

RESEARCH ARTICLE

EFFECTS OF AN EXERCISE-ORIENTED REHABILITATION PROGRAM ON MECHANICAL EFFICIENCY AND AEROBIC CAPACITY IN CHILDREN WITH SPASTIC CEREBRAL PALSY

M. Izadi MSc¹,
MM. Taghdiri MD²,
GH. Bagheri PhD³,
HR. Samarkhalaj MSc¹,
D. Khorshidi MSc¹,
S. Namdar tajari MSc¹

1. Master of science, Department of Physical Education and Sport Sciences, Islamic Azad University of Saveh Branch
2. Assistant professor of Pediatric Neurology, Hamadan University of Medical Sciences
3. Assistant professor, Department of Physical Education and Sport Sciences, Islamic Azad University of Saveh Branch

Corresponding Author:
M. Izadi
Tel: +98 255 2241553
Email: izadimojtaba2006@yahoo.com

Abstract

Objective

Children suffering from Cerebral Palsy (CP), exhibit movement limitations and physiological abnormalities as compared to normal individuals. The objective of this study was to assess mechanical efficiency and certain cardiovascular indices before and after an exercise-rehabilitation program in children with diplegia spastic cerebral palsy (experimental group) in comparison with able-bodied children (controls).

Material and Methods

In this study, 15 spastic cerebral palsy (diplegic) children participated in an exercise-rehabilitation program, three days a week for three months with an average 144bpm of heart rate. The mechanical efficiency (net, gross), rest and submaximal heart rate and maximal oxygen consumption (VO_{2max}) were measured before (pretest) and after (posttest) exercise program on the cycle ergometer according to the Macmaster ergometer protocol. Then control group, of 18 normal children underwent the exercise program and were assessed, following which results of the 2 groups were compared using SPSS for statistical analysis ($P < 0.05$).

Results

Mechanical efficiency (net, gross) increased significantly in CP patients after the exercise-rehabilitation program; results did not alter significantly for the controls. Rest and submaximal heart rate in CP patients decreased significantly after exercise program. Maximal oxygen consumption, which remained unchanged in patients following the exercise program, was similar in patients and controls after the program.

Conclusion

Cerebral palsy patients, because of their high muscle tone, severe degree of spasticity, and involuntary movements are physically more incapacitated and need more energy than normal able-bodied individuals. Rehabilitation and aerobic exercise can be effective in improving their cardiovascular fitness and muscle function and increasing their mechanical efficiency.

Keywords: spastic cerebral palsy, maximal oxygen consumption, heart rate, mechanical efficiency, rehabilitation.

Introduction

Cerebral palsy (CP) is a disorder of the neuromuscular system that appears to follow cerebral cortex damage or failure of cerebrospinal paths, before and during of

birth or early years of life. This disease occurs two in every hundred births (1,2). Almost half of cerebral palsy patients are spastic(2).

Spastic muscles are always in contraction, resulting in high muscle tone (spasm) in agonist muscles and weakness in antagonist muscles. These disabilities during deambulation may lead to excessive energy cost and hence to compromised energy efficiency(3). Spastic patients, because of low physical activity and movement limitation during exercise, have higher oxygen uptake and lower mechanical efficiency and physical work capacity than do healthy people(1,4). One study showed that submaximal energy expenditure for walking on treadmill in spastic children is threefold that of normal children(5).

The researches indicated that exercise–rehabilitation on the side of clinical and physical therapy, leads to improving these patients. In this regard, Lundberg pointed out that physical work capacity in cerebral palsy patients is half that of normal people; their mechanical efficiency is lower than normal people during ergometry exercise, so that in submaximal exercise conditions on the ergometer, difference in mechanical efficiency between CP patients and able bodied children in light power output is little but in high power output, mechanical efficiency in CP group is much lower than normal people(6,7).

Mechanical efficiency(ME) may be a useful objective technique to assess the effects of interventions intended to improve the efficiency of the movement of children with CP(8). Mechanical efficiency is the efficiency of the conversion of chemical energy into mechanical energy at the cross-bridges and is based on phosphorylative coupling and contraction coupling which are essentially linked in series(9). Degroot indicated that a 3-week aerobic exercise program led to an increase of mechanical efficiency in cerebral palsy children(2). Bar study conducted on thirty five spastic adolescents for a year, twice a week, led to significantly increased mechanical efficiency(1). He reported that cardiovascular fitness and aerobic capacity(VO_{2max})¹ in their spastic group was almost 10-30% lower than the normal group(1). However, Bowen reported no statistically significant differences in the percentage of variability of oxygen cost, oxygen consumption, or physiological cost index between subjects with and without CP with free-

walking velocity(10). Many researches, however, did not observe significant differences in oxygen consumption, pulmonary ventilation, heart rate, oxygen pulse, respiratory exchange ratio and cardiorespiratory endurance between CP patients and able bodied children while walking on treadmill(10,11,12). Piccinini have showed that mean values for heart rate and oxygen consumption (mL/kg/min) did not differ significantly between normal subjects and patients CP(3). A review of related studies shows that findings are inconsistent or equivocal, hence there is a lack of comprehensive information in literature and consequently a lack of relevant postgraduate training programs for physicians in health care systems, requiring further research. Unfortunately, rehabilitation and therapy services for persons with CP often decrease dramatically or cease at adulthood, and rarely include fitness related goals. Because of the dangers of inactivity, innovative forms of physical activity and exercise for persons with mobility impairment need to be developed and implemented.

Therefore the aim of our study was to estimate the effect of a 3-times a week, three month, submaximal aerobic exercise–rehabilitation program on the mechanical efficiency, aerobic capacity and other cardiovascular factors in spastic cerebral palsy children and in comparison with normal children.

Material and Methods

Subjects: This study is semiexperimental. Fifteen male children, age 11 ± 1 years, height; 131 ± 6.3 cm, weight; 29.8 ± 5.6 kg) with spastic cerebral palsy were recruited with the consent of their parents and their physician, as the experimental group) and eighteen able bodied children with similar physical characteristics were selected randomly as controls. The degree of spasticity in patient ranged between average to severe or the third degree according to the Ashword scale(5). Before participation, subjects and their parents were informed of the purpose of study and the benefits and probable risks of the investigation, and written informed consent was obtained from them, permitting the children to participate in the study. Participants were instructed not to engage in vigorous exercise the day before and the day of testing. They were also asked to refrain from eating 2 hr prior to testing. All participants were screened using a physical

activity readiness questionnaire (PAR-Q) and a medical history questionnaire to ensure they were physically able to participate in the testing.

Testing protocol: Mechanical efficiency(net and gross), maximal oxygen consumption and heart rate in CP patients were measured before(pretest) and after(posttest) exercise–rehabilitation program, on electronically braked cycle ergometer (Ergo Tunturi, E604. Finland) according to the Macmaster protocol that is specific for children (13); the control group also performed this protocol, only at baseline, to facilitate comparison with the experimental group. The exercise–rehabilitation program in the CP group was three times a week for three months with average of exercise intensity equal to 144_{bpm} (beat per minute) of heart rate. The test was preceded by a 2 minute warm-up period. The protocol is performed in 4 stages. The initial power output was set at 12.5 W. The power output was then increased by 25 W every 2 minute. A physician supervised each test. Subjects were instructed to maintain a constant pedal rate throughout the entire test. All subjects were verbally encouraged to continue exercise until final stage. For each subject, HR was monitored continuously, and recorded in the rest, and over the last 10, of each stage of the MacMaster ergometry protocol, as well as during the final 10 s of test by polar. All data were presented as mean ± standard deviation. A two-way repeated measure ANOVA was used to determine significant differences between the

two groups, for which statistical significance was set at P<0.05 for all variables.

Results

The Macmaster protocol consisted of 4 stages and the subjects, based on their capacity depend on performed this protocol. Three spastic patients did not complete all 4 stages of ergometry protocol in pretest, but in the post test, all patients completed all stages of the exercise protocol. All healthy children performed all 4 stages of ergometry protocol. Mean and standard deviations were calculated for age, height, weight and the physiological parameters measured during the ergometry protocol. Descriptive details of these characteristics (means and standard deviations) and physiological measurements of all participants are summarized in table 1.

Mechanical efficiency (net,gross) in patients after exercise - rehabilitation increased significantly comparing to pretest values (P<0.05) (figure1).

The maximal oxygen consumption was almost similar in patient and control groups and this factor increased slightly, but not significantly in patients after rehabilitation program(P<0.05) (figure 2).

The exercise–rehabilitation program in patients caused a significant decrease in the post test rest and submaximal heart rate compared to pre test values (P<0.05); however the heart rates of the controls were lower than those of the patients, both pre- and post test (figure 3).

Table 1: The mean and standard deviation of physical factor and physiological indexes in subjects.

group	Age (Year)	Height (cm)	Weight (kg)	Rest heart rate (bpm)	Exercise heart rate (bpm)	VO2ma (ml / min/ kg)	Net efficiency (%)	Gross efficiency (%)
CP(pretest)	11±1	131±6.34	29.83±5.64	88±7.12	139±8.47	39±4.31	14 ± 1.4	12.7± 1.1
CP(posttest)	11±1	131±6.34	30±5.8	84±6.29	133±8.6	40±5.80	15.8± 1.1	14.3 ± 0.9
control	11±1	133±5.4	28.14±4.18	77±13.51	121±8.6	43±6.75	16.3 ± 1.4	14.8± 1.9

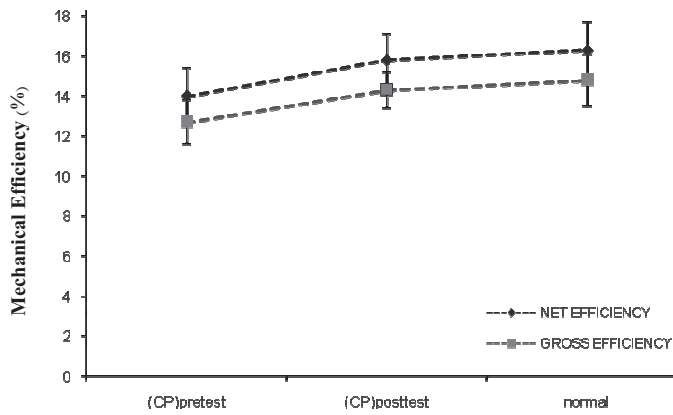


Figure 1. The changes of mechanical efficiency(net, gross)during ergometry protocol

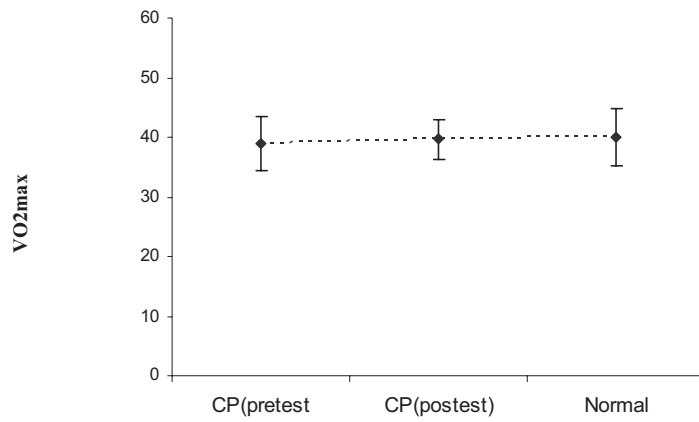


Figure 2. The mean and standard deviation of aerobic capacity (VO2max) during ergometry protocol in subjects.

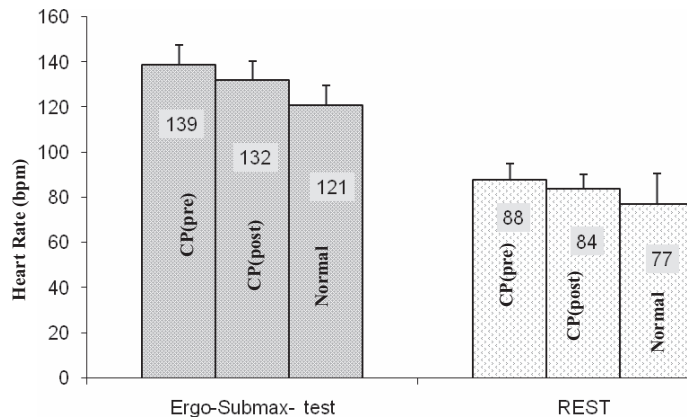


Figure 3. The changes of rest and submaximal ergometry heart rate in study groups

Discussion

The effect of aerobic exercise-rehabilitation program was examined on mechanical efficiency and some cardiovascular indexes in cerebral palsy children. The study findings demonstrated that the range of mechanical efficiency and exercise intensity in spastic patients was close to normal people under given work followed by aerobic exercise. Spastic children because of being immobile and sedentary or having low physical activity have lower physiological capability than their able bodied peers (14).

Untrained people have lower aerobic fitness and higher heart rate in rest or exercise than the normal people. Disability type influences the heart rate response to physical activity, and may affect the ability to sustain training intensities associated with fitness improvement(15). Suzuki observed that in CP patients with high physical activity levels, the heart rate was significantly closer to the normal group, while walking on a treadmill(16). Bar observed that heart rate in CP children significantly decreases after endurance training(1). In our study, sub-maximal training program significantly decreased the rest and sub-maximal heart rate in the spastic group. Because of high physical fitness of the normal group, their rest and sub-maximal heart rate was lower than the spastic group. Drensen observed that heart rate of the 2 groups is similar during light exercise, but during heavy exercise it is much higher in the spastic group as compared to normal people(17), findings similar to those of our study.

Sub-maximal training depending on intensity and duration of exercise increases maximal oxygen consumption. In the laboratory, VO_{2max} is calculated by direct measurement of measured oxygen, on an ergo cycle or treadmill. The measurement is very precise, but lab conditions never really replicate real conditions. In our study, VO_{2max} was calculated using a formula via monitored heart rate. The results of the Shinohara study demonstrated that cycle ergometer exercise at the AT point is effective in improving the physical endurance and VO_{2max} of children with CP(18); this change can be due to decreasing of difference between arterial and venous blood oxygen and increasing of cardiac output and greater capability of skeletal muscle in oxygen uptake(12). Our study showed that VO_{2max} in the spastic

group(pretest) is similar to the control group and sub-maximal exercise rehabilitation program causes very little improvement of VO_{2max} in these patients; but it is remarkable from the clinical perspective. Of course, Maltais stated that the individuals' physical activity level was not exactly related to their peak VO₂(19).

The basic causes of the decrease of exercise in CP children are the high metabolic cost of mechanical movements and low aerobic capacity(1), although many studies have not indicated the difference between CP patients and normal people(12). Exercise programs of judo and swimming for ten weeks leads to the increase of VO_{2max} and a 10% decrease of oxygen cost during ergometer exercise in CP patients(20). Moreover in the Wandenberg study, an exercise-rehabilitation program, of 2-4 times a week, for 9 months, significantly increased VO_{2max} in cerebral palsy children (21).

For the CP patient, aerobic capacity and endurance can be enhanced through exercise done at an intensity equal to 40-85 percent peak VO₂ for 20-40 minutes per session, three to five days a week(13). In our study, the low increase in VO_{2max} may be due to low intensity and time limitation in each session of training.

Measuring mechanical efficiency is potentially useful to assess motor performance in individuals with physical disabilities(22). Net mechanical efficiency is the ratio of the work accomplished to the energy expended, above that during rest, that is, the cost of resting metabolism is subtracted from the denominator in the computation:

$$\text{Net \% efficiency} = \left(\frac{\text{Work accomplished} \times 100}{\text{Energy expended above that at rest}} \right) (9)$$

But in calculation of gross mechanical efficiency, metabolism basal cost is not diminished

$$\text{Gross \% efficiency} = \left(\frac{\text{Work accomplished} \times 100}{\text{Energy expended}} \right) (5,9,23).$$

Kang stated that during exercise on the cycle ergometer, the changes in net and gross efficiency are equal(23). Depending on the base-line used, each mechanical efficiency index provided different values and was differently affected by the exercise intensity(24).

Luhtanen indicated that the highest mechanical efficiency is in aerobic threshold and the lowest is in anaerobic threshold(25). Therefore measure of mechanical efficiency must be under steady state submaximal

exercise, so that lactate threshold is not simulated (14). All the same, net mechanical efficiency increases with enhanced work intensity and reaches to plateau in adults and young boys in 40% VO_{2max} and 60% VO_{2max} respectively(26).

There are two primary factors that determine mechanical efficiency during exercise or other daily physical activities; the first factor is muscle efficiency that converts storage of chemical energy of carbohydrate and fat to mechanical energy for muscle contraction and the second factor is neuromuscular proficiency during exercise. Mechanical efficiency thus depends on velocity of contraction in the muscle filaments. The greatest efficiency is produced when velocity of muscle contraction is 1/3 of maximal velocity(14). The kind of muscle fiber has remarkable influence on mechanical efficiency. Research has shown that the more the slow twitch fibers in vastus lateralis, the more mechanical efficiency during exercise on ergometer or cycling. Thus, the increased neuromuscular performance, joint control strategy, and intramuscular coordination(primary factors), together with improved aerobic capacity (secondary factor), may result in reduced oxygen demands and increased ME(27).

This anatomical specialty indicates that slow twitch fibers in converting ATP energy to mechanical energy, have more efficiency than fast twitch fibers during submaximal exercise on the ergometer(14). Therefore, it seems that mechanical efficiency has remarkable influence on submaximal aerobic ergometry protocols or endurance exercise and depends on the kind of muscle fiber and particularly the neuromuscular proficiency(14); hence in CP patients, neuromuscular failure and chronic spastic disorder leads to limitation in the functioning of working muscles, thereby decreasing mechanical efficiency.

Rowland stated that mechanical efficiency is 13-23(%) in normal people on the ergometer(26). Taylor indicated that mechanical efficiency is 19/7(%) in able bodied boys(7-15 years) (28). Other studies have reported that mechanical efficiency in children and adults with cerebral palsy is lower than in normal people(1,6). In addition, Lundberg showed that the mechanical efficiency is 12-18(%) in CP children(6). Bar-Haim have showed that mechanical efficiency was significantly lower in CP

patients than in a normal group(29). Compared with the age-matched controls without CP, the children with CP were less mechanically efficient in their gait(30). The findings of our study showed that mechanical efficiency(net, gross) in CP patients was lower than in the normal group and exercise rehabilitation, depending on its duration, intensity and frequency of exercise, leads to enhanced mechanical efficiency in such children.

In conclusion, current data clearly show the need for improving both physical activity patterns and aerobic capacity in children with disabilities. Findings of other studies, as did ours, showed that physiological variables of spastic patients are remarkably weaker than their able bodied counterparts, a characteristic of inefficient deambulation in CP individuals that is probably directly related to simultaneous contraction of agonist and antagonist muscle in these patients. Thus, the inefficiency observed in the mechanical and physiological indices is due to the limited physical activity and sedentary nature of the daily routines and also the spasticity and high tone of the muscles involved in these individuals. Exercise programs of appropriate durations, intensity and frequency of training, would be very beneficial in the improvement of these indices; however more research is needed to confirm and enhance these strategies.

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