Effect of Physical Exercise on the Cardiorespiratory Response in Overweight Adolescents

Fazla Kilolu Adolesanlarda Fiziksel Egzersizin Kardiyorespiratuvar Yanıta Etkisi

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Abstract

Purpose: To evaluate the effects of an aerobic physical exercise program on the metabolic and cardiorespiratory response in overweight adolescents.

Material and Method: This is a randomized study evaluating overweight adolescents divided into intervention and control groups before and after an aerobic exercise program. Pre- and post-intervention aerobic fitness was evaluated by a submaximal incremental test on a cycle ergometer. The training program lasted 12 weeks, when the intervention group exercised three times per week on a cycle ergometer at individual training intensities corresponding to lactate threshold (LT) and onset of blood lactate accumulation (OBLA). The individual workload was increased by 10% at 2-week intervals.

Results: After intervention, an increase in workload levels corresponding to LT (33.3%) and OBLA (14.2%) was observed in the intervention group. In addition, the intervention group reached LT training intensity at a heart rate higher than that observed before intervention and that of controls ($p<0.05$).

Discussion: The program resulted in positive changes in aerobic fitness and heart rate, improving exercise tolerance. *Turk Jem 2012; 16: 14-8*

Key words: Aerobic exercise; overweight, lactic acid, anaerobic threshold, heart rate

Özet

Amaç: Fazla kilolu adolesanlarda, aerobik fiziksel egzersizin metabolik ve kardiyorespiratuvar yanıta olan etkilerinin değerlendirilmesi

Gereç ve Yöntemler: Bu çalışma, aerobik egzersiz programı öncesi ve sonrası girişim ve kontrol grubu olarak ayrılan fazla kilolu adolesanların değerlendirildiği randomize bir çalışmadır. Girişim öncesi ve sonrası aerobik fitnes, bisiklet ergometresinde submaksimal artış testi ile değerlendirildi. Çalışma programı 12 hafta sürdü ve girişim grubu tarafından haftada üç kere bisiklet ergometresi üzerinde laktat eşiğini (LT) ve kanda laktat birikiminin başlangıcını (OBLA) işaret eden bireysel çalışma yoğunluğunda egzersiz yapıldı. Bireysel çalışma yükü 2 hafta aralıklarla %10 arttırıldı.

Bulgular: Girişim sonrası, girişim grubunda LT (%33,3) ve OBLA'nın (%14,2) işaret ettiği şekilde çalışma yükü düzeylerinde artış gözlendi. Ek olarak, girişim grubu LT çalışma yoğunluğuna, girişim öncesinde gözlenenden ve kontrol grubundan daha yüksek bir kalp hızında ulaştığı görüldü ($p<0,05$).

Sonuç: Program, aerobik fitnes ve kalp hızında olumlu değişiklikler ve egzersiz toleransında düzelme sağlamıştır. *Türk Jem 2012; 16: 14-8*

Anahtar kelimeler: Aerobik egzersiz, fazla kilolu, laktik asit, anaerobik eşik, kalp hızı

Introduction

Overweight and obesity in adolescence are increasing at an alarming rate in developing countries (1). These conditions have become a cause for concern for government agencies (2), because excess body fat in adolescence leads to health problems, such as orthopedic and metabolic changes, and increased risk of mortality in adulthood (1,2).

Aerobic exercises have been considered an important component of physical activity programs for overweight adolescents, being endorsed as a key strategy in health-related physical activity guidelines (1-3). Studies with adolescents have confirmed the

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importance of aerobic physical exercise to improvements in metabolic profile (blood pressure and lipid profile) (4), cardiopulmonary functions (5) and energy expenditure (6).

It has long been known that excessive body fat has deleterious effects on obese individuals, and physical fitness has therefore been used as an important predictor of health problems in obese adolescents (7,8). Cummings et al. (9) found that high levels of physical fitness are able to promote cardiovascular protection by improving insulin resistance even in obese individuals, suggesting that it is more important to be fit than it is to be thin.

The National Association for Sport and Physical Education recommends that adolescents should perform moderate to vigorous physical activity every day of the week (3). Some interventions have used moderate-intensity exercise, which has traditionally been accepted to improve cardiorespiratory fitness (4). However, there is consistent evidence that physical activities performed at high intensity, such as exercise performed in the heavy physiological domain, can also determine adjustments which in turn have effects on the health of persons exposed, improving cardiorespiratory fitness and resulting in greater energy expenditure than moderate-intensity exercise (5). Thus, two intensities as determined by blood lactate concentration have been shown to be sufficient to cause organic changes and are therefore recommended to improve fitness: 1) intensity immediately before the increase in blood lactate in relation to the resting level, known as lactate threshold (LT) or aerobic threshold (10); 2) intensity at the maximal lactate steady state (MLSS) or at the onset of blood lactate accumulation (OBLA), i.e., highest intensity that can be identified as maintaining a maximum balance between lactate produced and released by muscle into the bloodstream and clearance rate during prolonged exercise (11).

Exercises performed at MLSS or OBLA intensity provide significant increases in maximal oxygen uptake (VO_2max), energy expenditure during activity, oxygen uptake during recovery, and mitochondrial activity, in addition to a reduction in lipid profile (5,12).

Programs with exercises to be performed at an intensity corresponding to LT have been developed for young adults (13) and middle-aged individuals (14), showing significant improvements in aerobic capacity. A few studies have been conducted with adolescents in order to determine the lactate kinetics in incremental tests at constant workloads (15). However, no studies have investigated the effects of an exercise program performed at OBLA intensity on overweight adolescents.

This study aimed to evaluate the effects of an aerobic exercise program (stationary cycling) performed in the heavy physiological domain on the metabolic and cardiorespiratory response in overweight adolescents.

Materials and Methods

This experimental study was designed to evaluate pre- and post-intervention physical activity status of overweight adolescents engaged in an aerobic exercise program. The study is part of a project entitled "Effects of physical exercise in adolescents with metabolic syndrome," which was approved by the Research Ethics Committee of Federal University of Santa Catarina - UFSC (protocol no. 396/07).

Research Subjects

The study sample included 36 overweight adolescents of both sexes, aged 13-17 years, who were randomly divided into two groups: experimental group (EG; n=23) and control group (CG; n=13).

An exercise program was developed at UFSC (16) and adolescents were eligible for participation if they met the following inclusion criteria: excessive body weight as measured by the body mass index (BMI), according to the cutoff points defined by Cole et al. (17); have not partaken in any weight-loss program or nutritional intervention within at least the previous three months; commitment not to make changes in eating habits during the training period; not be participating in any other exercise program or sports training school, except for physical education classes in school; have not used weight-loss drugs within at least the previous three months and during the intervention.

To ensure internal and external validity of the study, adolescents who enrolled in other exercise programs or sports training schools during the intervention (n=2), those who failed to attend at least 75% of the intervention sessions (n=17) and those with any orthopedic injury (n=3) were excluded. Thus, the EG was composed of 9 and the CG of 5 adolescents.

Anthropometry and Body Composition

Body mass (BM) was measured to the nearest 100 g using a Plenna® digital scale. Standing height was measured to the nearest 0.1 cm using a stadiometer, which consisted of a Cardiomed® tape measure fixed to the wall in a straight line towards the floor. Height and weight were used to calculate BMI (BM/height^2). All anthropometric measurements followed the standards proposed by Petroski (18) and were obtained both in the pre- and post-intervention period by two trained evaluators, with adequate levels of technical error of measurement according to Gore et al. (19).

Measurements of bioelectrical impedance analysis (BIA) (strength and hydration of fat-free tissues) were performed using a Biodynamics® tetrapolar body-composition analyzer (model BF-310, Biodynamics Corporation, Seattle, Washington, USA) to determine the percentage of body fat (%BF) and fat-free mass (FFM) of adolescents, according to the manufacturer's instructions. In addition to the standards established for BIA, the pretest care planning suggested by Heyward (20) was also followed.

Incremental Exercise Laboratory Protocol

In the pre-and post-intervention period, a submaximal incremental exercise test was performed to determine the workload to be applied to the cycle ergometer, following the incremental test proposed by Armstrong et al. (21) for cycle ergometry. A cycle ergometer with electromagnetic brakes (ERGO-FIT® model 167 CYCLE) was used. The saddle height and handlebar position were adjusted to the adolescents' leg and arm lengths. The initial test load was set at 30 watts (stage 1) and increased by 30 watts every three minutes (subsequent stages). Throughout the test, participants should maintain a pace of 60 revolutions per minute (rpm). The test was interrupted when the subject could no longer maintain the prescribed pedaling cadence or reached 85% of maximal heart rate (HR) as previously determined (HRmax = 208 - 0.7 x age) (22).

LT and OBLA Determination

At rest and at the end of each stage of the incremental test, 25 µl of arterial blood were collected from the earlobe without hyperemia to

determine lactate concentration. Blood was immediately transferred into 1.5-µl polyethylene microtubes with lid (Eppendorf type) containing 50 ml of 1% sodium fluoride solution. The samples were analyzed immediately after collection using an electrochemical analyzer (YSI STAT® 2700, Yellow Springs, Ohio, USA).

Exercise was performed at two training intensities, as follows: 1) LT, defined as the moment at which blood lactate concentration begins to increase and sustains the increase above the resting level (10); 2) OBLA, determined through linear interpolation, adopting a fixed lactate concentration of 3.5 mmol (23).

HR Determination

HR was measured throughout the incremental test using a Polar® S610i HR monitor. HR LT, HR OBLA and peak HR (HRpeak) were analyzed.

Intervention Program

The training program lasted 12 consecutive, uninterrupted weeks. The EG was subjected to a physical exercise program using an electromagnetic cycle ergometer (Moviment®, Biocycle 2600) and the CG had no intervention.

On Mondays and Fridays, the participants exercised for 40 continuous minutes at an intensity corresponding to LT (in watts). On Wednesdays, training was performed at an intensity corresponding to OBLA for 30 minutes divided into 6x5-min bouts interspersed with 1-min rest periods. Every two weeks, the individual workload was increased by 10% for each adolescent.

Statistical Analysis

Shapiro-Wilk tests were performed to verify the normality of the data, and the following variables showed a normal distribution: height, %BF, FFM, LT, OBLA, peak lactate (Lacpeak), HR LT, HR OBLA, and HRpeak. Variables with non-normal distribution (BM, BMI) were log transformed and investigated again for data distribution. After log transformation, all variables were normally distributed. The Student t-test for independent samples was used to compare groups regarding anthropometric variables, HRmax, and delta percentage of lactate response and HR. Two-way analysis of variance (ANOVA) was used to assess interactions between the groups (EG and CG) and between intervention periods (pre and post) for lactate response and HR. Statistical significance was set at 5% ($p \leq 0.05$) for all analyses.

Results

Table 1 shows anthropometric characteristics, body composition and estimated HRmax of the adolescents from both groups. After the intervention period, there was a decrease in %BF and an increase in FFM in the EG ($p < 0.05$). For other variables (BM, height, BMI, and HRmax), no significant differences were observed between pre- and post-intervention values or between the groups. Table 2 shows workload values achieved at LT and OBLA intensities and Lacpeak concentrations in the pre- and post-intervention period. After intervention, there was an increase in workloads associated with LT (33.3%) and OBLA (14.2%) in the EG ($p < 0.05$). The adolescents in the EG also showed higher workload values at LT than controls in the post-intervention period ($p < 0.05$).

HR values obtained during the submaximal test before and after intervention for EG and CG are described in Table 3. After intervention, the adolescents in the EG reached LT training intensity at an HR higher (5.8%) than that at baseline and that of controls ($p < 0.05$).

Figure 1 shows the mean lactate values for the adolescents in both groups at each stage of the incremental test. Post-intervention

Table 1. Anthropometric characteristics, body composition and maximal heart rate of adolescents participating in an aerobic exercise program

	Intervention		Δ%
	Pre	Post	
	$\bar{x}$ (SD)	$\bar{x}$ (SD)	
BM (kg)			
EG	79.4 (14.9)	79.5 (14.2)	0.3 (3.2)
CG	71.3 (7.9)	71.1 (6.6)	-0.1 (2.9)
Height (m)			
EG	1.61 (0.1)	1.61 (0.1)	0.0 (0.0)
CG	1.65 (0.1)	1.65 (0.1)	0.0 (0.0)
BMI (kg/m^2)			
EG	30.6 (5.2)	30.3 (5.1)	-0.9 (2.4)
CG	26.0 (0.9)	26.0 (0.6)	-0.7 (4.4)
%BF			
EG	28.8 (5.4)	27.6 (5.6)*	-4.2 (3.8)
CG	22.8 (5.4)	20.7 (5.9)	-9.9 (10.2)
FFM (kg)			
EG	56.2 (7.0)	57.1 (7.1)*	1.7 (1.5)
CG	55.0 (7.5)	56.5 (8.1)	2.7 (2.6)
HR_{max} (bpm)			
EG	197.6 (1.4)	197.6 (1.4)	0.0 (0.0)
CG	198.1 (1.3)	198.1 (1.3)	0.0 (0.0)

$\bar{x}$= Mean; SD = standard deviation; EG = experimental group; CG = control group; BM = body mass; BMI = body mass index; %BF = percentage of body fat; FFM = fat-free mass; HRmax = maximal heart rate (determined by the equation HRmax = 208 - 0.7 x age); * Intra-group comparison (pre vs. post).

Table 2. Mean values and standard deviation of workloads associated with LT and OBLA training intensities and pre- and post-training Lac_{peak} concentrations

	Intervention		Δ%
	Pre	Post	
	$\bar{x}$ (SD)	$\bar{x}$ (SD)	
LT (w)			
EG	56.7 (10.0)	73.3 (15.8)*	33.3 (35.4) †
CG	48.0 (16.4)	36.0 (13.4)†	-20.0 (27.4)
OBLA (w)			
EG	111.3 (13.4)	126.2 (19.2)*	14.2 (17.5)
CG	95.2 (16.2)	104.6 (32.8)	8.3 (18.2)
Lacpeak (mM)			
EG	7.2 (2.4)	7.7 (2.3)	13.3 (39.3)
CG	6.6 (1.4)	6.0 (1.4)	-8.0 (9.8)

$\bar{x}$= Mean; SD = standard deviation; EG = experimental group; CG = control group; LT = lactate threshold; OBLA = onset of blood lactate accumulation;
Lac = lactate; * Intra-group comparison (pre vs. post); † Inter-group comparison.

plasma lactate concentrations in the EG were lower than those in the CG for workloads of 60 and 90 watts ($p < 0.05$).
Figure 2 shows mean HR values for both groups at each stage of the incremental test. HR of the adolescents in the EG tended to be lower in the post-intervention period compared to pre-intervention and CG values, although no significant differences were found.

Discussion

Our main finding was that exercise prescribed at LT and OBLA training intensities led to significant changes in the metabolic and aerobic capacity of overweight adolescents. In addition, no studies investigating the physiological effects of an exercise program for overweight adolescents, with characteristics similar to the present study, were found in literature. Thus, these results may serve as a reference for future physical activity programs designed to control body weight and improve cardiorespiratory fitness in adolescents.
The training intensity used in the present study was based on the model described by Gaesser and Poole (26), who proposed three domains for effort intensity: moderate, heavy and severe. Briefly, the moderate domain corresponds to exercise performed at an intensity that does not change blood lactate in relation to the resting level, i.e., below LT. Exercise duration in this domain is dependent on substrate depletion, fluid and electrolyte imbalance, and thermoregulatory imbalances (27). The heavy domain starts with low exercise intensity at which blood lactate concentration begins to increase (LT) and upper boundary to this domain corresponding to OBLA or MLSS. In the severe domain, there is no stability of metabolic variables and blood lactate rises until exhaustion (26).
After three-month training at the lower and upper limit of the heavy domain, the adolescents in thr EG showed improved aerobic capacity. LT and OBLA were achieved at workloads greater than those observed before intervention. This result was not detected in controls, who showed a similar performance in the pre- and post-training periods. Our findings are similar to those obtained at LT and OBLA training intensities with obese sedentary women (14), with normal-weight individuals aged 18 to 24 years (13), and with monozygotic twins (5). Although there are no reports in the literature on interventions involving overweight adolescents, it appears that a physical activity program prescribing exercise at heavy domain intensities may lead to significant changes in the aerobic capacity of adolescents and adults.
The improvement in aerobic capacity observed in the EG may be related to mechanisms that control lactate metabolism during exercise, such as adaptations in skeletal muscle due to training, which determine increased lactate clearance during exercise and, consequently, a decrease in blood lactate concentration for the same effort intensity, thus improving performance (28). This increase in lactate oxidative capacity resulting from exercise causes a shift to the right in the lactate vs. intensity curve, as shown in Figure 1 for the EG in the post-training period.
Another mechanism that might have influenced the increase in aerobic capacity of the adolescents in the EG may be related to the hydrogen-ion (H^+) control system and a possible increase in monocarboxylate transporters (MCTs) during exercise. During physical exercise performed at an intensity corresponding to heavy or severe physiological domains, lactic acid production reaches high levels, and in untrained individuals, the acid-base buffer system is

Table 3. Mean values and standard deviation of HR values associated with LT, OBLA and peak HR

	Intervention		Δ%
	Pre	Post	
	$\bar{x}$ (SD)	$\bar{x}$ (SD)	
HR LT (bpm)			
EG	127.8 (8.3)	135.1 (10.2)*†	5.8 (6.6)†
CG	130.4 (10.2)	118.8 (14.0)	-8.1 (16.4)
HR OBLA (bpm)			
EG	167.9 (9.1)	165.4 (8.5)	-1.4 (3.8)
CG	165.6 (4.6)	169.6 (5.9)	2.5 (4.6)
HR_{peak} (bpm)			
EG	190.0 (8.7)	188.4 (6.5)	-0.8 (2.5)
CG	190.2 (9.6)	185.4 (9.7)	-2.5 (3.9)

$\bar{x}$= Mean; SD = standard deviation; EG = experimental group; CG = control group; LT = lactate threshold; OBLA = onset of blood lactate accumulation; HR = heart rate; * Intra-group comparison (pre vs. post); † Inter-group comparison

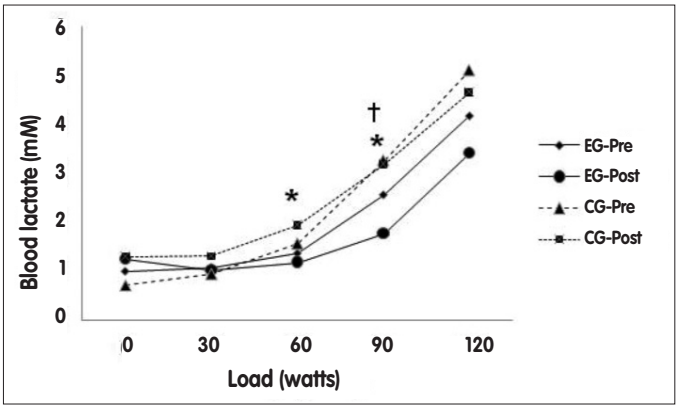

Figure 1. Blood lactate behavior for kinetics during incremental test. EG - experimental group, CG - control group, Pre - period before intervention, Post - period after intervention. * $p < 0.05$ - EG-Post x CG-Post; † $p < 0.05$ – EG-Post x CG-Pre

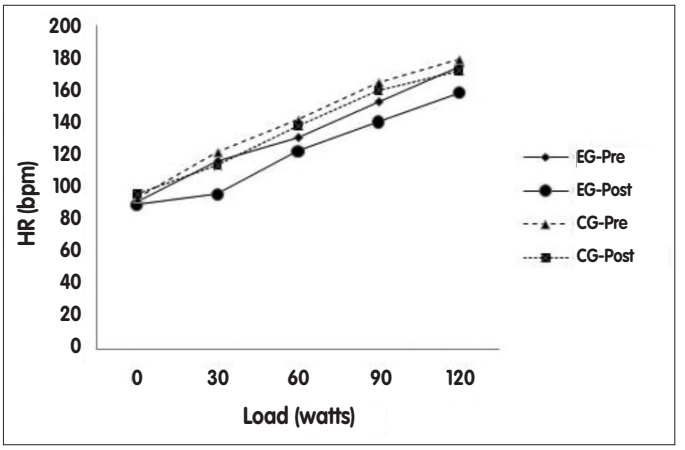

Figure 2. Heart rate (HR) behavior for kinetics during incremental test. EG - experimental group, CG - control group, Pre - period before intervention, Post - period after intervention

limited, causing a decrease in the pH of body fluids and thus resulting in acidosis and exercise intolerance (5, 27). Therefore, H^+ and lactate removal is accomplished through the mediation of MCT proteins, specifically MCT1 and MCT4, whose concentrations are increased after exercise training (29). These results suggest that high-intensity training may improve lactate/H^+ transport capacity in skeletal muscle, increasing exercise tolerance.

Furthermore, the improvement in aerobic capacity may be associated with greater availability of energy substrates in the form of free fatty acids (FFA) (27). Training conducted at high intensities leads to increased oxidation of fat as an energy substrate, mainly due to increased intramuscular triglyceride concentration and aerobic enzyme activity, resulting in greater exercise tolerance (14). The adolescents in the EG reached the lower-limit exercise intensity of the heavy domain at 63.2 and 68% of HRmax, respectively, for the pre- and post-training periods. Controls showed a decrease in HRmax values from 65.8% in the pre-training period to 59.9% after three months. These results demonstrate that the training program was effective in causing metabolic improvement in HR of the adolescents in the EG, which resulted in increased exercise tolerance. Similar results of improvement in HR and exercise tolerance were also found in adults who were prescribed exercise at an intensity corresponding to LT (14).

The adolescents in both groups reached OBLA training intensity at approximately 85% of HRmax. HR values corresponded to workloads on a cycle ergometer (in watts) of 126.2 (±19.2) and 104.6 (±32.8) for the EG and CG, respectively. These results are consistent with reports in the literature indicating that, for non-athletes, OBLA is reached at approximately 85% of HRmax (31).

This study has some limitations, such as the small number of subjects who completed 12 weeks of training, difficulty in recruiting individuals and in meeting the criteria for final analysis. Conversely, our data add relevant information to the literature about intervention involving physical exercise for overweight adolescents, with the prescription of high-intensity exercises causing cardiorespiratory and metabolic improvements.

Based on our findings, we can conclude that our training program, targeting overweight adolescents and involving indicators related to blood lactate response during exercise, led to an improvement in aerobic capacity, increasing exercise tolerance among the adolescents who participated in the program. These findings can supposedly reduce the risk of cardiovascular disease in adulthood. Thus, exercise intensities prescribed in this study may be used by health and sports medicine professionals who work with this population.

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