Biology of Sport, Vol. 23 N°3, 2006

PHYSIOLOGICAL RESPONSES TO GRADED EXERCISE TEST IN YOUTHS WITH SPASTIC TETRAPLEGIA SUBJECTED TO UPPER EXTREMITY TRAINING

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Abstract. The aim of the study was to assess the effects of exercise therapy of moderate intensity on cardiorespiratory functions in youths suffering from tetraplegia in cerebral palsy. Eight schoolboys, aged 17.5±0.3 years, suffering from spastic tetraplegia were studied. They were subjected to graded cycle ergometer exercise, adapted for upper extremities, until exhaustion. The following variables were recorded: tolerated load, total work output and cardiorespiratory indices. Exercise therapy lasted two weeks and consisted of cycle ergometer arm exercises at a load equal to 75% HRmax. Every session lasted 20 min, once daily. Mean maximal oxygen uptake increased from 26.4 to 35.9 $ml \cdot kg^{-1}$ and minute ventilation at maximum load from 48.0 to 68.0 breaths $\cdot$ min^{-1}, all differences being significant ($p<0.01$).In conclusion, the therapy brought about a marked increase in power output, from 1.69 $W \cdot kg^{-1}$ to 2.28 $W \cdot kg^{-1}$ (pre- and post-training, respectively), evidencing improvements in mechanical conditions of muscle work and in aerobic capacity. ***(Biol.Sport 23:283-290, 2006)***

Key words: Tetraplegia – Physical capacity – Therapeutic training

Introduction

Primordial reflex mechanisms in subjects suffering from spastic tetraplegia are not replaced by cortical control of body posture and equilibrium. Contractured muscles cannot participate in dynamic movements which results in impairment of locomotor and of precise manipulatory functions.

Many authors reported physical capacity and physiological responses to exercise in patients with cerebral palsies and despite great between-population differences oxygen uptake data were highly consistent [2,3,7,14,16,18]. It should be emphasised that lower work output in relation to oxygen uptake observed in subjects with cerebral palsy, compared with their healthy mates, was due rather to

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the degree of spasticity of the former than to their relative muscle mass [9,11,15,19]. Diminished muscle strength has been long regarded as typical of spastic form of cerebral palsy but very rarely considered a therapeutic issue, although strength training was routinely applied to other diseases. Berg [1], Fernandez *et al.* (5), and Piskorz and Klimek-Piskorz [13] demonstrated that appropriate exercises improve the co-ordination and strength of respiratory muscles in youths with diplegia in cerebral palsy, as reflected by improved functional indices. Hutzler *et al.* [8] emphasise the impact of water exercises on the indices of vital capacity, tidal volume and chest amplitude. On the other hand, Berg [1] warned that exercises performed under external load, aimed at increasing muscle strength, might intensify spasticity and, in effect, to minimising the therapeutic effects.

The aim of the study was to assess the effects of exercise therapy of moderate intensity on cardiorespiratory functions in youths suffering from tetraplegia in cerebral palsy.

Materials and Methods

Subjects: Eight schoolboys, aged 17.5±0.3 years, suffering from spastic tetraplegia were studied. Their body height was 157±1,8 cm, body mass was 53.3±1.9 kg. They had adductive flexures at hip joints, contractures at knee joints and horse position of feet, repeatedly corrected surgically. Five subjects could move with the aid of two elbow crutches, 3 other ones could use only wheelchairs. All of them complained of difficulties when walking or performing routine job-related activities. The existing pelvic anteversion was compensated by increased lumbar and cervical lordoses and thoracic kyphosis, and by a relatively poor head stabilisation. The ranges of movement of the head, cervical spine, of flexion and extension of thoracic spine, and of lateral bends and rotation of lumbar spine were restricted. The subjects had elevated and protruded shoulders, chest in inspiration position and relatively weak abdominal muscles. The range of movement at the elbow joint was restricted, forearm was pronated, palms bent at wrist joints, metacarpal joints extended.

No medical objections to applying exercise tests were formulated with respect to cardiorespiratory functions.

Anthropometric measurements: Body height was measured in supine position with the use of anthropometer (Sieber Hagner, Switzerland), with an accuracy of 0.5 cm. Body mass was measured using Sartorius F 150 S 02-A scales (Germany) with an accuracy of 10 g.

Physiological procedures: Graded arm exercise on a cycle ergometer (Zimmermann, Germany) was applied to determine adaptation to physical loads. Split seat, its height and distance from the axis being adjustable, enabled setting the axis at the level of shoulder joints which, in turn, made the work position comfortable and almost full extension of arms in elbow joints. Knees were slightly bent, feet firmly set against footrest. An elastic backrest comfortably restricted back movements of the trunk.

The exercise begun at a load equal to 37.5 W which lasted 5 min and then was increased by 15 W every 1 min until exhaustion. Exercise sessions took place in the morning hours following a light breakfast and one-hour rest. Ambient temperature was 21±1ºC, relative humidity was 60%, air pressure was 1020 hPa, airflow was 0.2-0.4 m/s.

Respiratory parameters were continuously recorded with the use of spiroergotest device (Medikro, Finland), the printout being set for 30-s intervals, at rest, during the warm-up, graded exercise, and until 3 min post-exercise. The following variables were recorded: minute ventilation (V_E), oxygen uptake (VO_2) and carbon dioxide elimination (VCO_2), and heart rate (HR). From these, several indices were computed: respiratory quotient (RQ), ventilatory equivalent of O_2 ($V_{E}\cdot VO_2^{-1}$) and of CO_2 ($VE\cdot VCO2^{-1}$), oxygen pulse ($VO_2\cdot HR^{-1}$) and relative oxygen uptake ($VO_2\cdot kg^{-1}$).

Heart rate was recorded with the use of Sport - Tester PE-3000 (Polar, Finland) before starting the exercise, until 3 min after the last exertion had been discontinued. The results were averaged at 15-s intervals.

Exercise therapy: The therapeutic trainings were preceded by an introductory period lasting 2 days, during which the subjects familiarised themselves with using the device and with adjusting workout loads. Training sessions consisted of a no-load warm-up lasting 3 min followed by workout lasting 21 min at a load equal to 22.5-37.5 W and heart rate amounting to 120-130 bpm. The rate equal to 50 rpm was metronome-controlled. The loads applied in the consecutive training sessions were individually adjusted so as to attain 75% of the predetermined HRmax value. Heart rates were continuously recorded before and throughout the session until 3 min after the exercise had been discontinued. Training sessions took place every day for 14 days, during which all activities other than swimming and cycle ergometer trainings were recorded in detail. All experimental activities were conducted under identical conditions as described above. A physician and a qualified nurse provided medical care throughout the study.

Data analysis: Student's t-test for dependent data was used to assess the training-induced differences, the level $p\leq0.05$ being considered significant.

Results

Table 1
Resting levels of physiological variables recorded in boys with spastic tetraplegia (n=8) pre- and post-training

Variable	Pre-training	Post-training	Post-pre difference (%)
V_E ($l \cdot min^{-1}$)	20.5±4.2	18.5±4.0	-9.5*
VO_2 ($l \cdot min^{-1}$)	0.51±0.21	0.42±0.11	-17.6*
VO_2 ($ml \cdot min^{-1} \cdot kg^{-1}$)	9.89±0.15	8.25±0.18	-16.6*
VCO_2 ($l \cdot min^{-1}$)	0.41±0.08	0.41±0.10	0
HR (beats$\cdot min^{-1}$)	93±12	80.0±8	-14.0**
Respiratory rate (breaths$\cdot min^{-1}$)	30.0±12.3	26.7±7.5	-11.0
Tidal volume (l)	0.75±0.16	0.69±0.17	-8.0

*p<0.05; **p<0.01; ***p<0.001

Table 2
Physiological responses to standard exertion recorded in boys with spastic tetraplegia (n=8) pre- and post-training

Variable	Pre-training	Post-training	Post-pre difference (%)
V_E ($l \cdot min^{-1}$)	35.2±6.8	36.4±5.4	3.5
VO_2 ($l \cdot min^{-1}$)	1.01±0.18	1.03±0.24	2.0
VO_2 ($ml \cdot min^{-}1 \cdot kg^{-1}$)	19.4±2.6	20.0±3.8	3.2
VCO_2 ($l \cdot min^{-1}$)	0.88±0.09	0.90±0.08	2.3
HR (beats$\cdot min^{-1}$)	147±21	126±19	-14.3***
HR (%HRmax)	83.0±10.6	69.6±10.3	-16.1***
VO_2 (%VO_2 max)	69.8±7.2	56.1±12.6	-19.6***
Respiratory rate (breaths$\cdot min^{-1}$)	37.0±9.8	43.0±7.9	16.2*
Tidal volume (l)	0.97±0.01	0.85±0.01	-12.4

*p<0.05; **p<0.01; ***p<0.001

Resting values of physiological variables and the responses to the applied exercise therapy are presented in Tables 1 and 2. The responses to graded exercise before and after the training period are presented in Table 3.

Table 3
Effects of maximal exercise recorded in boys with spastic tetraplegia (n=8) pre- and post-training

Variable	Pre-training	Post-training	Post-pre difference (%)
Exercise duration (min)	8.51±1.51	10.12±1.55	18.9**
Load applied (W)	90.0± 26.0	116.2±25.6	29.1***
Relative load ($W \cdot kg^{-1}$)	1.69±0.25	2.28±0.46	34.9**
Work output (kJ)	26.7±9.9	37.0±10.6	38.6***
Relative work output ($kJ \cdot kg^{-1}$)	0.50±0.11	0.73±0.20	46.0**
V_E max ($l \cdot min^{-1}$)	48.0±10.8	68.0±10.4	41.7***
VO_2 max ($l \cdot min^{-1}$)	1.41±0.28	1.86±0.31	31.9***
VO_2 max ($ml \cdot min^{-}1 \cdot kg^{-1}$)	26.4±3.3	35.9±3.6	35.9***
VCO_2 max ($l \cdot min^{-1}$)	1.46±0.29	1.89±0.36	29.4**
$V_E \cdot VO_2^{-1}$ ($ml \cdot l^{-1}$)	34.1± 4.1	37.0±4.3	8.5
Heart rate (HRmax; bpm)	177±12	181±12	2.3
Respiratory rate ($breaths \cdot min^{-1}$)	41.0±10.6	47.0±5.0	14.6**
Tidal volume (l)	1.17±0.2	1.4±0.31	19.7**

*p<0.05; **p<0.01; ***p<0.001

Discussion

Body height is very strongly genetically determined, thus only strong, prolonged stimuli could influence the impaired growth potential. It seems that growth impairment may be due to muscle spasticity and to reduced effect of the gravitational load. Body height of the subjects in this study was very low, below the 10^{th} percentile, and this was paralleled by body mass. Interestingly, the training-induced increase in body height, amounting to 1-2 cm, could have been brought about by relaxation of their contractured muscles, which was perceived by the subjects as a greater ease of movements.

The presented results evidence a steadily progressing improvement in work economy as reflected by decreasing tendency in the relative oxygen uptake (%VO_2 max) and in the physiological cost of 5-min exertion at constant intensity (%HRmax).

Compensatory processes resulting from a deficient postural tonus are believed to affect the ventilatory capacity [4,12]. Low values of the respective indices are the result of insufficiency of the expiratory muscles and of a disorganized voluntary expiration rather than of a restricted air flow. In view of that, the low values of ventilation found in this study, as well as in reports of other authors [10,13,14,17] are hardly explainable. Minute ventilation, like global oxygen uptake, depends on body size throughout the growth period.

The obtained results led to the conclusion that training an appropriate pace was the key factor in aerobic exercises. In order to induce significant aerobic capacity, reflected by maximal oxygen uptake, the intensity should amount to 75-80% HRmax and this, in turn, requires increasing the heart rate by at least 60-70% of the maximal-resting HR difference. Thus, an effective load would be associated by a heart rate of about 150 bpm. Such an optimum load does not induce an excessive muscle tension, neither mobilises larger muscle groups. Instead, it provides an effective stimulus for cardiovascular adaptation, thus bringing about a considerable increase in work capacity.

A thorough medical monitoring throughout the training in no case revealed an overload. The responses to the applied loads included a general stimulation within the first two minutes, reflected by an increased muscle tension accompanied by tremor of legs. Muscle tension and tremor disappeared within a few minutes, while moderate atetotic movements were initially intensified but gradually decayed.

Our results do not support the view that exercise performed under an external load may intensify spasticity and, in consequence, minimise therapeutic effects, thus confirming the results reported by Fowler [6].

As follows from our experience, tetraplegic youths tolerate prolonged, moderate-to-submaximal workouts better than short-lasting, highly intense ones. Therefore, interval exercise should not be recommended as a highly effective form of training, as it is associated with increased muscle tension which hinders the execution of co-ordinated, powerful movements, compared with a moderate and equally effective continuous training.

Summing up, cycle ergometer training at a load equal to 75% HRmax significantly improves the functional fitness of young subjects with tetraplegic cerebral palsy. Such training improves oxygen uptake, transport and utilisation, as well as normalises muscle tonus and improves neuro-muscular co-ordination.

Furthermore, the increased tolerance to exercise, reflected by increased maximal oxygen uptake and ventilation, evidences an improved work potential.

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Accepted for publication 10.02.2005