitor the blood pressure of high-level SCI persons especially during the initial training session. Because of the possibilities of intensity adjustment, the present training program enabled us to respect the individual characteristics.

Indeed, the physiological and metabolic responses to constant load exercise compared with the SWEET are different. Constant high-level exercise mainly challenges the metabolic acidosis tolerance, because the exercise intensity is above the ventilatory threshold, and is associated with a progressive increase in lactate. The resulting metabolic acidosis cannot be compensated.²⁹ However, during SWEET hyperventilation produces ventilatory alkalosis during and after the peak. In addition, the 4 min of the base stimulates neoglycogenesis, allowing the muscles to transform lactate into glucose. Therefore, lactates decrease and lactic acidosis is reduced.²⁷ The tailored SWEET exercise is performed using high energy expenditure under aerobic conditions and satisfactory homeostasis.³⁰ Applying this concept of SWEET training to wheelchair users seems to substantially improve their performance and fitness.

Conclusion

A 4 week program, upper arm training three times a week, with specific intervals is efficient in improving the maximal tolerated power and peak $\dot{V}O_2$ that could be considered a valid indicator of fitness level. Moreover this short training program improves endurance capacity. The present results clearly show that performance of a particular task will be less stressful after this kind of program training. This could result in greater independence and allow the pursuit of a more active lifestyle and help in the comprehensive rehabilitation therapy of spinal-cord injured paraplegics.

Acknowledgements

The authors thank the subjects for their enthusiastic and regular participation, and the technicians of the Service de Physiologie Clinique et des Explorations Fonctionnelles des Hôpitaux Universitaires de Strasbourg 67091 for their assistance. Appreciation is also extended to Virginie Sandrin for her help.

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