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ORIGINAL ARTICLE

Effects of high-intensity interval training on physical capacities and substrate oxidation rate in obese adolescents

S. Lazzer[1,2,3] · G. Tringali[3] · M. Caccavale[3] · R. De Micheli[3] · L. Abbruzzese[3] · A. Sartorio[3,4]

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Abstract
Purpose To investigate the effects of a 3-week weight-management program entailing moderate energy restriction, nutritional education, psychological counseling and three different exercise training (a: low intensity, LI: 40 % $V'O_2$max; b: high intensity, HI: 70 % $V'O_2$max; c: high-intensity interval training, HIIT), on body composition, energy expenditure and fat oxidation rate in obese adolescents.
Methods Thirty obese adolescents (age: 15–17 years, BMI: 37.5 kg m^{-2}) participated in this study. Before starting (week 0, W0) and at the end of the weight-management program (week 3, W3), body composition was assessed by an impedancemeter; basal metabolic rate (BMR), energy expenditure and substrate oxidation rate were measured during exercise and post-exercise recovery by indirect calorimetry.
Results At W3, body mass (BM) and fat mass (FM) decreased significantly in all groups, the decreases being significantly greater in the LI than in the HI and HIIT subgroups (BM: −8.4 ± 1.5 vs −6.3 ± 1.9 vs −4.9 ± 1.3 kg and FM: −4.2 ± 1.9 vs −2.8 ± 1.2 vs −2.3 ± 1.4 kg, $p < 0.05$, respectively). $V'O_2$peak, expressed in relative values, changed significantly only in the HI and HIIT groups by 0.009 ± 0.005 and 0.007 ± 0.004 L kg FFM^{-1} min^{-1} ($p < 0.05$). Furthermore, the HI and HIIT subgroups exhibited a greater absolute rate of fat oxidation between 50 and 70 % $V'O_2$peak at W3. No significant changes were observed at W3 in BMR, energy expenditure during exercise and post-exercise recovery.
Conclusion A 3-week weight-management program induced a greater decrease in BM and FM in the LI than in the HI and HIIT subgroups, and greater increase in $V'O_2$peak and fat oxidation rate in the HI and HIIT than in the LI subgroup.

Keywords Obesity · Exercise intensity · Fat metabolism · Energy metabolism · Body composition

Introduction

The main objectives of a weight-management programs are to change food and behavioral habits, to reduce fat mass (FM), to maintain fat-free mass (FFM) and to enhance physical capabilities in order to improve long-term weight regulation [1]. Physical activity promotes negative energy balance and also negative fat balance [2] and appears to be one of the major factors determining success in long-term weight maintenance [3]. Therefore, recommendations for the duration, type and intensity of the physical activity sessions are needed to optimize energy expenditure, fat oxidation and improve physical capacities during the weight-management programs.

Moderate-intensity activity for approximately 45–60 min per day seems adequate to prevent the development of overweight or obesity and 90 min per day is reported to be necessary to reduce body weight in

✉ S. Lazzer
stefano.lazzer@uniud.it

1 Department of Medical and Biological Sciences, University of Udine, P.le Kolbe 4-33100, Udine, Italy

2 School of Sport Science, University of Udine, Udine, Italy

3 Laboratorio Sperimentale di Ricerche Auxo-Endocrinologiche, Istituto Auxologico Italiano, IRCCS, Milan, Verbania, Italy

4 Divisione di Auxologia and Malattie Metaboliche, Istituto Auxologico Italiano, IRCCS, Milan, Verbania, Italy

overweight subjects [4]. Walking appears to be a more convenient physical activity for obese adolescents than cycling, because in obese adolescents, the target energy expenditure was attained at lower heart rate (HR), with lower blood lactate concentration and greater fat oxidation [5]. Low-intensity (LI) exercise seems to increase fat oxidation during the exercise (but not at rest) and results in a greater total fat oxidation than moderate- or high-intensity (HI) exercise with similar energy expenditure [6–8]. In addition, high-intensity interval training (HIIT) is reported to be a feasible and efficacious strategy for increasing health-related fitness in overweight and obese youth [9]. HIIT generally consists of short, yet intense bouts of exercise interspersed with rest periods. The main appeal of HIIT is that this type of training can be completed in a short period of time (compared to traditional aerobic training), and it requires no or minimal equipment and is perceived as a more enjoyable exercise compared to other exercise modalities [10]. HIIT produced equal or better cardiometabolic gains in a shorter time period in comparison with traditional endurance training [11, 12] in both healthy [13] and obese people [14], while no effects were described on body composition and on muscular fitness [15]. Similarly, there are no consistent findings supporting the view that moderate-intensity training can increase fat oxidation to a greater extent than HI or HIIT exercise in obese subjects [16]. Discrepancies among different studies might be attributed to the fact that prescription of HIIT consists of manipulating different variables (e.g., work interval intensity and duration, relief interval intensity and duration, exercise modality, number of repetitions, number of series, between-series recovery duration and intensity) [17]. For this reason, the HIIT interventions for overweight and obese children are heterogeneous and further studies are still requested to define the most suitable combination for maximizing health improvements in a better way.

Thus, the aim of the present study was to determine the effects of a 3-week multidisciplinary body weight-management program entailing moderate energy restriction, nutritional education, psychological counseling (common to all subjects) and three different exercise training (subgroup a: low intensity, LI: 40 % $V'O_2$max; subgroup b: high intensity, HI: 70 % $V'O_2$max; subgroup c: high-intensity interval training, HIIT), on body composition, energy expenditure and fat oxidation rate in severely obese adolescents.

Study design and methods

Subjects

Thirty severely obese boys (BMI SDS > 2, [18]) aged 15 to 17 years, with a pubertal stage >3, according to the Tanner pubertal staging [19], were admitted to the study. The subjects were recruited as inpatients from the Division of Auxology, Italian Institute for Auxology, IRCCS, Piancavallo (VB), Italy. All subjects had a full medical history and physical examination, with the routine hematology and biochemistry screens and urine analysis. Body mass (BM) was stable during the previous 2 months (changes less than ± 1 kg). None of the subjects had evidence of significant disease, notably non-insulin-dependent diabetes mellitus or other endocrine disease, and none were taking medications regularly or using any medication known to influence energy metabolism.

All the participants were admitted to a 3-week multidisciplinary body weight reduction program entailing moderate energy restriction, nutritional education and psychological counseling. As far as physical activity is concerned, participants were randomly assigned to a low-intensity subgroup (LI, n. 11, exercising at HR corresponding to 40 % of $V'O_2$max), to a high-intensity subgroup (HI, n. 9, exercising at HR corresponding to 70 % of $V'O_2$max) and to a high-intensity interval training (HIIT, n. 10, consisting of repeated 40-s efforts of high-intensity walking at HR corresponding to 100 % of $V'O_2$max, which were intermixed with 5 min of walking at low intensity corresponding to 40 % of $V'O_2$max).

Study protocol

The study was approved by the Ethics Committee of the Italian Institute for Auxology (Milan) and has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The purpose and objective of the study were explained to each subject and his or her parents, and written informed consent was obtained before beginning the study. The adolescents were hospitalized for a multidisciplinary body weight reduction program. During the first days, subjects had physical examination, routine hematology and biochemistry screens and urine analysis. Thereafter, they followed a 3-week personalized weight-management program entailing moderate energy restriction, nutritional education, psychological counseling (common to all subjects) and three different exercise training (described in detail in the following section). Full testing sessions were conducted just before the beginning (Week 0, W0) and at completion of the 3-week weight-management program (Week 3, W3). The testing session included assessment of anthropometric characteristics, body composition, basal metabolic rate (BMR), energy expenditure (EE) and substrate oxidation rate during submaximal exercise and post-exercise recovery.

Diet and nutritional education

During the 3-week weight-management program, personalized diets were offered on the basis of the initial BMR test and physical activity level for each adolescent. Energy supply was adjusted to be close to 1.2 times the initial BMR, which is about 15–20 % less than the estimated daily EE. The composition of diet was formulated according to the Italian recommended daily allowances [20], and the subjects were instructed to consume all the meals. During the 3-week weight-management program, the consumption of meals always occurred under the supervision of a dietician.

Physical activity

During the 3-week weight-management program, the adolescents participated in a personalized exercise training program, from Monday to Friday, which included two endurance training sessions per day (followed by 5- to 7-min stretching) under heart rate (HR) monitoring and medical supervision. All subjects completed 28 ± 2 sessions of physical training.

Participants were randomly assigned to a low-intensity subgroup (LI, n. 11, exercising at HR corresponding to 40 % of $V'O_2$max), or to a high-intensity subgroup (HI, n. 9, exercising at HR corresponding to 70 % of $V'O_2$max), or to a high-intensity interval training subgroup (HIIT, n. 10, consisting of 6 repeated 40-s efforts of high-intensity walking at HR corresponding to 100 % of $V'O_2$max, which were intermixed with 5 min of walking at low intensity corresponding to 40 % of $V'O_2$max).

The amounts of energy expended during a training session were similar for both groups (20 kJ per kg of fat-free mass, FFM, about 1.4 MJ per session). Each training session lasted 45 ± 6 min for LI program, 31 ± 4 min for the HI training program and 37 ± 3 min for the HIIT training program. In addition, subjects had one hour·day^{-1} of aerobic leisure activities at the institution on Saturday and Sunday. The research assistant and the physical trainers verified that each subject participated in each training session, performed exercises correctly and completed at least 95 % of the exercise session and program. Additionally, all the subjects considered in the present paper completed more than 97 % of the exercise session and program.

Measurements

Physical characteristics and body composition

The medical history and a physical examination of subjects were taken at the time of admission to hospital. Body mass (BM) was measured to the nearest 0.1 kg with an electronic scale (Selus, Italy) with the subject dressed only in light underwear. Stature was measured to the nearest 0.5 cm on a standardized Harpenden stadiometer (Holtain Ltd, UK). The body mass index (BMI) was calculated as weight (kg) divided by stature (m) squared. Body composition was measured by using a multifrequency tetrapolar impedancemeter (BIA, Human-IM Scan, DS-Medigroup, Milan, Italy) with a delivered current of 800 μA at a frequency of 50 kHz. In order to reduce errors of measurement, attention was paid to the standardization of the variables that affect measurement validity, reproducibility and precision. Measurements were performed according to the method of Lukaski (1987) [21] after 20-min resting in a supine position with arms and legs relaxed and not in contact with other body parts. FFM was calculated using the prediction equation developed by Lazzer (2008) [22], and fat mass (FM) was derived as the difference between BM and FFM.

Basal metabolic rate

BMR was determined in the morning (measurements starting between 0800 and 1000 a.m.), after an overnight fast by means of open-circuit, indirect computerized calorimetry (Vmax 29, Sensor Medics, Yorba Linda, Ca, USA) with a rigid, transparent and ventilated canopy. Before each test, the gas analyzers were calibrated using a reference gas mixture (95.00 % O_2 and 5.00 % CO_2). BMR of subjects was measured for 45 min. Oxygen consumption ($V'O_2$) and carbon dioxide production ($V'CO_2$), standardized for temperature, barometric pressure and humidity, were recorded at 1-min intervals. Results from the first 5–10 min, which corresponded to adaptation to the procedural environment, were excluded from the analysis. Energy expenditure was derived from the measured oxygen uptake and carbon dioxide output according to the formula of Weir (1949) [23] and averaged over the whole measurement period.

Physical capacities and maximal fat oxidation rate

Peak oxygen uptake and maximal fat oxidation rate were determined by using a graded exercise test on a motorized treadmill (TechnoGym, Gambettola, Italy), under medical supervision. Subjects were asked to avoid strenuous exercise the day before the test and came to the laboratory after a 12-h overnight fast. Before the beginning of the study, subjects were familiarized with the equipment and the procedures. Each test was undertaken in the morning (exercise starting between 0800 and 1000 a.m.) and comprised a 10-min rest period followed by walking in stages of 5-min duration. The rates in m s^{-1} and incline in % followed a sequence : 0.6 (0 %), 1.0 (0 %), 1.0 (3 %), 1.3 (3 %), 1.4 (6 %), 1.4 (9 %) and 1.4 (12 %). The workload was progressively increased until a HR of approximately 180 beats min^{-1} was reached, at which point exercise was concluded in order to avoid any cardiovascular complications associated with maximal effort which would be particularly risky in this kind of population. During the experiment, ventilatory and gas exchange responses were measured continuously by indirect calorimetry (CPX Express, Medical Graphics Corp, MN, USA). The flowmeter and gas analyzers of the system were calibrated using, respectively, a 3-L calibration syringe and calibration gas (16.00 % O_2; 4.00 % CO_2). During the exercise test, an electrocardiogram was recorded continuously and displayed online for visual monitoring, and heart rate (HR) was measured with a dedicated monitor device (Polar, Finland). The peak oxygen uptake ($V'O_2$peak) was estimated for each subject considering the last 20 s of the graded exercise test.

The substrate oxidation rate was calculated from $V'O_2$ and $V'CO_2$ (CPX Express, Medical Graphics Corp, MN, USA) during the last minute of each workload level, according to the protocol of Achten (2002) [24] and using the following equations [25]:

$$\text{Fat oxidation rate}\ (\text{g/min}) = 1.67 \times V'O_2\,(\text{l/min}) - 1.67 \times V'CO_2\,(\text{l/min}) - 0.307 \times \text{Pox}$$

$$\text{Carbohydrate oxidation rate}\ (\text{g/min}) = 4.55 \times V'CO_2\,(\text{l/min}) - 3.21 V'O_2\,(\text{l/min}) - 0.459 \times \text{Pox}$$

where Pox is the protein oxidation rate. The protein oxidation rate was estimated by assuming that protein oxidation contributed approximately 12 % of resting energy expenditure [25]:

$$\text{Pr otein oxidation rate}\ (\text{g/min}) = \left[\text{energy expenditure (kJ/min)} \times 0.12\right] / 16.74\ (\text{kJ/g})$$

For each subject, the results of the graded exercise test were used to compute the relationship between fat oxidation rate as a function of exercise intensity expressed as %$V'O_2$peak and %HRmax. The best fit was obtained with a polynomial relationship of the second order. The relationship between fat oxidation rate and %$V'O_2$ was used to determine the exercise intensity which corresponded to the highest rate of fat oxidation. The graded exercise test on the motorized treadmill was performed in the same conditions (speed and incline) at W0 and W3.

Energy expenditure and substrate oxidation rate during submaximal exercise and post-exercise recovery

After determining the physical capacities of subjects and the exercise intensity that corresponded to the highest rate of fat oxidation, all the subjects were randomly split into three subgroups: 11 subjects participated in a LI training, 9 subjects in a HI training and 10 subjects in a HIIT program.

The submaximal tests took place two days after the $V'O_2$peak test. Tests were designed in such a way that equal amounts of energy were expended during LI, HI and HIIT exercises on a motorized treadmill (TechnoGym, Gambettola, Italy). Subjects were asked to avoid strenuous exercise the day before the test and came to the laboratory after a 12-h overnight fast.

The LI exercise test comprised a 10-min rest period in a standing position on a treadmill, followed by about 45-min walking at maximal fat oxidation rate intensity previously determined for that subject and then a 60-min post-exercise recovery period. The HI exercise test comprised a 10-min rest period in standing position on a treadmill, followed by about 30-min walking at about 70 % of $V'O_2$peak and then a 60-min post-exercise recovery. The HI exercise corresponded to the maximum exercise intensity that these subjects could maintain for 30 min continuously. The HIIT exercise test comprised a 10-min rest period in standing position on a treadmill, followed by about 37-min walking intermixed with 6 high-intensity intervals at 100 % of $V'O_2$peak and then a 60-min post-exercise recovery.

$V'O_2$ and $V'CO_2$ were measured continuously (CPX Express, Medical Graphics Corp, MN, USA) during the rest, exercise and post-exercise recovery periods. Substrate oxidation rate was calculated over consecutive 5-min periods using the equations of Frayn (1983) [25] as described above. Energy supply (kJ min^{-1}) during exercise and during post-exercise recovery was calculated as the sum of each substrate oxidation rate (g min^{-1}) multiplied by the appropriate conversion factor (carbohydrates and protein = 16.7 kJ g^{-1}; fat = 37.7 kJ g^{-1}). During the exercise tests and the post-exercise recovery period, an electrocardiographic record was performed continuously and displayed online for visual monitoring, and HR was measured with a dedicated monitor device (Polar, Finland).

Statistical analyses

Statistical analyses were performed using PASW Statistic 18 (SPSS Inc., IL, USA) with significance set at $p < 0.05$. All results were expressed as means and standard deviation (SD). Any associations of the period (W0 vs W3), group (LI vs HI vs HIIT) and interaction (period × group) with physical characteristics, body composition, BMR, energy expenditure and substrate oxidation were tested with general linear model repeated measures. Post hoc comparisons were made using Bonferroni procedure for significant differences.

Table 1 Physical characteristics of adolescents before (Week 0) and at the end (Week 3) of the multidisciplinary weight-management program

	LI (*n*: 11)		HI (*n*: 9)		HIIT (*n*: 10)		Significance		
	Week 0	Week 3	Week 0	Week 3	Week 0	Week 3	G	P	G × P
Age (year)	16.4 ± 1.1	16.5 ± 1.1	16.1 ± 1.1	16.2 ± 1.0	16.8 ± 0.7	16.9 ± 0.7	.353	.001	.298
Height (m)	1.73 ± 0.07	1.73 ± 0.07	1.72 ± 0.08	1.72 ± 0.08	1.77 ± 0.06	1.77 ± 0.06	.244	.163	.232
Body mass (kg)	111.5 ± 14.8	103.2 ± 13.9	115.5 ± 9.1	109.3 ± 9.4	109.3 ± 9.0	104.4 ± 9.2	.578	.001	.001
BMI (kg m^{-2})	37.1 ± 3.1	34.3 ± 3.0	39.2 ± 3.7	37.0 ± 3.9	34.8 ± 3.0	33.2 ± 2.9	.085	.001	.001
FFM (kg)	69.2 ± 7.5	65.0 ± 8.4	70.9 ± 5.6	67.4 ± 6.3	69.6 ± 5.3	67.3 ± 5.6	.814	.001	.135
FM (kg)	42.4 ± 7.6	38.2 ± 6.0	44.6 ± 4.2	41.8 ± 3.8	39.6 ± 4.1	37.3 ± 4.4	.218	.001	.148
FM (%)	37.8 ± 2.1	37.0 ± 2.0	38.6 ± 1.5	38.3 ± 1.7	36.3 ± 1.2	35.6 ± 2.0	.094	.081	.807
BMR (MJ die^{-1})	8.66 ± 0.78	8.13 ± 1.02	9.27 ± 0.89	9.04 ± 0.96	9.68 ± 0.58	9.39 ± 0.59	.082	.014	.600
BMR (MJ kg FFM^{-1} die^{-1})	0.13 ± 0.02	0.13 ± 0.01	0.13 ± 0.02	0.14 ± 0.02	0.14 ± 0.01	0.14 ± 0.01	.088	.424	.539
$V'O_2$max (L min^{-1})	3.60 ± 0.44	3.62 ± 0.36	3.46 ± 0.35	3.89 ± 0.43	3.26 ± 0.66	3.62 ± 0.65	.621	.001	.023
$V'O_2$max (L kg FFM^{-1} die^{-1})	0.052 ± 0.006	0.056 ± 0.007	0.049 ± 0.003	0.058 ± 0.007	0.047 ± 0.008	0.054 ± 0.009	.447	.001	.147

All values are mean and standard deviation (SD)

LI low-intensity subgroup, *HI* high-intensity subgroup, *HIIT* high-intensity interval training subgroup, *BMI* body mass index, *FFM* fat-free mass, *FM* fat mass, *BMR* basal metabolic rate and *$V'O_2max$* maximal oxygen uptake

Significance by GLM repeated measures: group (G), period (P) and group × period interaction (G × P)

Results

Physical characteristics of subjects

Before the beginning of the weight-management program (W0), no significant differences were observed in the anthropometric and body composition characteristics between the three subgroups (Table 1). Mean BM, BMI, FFM and %FM were 111.8 ± 11.3 kg, 36.9 ± 3.6 kg m^{-2}, 69.8 ± 6.1 kg and 37.5 ± 1.8 %, respectively. BMR and $V'O_2$peak, expressed in absolute and in relative values, were not significantly different between the subgroups (on average: BMR, 9.21 ± 0.84 MJ d^{-1} and 0.13 ± 0.01 MJ kg FFM^{-1} d^{-1}; $V'O_2$peak: 3.44 ± 0.50 L min^{-1} and 0.049 ± 0.006 L kg F FM^{-1} min^{-1}).

Between W0 and W3, the decreases in BM and BMI were significantly greater in the LI than in the HI and HIIT subgroups (BM: −8.4 ± 1.5 vs −6.3 ± 1.9 and −4.9 ± 1.3 kg; BMI: −2.8 ± 0.4 vs −2.2 ± 0.6 and −1.6 ± 0.5 kg·m^{-2}, $p < 0.05$).

FFM and FM decreased significantly in all the three subgroups ($p < 0.005$), but changes were greater in the LI than in the HI and HIIT subgroup (FFM: −4.2 ± 1.4 vs −3.5 ± 2.4 and −2.2 ± 2.2 kg, $p < 0.05$; FM: −4.2 ± 1.9 vs −2.8 ± 1.2 and −2.3 ± 1.4 kg, $p < 0.05$).

BMR expressed both in absolute and in relative values did not change significantly between W0 and W3. $V'O_2$peak expressed both in absolute and in relative values did not change significantly in the LI subgroup, a significant increase ($p < 0.005$) being found in the HI (by 0.43 ± 0.39 L min^{-1} and 0.009 ± 0.005 L kg FFM^{-1} min^{-1}) and HIIT (by 0.36 ± 0.21 L min^{-1} and 0.007 ± 0.004 L kg FFM^{-1} min^{-1}) subgroups.

Energy expenditure and substrate oxidation rate during the incremental test

Relationships between EE (J min^{-1}) and substrate oxidation rate during walking at different intensities expressed as a percentage of $V'O_2$peak are reported in Fig. 1. At W0, mean energy expenditure, fat and carbohydrate oxidation rate were not significantly different between the LI, HI and HIIT subgroups at all exercise intensities. Energy expenditure and carbohydrate oxidation rate, expressed as absolute values, increased progressively with exercise intensity, whereas fat oxidation rate increased up to 45 % $V'O_2$peak and then decreased. In fact, with increasing exercise intensity, fat oxidation rate increased by mean to a maximum of 0.44 ± 0.05 g min^{-1} at 44 ± 4 % $V'O_2$peak (Fig. 1g, h, i). At exercise intensities above 57 ± 5 % $V'O_2$peak, fat oxidation rate decreased markedly and carbohydrates became the predominant source of energy for oxidation. The contribution of fat oxidation to energy supply became negligible above 72 ± 8 % $V'O_2$peak.

At W3, energy expenditure, carbohydrate and fat oxidation rates were not significantly different from those at W0 with all exercise intensities in the LI subgroup (Fig. 1 a, d, g). By contrast, the HI and HIIT subgroups exhibited a greater absolute rate of fat oxidation between 50 and 70 %$V'O_2$peak (Fig. 1 h, i), while the energy expenditure

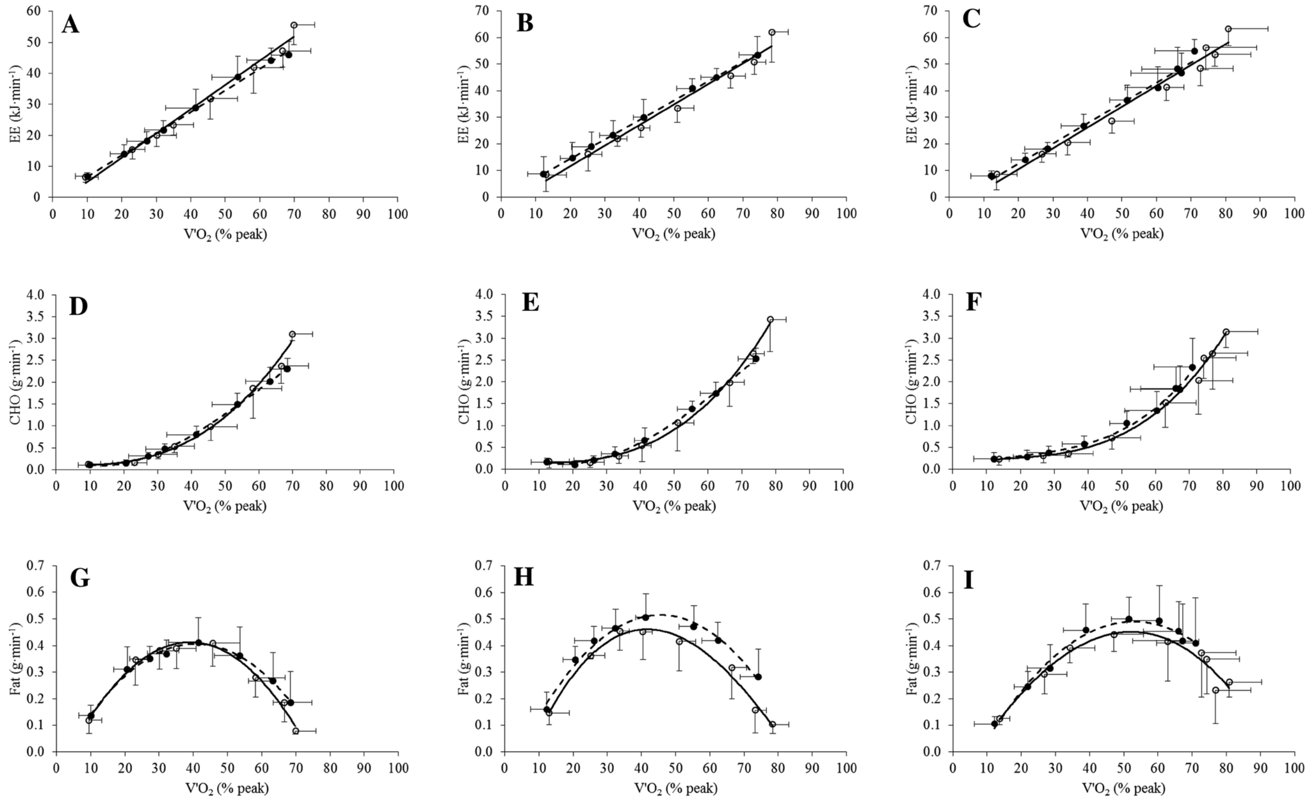

Fig. 1 Energy expenditure (EE, J·min^{-1}, panels a, b, c), carbohydrate (CHO, g·min^{-1}, panels d, e, f) and fat (g·min^{-1}, panels g, h, i) oxidation rates as a function of exercise intensity expressed as percent of peak oxygen uptake ($V'O_2$peak) in LI (panels a, d, g), HI (panels b, e, h) and HIIT (panels c, f, i) groups, before (Week 0, *opened circle*) and at the end (Week 3, *filled circle*) of the multidisciplinary weight-management program

and carbohydrate oxidation rate in W3 were not significantly different from those at W0 with all exercise intensities (Fig. 1 b, e, c, f).

Energy expenditure and substrate oxidation rate during the submaximal exercise and during the post-exercise recovery period

At W0, energy expenditures (EEs, Table 2) during the LI, HI and HIIT exercises were not significantly different (1521 ± 256 vs 1527 ± 102 vs 1494 ± 289 kJ, respectively, $p = 0.566$). Similarly, energy EEs during the post-exercise recovery period were not significantly different between the subgroups (488 ± 134 vs 527 ± 65 vs 498 ± 113 kJ, respectively, $p = 0.304$). Consequently, total EEs during the exercises and post-exercises recovery periods were not significantly different between the LI, HI and HIIT subgroups (2009 ± 378 vs 2054 ± 93 vs 1992 ± 391 kJ, $p = 0.450$).

However, during the exercise periods, energy from fat and the amount of fat oxidized was significantly greater in the LI group than in the HI and HIIT subgroups (+367 and +347 kJ; +10 and +9 g; respectively; $p < 0.001$), whereas energy from carbohydrates and the amount of carbohydrates oxidized was significantly lower in the LI group than in the HI and HIIT subgroups (−371 and −312 kJ; −21 and −19 g; $p < 0.001$) (Table 2). In addition, during the post-exercise recovery period, no significant differences were shown between the LI, HI and the HIIT groups, either in fat or carbohydrate oxidation rates (Table 2).

Between W0 and W3, EEs, fat and carbohydrate oxidation rates did not change significantly in the LI, HI and HIIT groups, during the exercise and the post-exercise recovery period (Table 2).

Discussion

The 3-week multidisciplinary body weight-management program entailing moderate energy restriction, nutritional education, psychological counseling (common to all subjects) and three different exercise training (LI, HI or HIIT) results in: (1) greater decreases in BM, FFM and FM in the LI than in the HI and HIIT subgroups; (2) significant improvement of $V'O_2$peak in the HI and HIIT subgroups; (3) significant increase in fat oxidation rate during the

Table 2 Energy expenditure and substrate oxidized during LI, HI and HIIT exercises and post-exercise recovery period before (Week 0) and at the end (Week 3) of the multidisciplinary body weight-management program

	LI (*n*:11)		HI (*n*:9)		HIIT (*n*: 10)		Significance		
	Week 0	Week 3	Week 0	Week 3	Week 0	Week 3	G	P	G × P
Total EE and substrate oxidized									
Total EE (kJ)	2009 ± 378	1978 ± 272	2054 ± 93	2211 ± 199	1992 ± 391	1955 ± 151	.450	.757	.727
EE from Fat (kJ)	1130 ± 269	1065 ± 285	750 ± 150	750 ± 243	761 ± 269	677 ± 209	.002	.582	.925
EE from CHO (kJ)	653 ± 115	699 ± 165	1072 ± 94	1211 ± 275	992 ± 126	1043 ± 221	.001	.213	.815
EE from Protein (kJ)	227 ± 43	222 ± 30	231 ± 8	249 ± 24	239 ± 47	235 ± 18	.555	.817	.730
Fat (g)	30 ± 7	28 ± 8	20 ± 4	20 ± 6	20 ± 7	18 ± 6	.002	.582	.925
CHO (g)	39 ± 7	42 ± 10	63 ± 5	71 ± 16	59 ± 8	62 ± 13	.001	.213	.815
Protein (g)	14 ± 3	13 ± 2	14 ± 1	15 ± 1	14 ± 3	14 ± 1	.555	.817	.730
EE and substrate oxidized during exercise									
Total EE (kJ)	1521 ± 256	1549 ± 201	1527 ± 102	1662 ± 156	1494 ± 289	1489 ± 172	.566	.511	.765
EE from Fat (kJ)	831 ± 178	812 ± 221	464 ± 106	466 ± 186	484 ± 178	441 ± 128	.001	.751	.950
EE from CHO (kJ)	518 ± 107	563 ± 142	889 ± 87	1007 ± 198	830 ± 120	869 ± 229	.001	.244	.836
EE from Protein (kJ)	172 ± 30	173 ± 22	173 ± 8	188 ± 19	179 ± 35	178 ± 21	.788	.581	.767
Fat (g)	22 ± 5	22 ± 6	12 ± 3	12 ± 5	13 ± 5	12 ± 3	.001	.751	.950
CHO (g)	31 ± 6	34 ± 9	52 ± 5	59 ± 11	50 ± 7	51 ± 14	.001	.244	.836
Protein (g)	10 ± 2	10 ± 1	10 ± 1	11 ± 1	11 ± 2	11 ± 1	.788	.581	.767
EE and substrate oxidized during post-exercise recovery period									
Total EE (kJ)	488 ± 134	438 ± 91	527 ± 65	549 ± 56	498 ± 113	467 ± 108	.304	.590	.754
EE from Fat (kJ)	300 ± 93	253 ± 67	286 ± 56	284 ± 69	277 ± 94	237 ± 88	.708	.327	.830
EE from CHO (kJ)	134 ± 36	136 ± 42	182 ± 30	204 ± 78	162 ± 19	173 ± 15	.071	.380	.850
EE from Protein (kJ)	54 ± 15	49 ± 10	59 ± 7	61 ± 6	60 ± 14	56 ± 13	.290	.590	.780
Fat (g)	8 ± 2	7 ± 2	8 ± 2	8 ± 2	7 ± 2	6 ± 2	.708	.327	.830
CHO (g)	8 ± 2	8 ± 3	11 ± 2	12 ± 5	10 ± 1	10 ± 1	.071	.380	.850
Protein (g)	3 ± 1	3 ± 1	4 ± 1	4 ± 1	4 ± 1	3 ± 1	.290	.590	.780

All values are mean and standard deviation (SD)

LI low-intensity subgroup, *HI* high-intensity subgroup, *HIIT* high-intensity interval training subgroup, *EE* energy expenditure and *CHO* carbohydrate

Significance by GLM repeated measures: group (G), period (P) and group × period interaction (G × P)

incremental test in the HI and HIIT groups; and (4) greater fat oxidation (in average 44 %) and lower carbohydrate oxidation (in average 70 %) during the submaximal exercises in the LI than in the HI and HIIT subgroups, both at W0 and W3.

The main objectives of the body weight-management programs in specialized institutions are to promote a correct lifestyle, to reduce FM, to maintain FFM and to improve cardiovascular fitness, thus enabling obese adolescents to increase spontaneous physical activities. Previous studies have shown that physical training associated with energy restriction (compared with energy restriction group alone) is a highly effective method in improving indexes of health, determining FM loss and preserving FFM during childhood [1, 26, 27]. In addition, increased physical capacities and optimizing fat oxidation during exercise are essential for promoting the reduction in adipose tissue [28]. In the present study, the LI, HI and HIIT groups had the same balanced diets formulated according to the Italian recommended dietary allowances [20]. Therefore, the greater decrease in FM observed between W0 and W3 in the LI than in the HI and HIIT subgroups could be attributed to the modality of training. This assumption concurs with the finding of greater fat oxidation rate in the LI than in the HI and HIIT groups during the submaximal exercise, as suggested by the results obtained during the incremental test in which the maximal fat oxidation rate was reached at 44 ± 4 % $V'O_2$peak. Therefore, LI exercise, corresponding to approximately 40 % $V'O_2$peak, seems an adequate level of physical activity to optimize fat oxidation rate, as observed in previous studies performed in obese children [29] and adolescents [5]. Otherwise, in children and adolescents, LI exercise is perceived as a boring exercise compared to other exercise modalities [10], which would have implications for participation in adherence to this type of activity, which could favor greater autonomous motivation [30].

At W3, HI and HIIT groups showed a greater increase in $V'O_2$peak than in LI (+12 and +11 %, respectively, $p < 0.005$), as previously shown [7, 15]. $V'O_2$max is an important marker of cardiometabolic health, and $V'O_2$max levels in youth predict cardiovascular disease in later life [31]. Particularly, several authors have shown that HI and HIIT improve $V'O_2$max favoring central effects (such as increasing maximal cardiac output, total hemoglobin and blood plasma volume) [32] and/or peripheral adaptations with an improved ability to extract and use available oxygen because of increased muscle oxidative potential [33]. In addition, in the HI and HIIT groups, fat oxidation rate, during the incremental test, was significantly greater in W3 than in W0, particularly between 50 and 70 %$V'O_2$peak (Fig. 1h, i). This difference could be related to the significantly greater $V'O_2$peak observed in W3 than in W0. In the present study, $V'O_2$peak increased significantly by mean 12 % between W0 and W3 in the HI and HIIT groups. Consequently, absolute workloads with comparable %$V'O_2$peak were greater in W3 than in W0, which could explain their greater absolute fat oxidation rate during exercise. The increase in fat oxidation rate (without changes in CHO oxidation rate) during exercise in obese subjects actually represents an interesting result because of improved metabolism and fat loss. Particularly, previous studies [34, 35] reported that obese subjects exhibited an earlier shift from lipid to CHO-derived fuels during exercise, compared to nonobese subjects. The earlier and greater participation of anaerobic glycogenolysis to energy production during exercise could be related to mitochondrial malfunction [36], or inefficient/incomplete b-oxidation [37], as well as to modifications of hormonal interactions [38], higher insulin and leptin levels [39] and reduced growth hormone and catecholamines responses to exercise [40]. Favoring fat oxidation rate during exercise could exert beneficial effects in long-term body weight reduction programs, although further additional studies are requested to confirm these preliminary observations.

Moreover, increasing or maintaining FFM is an important objective of the weight-management program because it is strongly related to physical capacities and BMR [41], which accounts for 60–70 % of daily energy expenditure in obese adolescents [42]. In the present study, the LI, HI and HIIT exercises were able to reduce FM, but not to maintain FFM. The lack of positive effects on FFM is not surprising after short-term training periods as in the present study, these effects being observed only with the inclusion of a strength training component in obese adolescents [43].

With reference to the submaximal exercises, previous studies have shown that exercise intensity also affected energy expenditure and fat oxidation rate during the post-exercise recovery period [44, 45]. However, in the present study, the LI, HI and HIIT equicaloric exercises did not significantly affect energy expenditure, or fat and carbohydrate oxidation rate during the post-exercise recovery period. Although the post-exercise period considered in our study was relatively short (60 min), our results are in agreement with previous studies which considered the effects of equicaloric LI and HI exercises on 24-h energy expenditure and substrate oxidation [46, 47].

Finally, several factors such as the patients' adherence to exercise contribute to the effects of the weight-management programs. Recent studies have reported that HIIT is perceived as a more enjoyable exercise compared to other exercise modalities and it appears more efficient in improving aerobic capacity and blood pressure, especially as compared to moderate-intensity continuous training [10]. Furthermore, both HI and HIIT programs seem to represent an effective alternative to LI program scheduled in a multidisciplinary body weight-management program, with the advantage of a lower volume of activity and reduced time commitment.

In conclusion, our data show that a 3-week weight-management program induces a greater decrease in BM and FM in the LI than in the HI and HIIT groups, and greater increase in $V'O_2$peak and fat oxidation rate in the HI and HIIT than in the LI group.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study was approved by the Ethics Committee of the Italian Institute for Auxology (Milan).

Informed consent Written informed consent was obtained before beginning the study.

References

1. Verrotti A, Penta L, Zenzeri L, Agostinelli S, De Feo P (2014) Childhood obesity: prevention and strategies of intervention. A systematic review of school-based interventions in primary schools. J Endocrinol Invest 37(12):1155–1164. doi:10.1007/s40618-014-0153-y
2. Swinburn B, Ravussin E (1993) Energy balance or fat balance? Am J Clin Nutr 57(5 Suppl):766S–770S

3. van Baak MA, van Mil E, Astrup AV, Finer N, Van Gaal LF, Hilsted J, Kopelman PG, Rossner S, James WP, Saris WH (2003) Leisure-time activity is an important determinant of long-term weight maintenance after weight loss in the Sibutramine Trial on Obesity Reduction and Maintenance (STORM trial). Am J Clin Nutr 78(2):209–214
4. Saris WH, Blair SN, van Baak MA, Eaton SB, Davies PS, Di Pietro L, Fogelholm M, Rissanen A, Schoeller D, Swinburn B, Tremblay A, Westerterp KR, Wyatt H (2003) How much physical activity is enough to prevent unhealthy weight gain? Outcome of the IASO 1st Stock Conference and consensus statement. Obes Rev 4(2):101–114
5. Lafortuna CL, Lazzer S, Agosti F, Busti C, Galli R, Mazzilli G, Sartorio A (2009) Metabolic responses to submaximal treadmill walking and cycle ergometer pedalling in obese adolescents. Scand J Med Sci Sports 23:23
6. Brandou F, Savy-Pacaux AM, Marie J, Bauloz M, Maret-Fleuret I, Borrocoso S, Mercier J, Brun JF (2005) Impact of high- and low-intensity targeted exercise training on the type of substrate utilization in obese boys submitted to a hypocaloric diet. Diabetes Metab 31(4 Pt 1):327–335
7. Lazzer S, Lafortuna C, Busti C, Galli R, Tinozzi T, Agosti F, Sartorio A (2010) Fat oxidation rate during and after a low- or high-intensity exercise in severely obese Caucasian adolescents. Eur J Appl Physiol 108(2):383–391. doi:10.1007/s00421-009-1234-z
8. van Aggel-Leijssen DP, Saris WH, Wagenmakers AJ, Senden JM, van Baak MA (2002) Effect of exercise training at different intensities on fat metabolism of obese men. J Appl Physiol 92(3):1300–1309
9. Garcia-Hermoso A, Cerrillo-Urbina AJ, Herrera-Valenzuela T, Cristi-Montero C, Saavedra JM, Martinez-Vizcaino V (2016) Is high-intensity interval training more effective on improving cardiometabolic risk and aerobic capacity than other forms of exercise in overweight and obese youth? A meta-analysis. Obes Rev 17(6):531–540. doi:10.1111/obr.12395
10. Lambrick D, Westrupp N, Kaufmann S, Stoner L, Faulkner J (2016) The effectiveness of a high-intensity games intervention on improving indices of health in young children. J Sports Sci 34(3):190–198. doi:10.1080/02640414.2015.1048521
11. Armstrong N, Tomkinson G, Ekelund U (2011) Aerobic fitness and its relationship to sport, exercise training and habitual physical activity during youth. Br J Sports Med 45(11):849–858. doi:10.1136/bjsports-2011-090200
12. Corte de Araujo AC, Roschel H, Picanco AR, do Prado DM, Villares SM, de Sa Pinto AL, Gualano B (2012) Similar health benefits of endurance and high-intensity interval training in obese children. PLoS ONE 7(8):e42747. doi:10.1371/journal.pone.0042747
13. Ramos JS, Dalleck LC, Tjonna AE, Beetham KS, Coombes JS (2015) The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a systematic review and meta-analysis. Sports Med 45(5):679–692. doi:10.1007/s40279-015-0321-z
14. Lunt H, Draper N, Marshall HC, Logan FJ, Hamlin MJ, Shearman JP, Cotter JD, Kimber NE, Blackwell G, Frampton CM (2014) High intensity interval training in a real world setting: a randomized controlled feasibility study in overweight inactive adults, measuring change in maximal oxygen uptake. PLoS ONE 9(1):e83256. doi:10.1371/journal.pone.0083256
15. Costigan SA, Eather N, Plotnikoff RC, Taaffe DR, Lubans DR (2015) High-intensity interval training for improving health-related fitness in adolescents: a systematic review and meta-analysis. Br J Sports Med 49(19):1253–1261. doi:10.1136/bjsports-2014-094490
16. Alkahtani SA, King NA, Hills AP, Byrne NM (2013) Effect of interval training intensity on fat oxidation, blood lactate and the rate of perceived exertion in obese men. Springerplus 2:532. doi:10.1186/2193-1801-2-532597
17. Buchheit M, Laursen PB (2013) High-intensity interval training, solutions to the programming puzzle: part I: cardiopulmonary emphasis. Sports Med 43(5):313–338. doi:10.1007/s40279-013-0029-x
18. Cacciari E, Milani S, Balsamo A, Spada E, Bona G, Cavallo L, Cerutti F, Gargantini L, Greggio N, Tonini G, Cicognani A (2006) Italian cross-sectional growth charts for height, weight and BMI (2 to 20 yr). J Endocrinol Invest 29(7):581–593
19. Tanner JM (1962) Growth at adolescence, 2nd edn. UK, Oxford
20. Nutrition ISo (1996) Recommended levels of energy and nutrients intake for the Italian population (LARN). Edra Medical Publishing and New Media, Milano
21. Lukaski HC (1987) Methods for the assessment of human body composition: traditional and new. Am J Clin Nutr 46(4):537–556
22. Lazzer S, Bedogni G, Agosti F, De Col A, Mornati D, Sartorio A (2008) Comparison of dual-energy X-ray absorptiometry, air displacement plethysmography and bioelectrical impedance analysis for the assessment of body composition in severely obese Caucasian children and adolescents. Br J Nutr 100(4):918–24. doi:10.1017/S0007114508922558
23. Weir JB (1949) New methods for calculating metabolic rate with special references to protein metabolism. J Physiol (Lond) 109:1–9
24. Achten J, Gleeson M, Jeukendrup AE (2002) Determination of the exercise intensity that elicits maximal fat oxidation. Med Sci Sports Exerc 34(1):92–97
25. Frayn KN (1983) Calculation of substrate oxidation rates in vivo from gaseous exchange. J Appl Physiol 55(2):628–634
26. Gutin B, Barbeau P, Owens S, Lemmon CR, Bauman M, Allison J, Kang HS, Litaker MS (2002) Effects of exercise intensity on cardiovascular fitness, total body composition, and visceral adiposity of obese adolescents. Am J Clin Nutr 75(5):818–826
27. Sothern MS, Loftin M, Suskind RM, Udall JN Jr, Blecker U (1999) The impact of significant weight loss on resting energy expenditure in obese youth. J Investig Med 47(5):222–226
28. Flatt JP (1993) Dietary fat, carbohydrate balance, and weight maintenance. Ann N Y Acad Sci 683:122–140
29. Maffeis C, Zaffanello M, Pellegrino M, Banzato C, Bogoni G, Viviani E, Ferrari M, Tato L (2005) Nutrient oxidation during moderately intense exercise in obese prepubertal boys. J Clin Endocrinol Metab 90(1):231–236 **Epub 2004 Oct 2013**
30. Saavedra JM, García-Hermoso A, Escalante Y, Domínguez AM (2014) Self-determined motivation, physical exercise and diet in obese children: a three-year follow-up study. Int J Clin Health Psychol 14:195–201
31. Bond B, Hind S, Williams CA, Barker AR (2015) The acute effect of exercise intensity on vascular function in adolescents. Med Sci Sports Exerc 47(12):2628–2635. doi:10.1249/MSS.0000000000000715
32. Astorino TA, Allen RP, Roberson DW, Jurancich M (2012) Effect of high-intensity interval training on cardiovascular function, VO2max, and muscular force. J Strength Cond Res 26(1):138–145. doi:10.1519/JSC.0b013e318218dd7700124278-201201000-00018
33. Burgomaster KA, Howarth KR, Phillips SM, Rakobowchuk M, Macdonald MJ, McGee SL, Gibala MJ (2008) Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. J Physiol 586(1):151–160. doi:10.1113/jphysiol.2007.142109
34. Gavarry O, Aguer C, Delextrat A, Lentin G, Ayme K, Boussuges A (2015) Severely obese adolescent girls rely earlier on carbohydrates during walking than normal-weight matched girls. J Sports Sci 33(18):1871–1880. doi:10.1080/02640414.2015.1021274

35. Perez-Martin A, Dumortier M, Raynaud E, Brun JF, Fedou C, Bringer J, Mercier J (2001) Balance of substrate oxidation during submaximal exercise in lean and obese people. Diabetes Metab 27(4 Pt 1):466–474
36. Boushel R, Gnaiger E, Schjerling P, Skovbro M, Kraunsoe R, Dela F (2007) Patients with type 2 diabetes have normal mitochondrial function in skeletal muscle. Diabetologia 50(4):790–796. doi:10.1007/s00125-007-0594-3
37. Koves TR, Ussher JR, Noland RC, Slentz D, Mosedale M, Ilkayeva O, Bain J, Stevens R, Dyck JR, Newgard CB, Lopaschuk GD, Muoio DM (2008) Mitochondrial overload and incomplete fatty acid oxidation contribute to skeletal muscle insulin resistance. Cell Metab 7(1):45–56. doi:10.1016/j.cmet.2007.10.013
38. Aucouturier J, Duche P, Timmons BW (2011) Metabolic flexibility and obesity in children and youth. Obes Rev 12(5):e44–e53. doi:10.1111/j.1467-789X.2010.00812.x
39. McMurray RG, Hackney AC (2005) Interactions of metabolic hormones, adipose tissue and exercise. Sports Med 35(5):393–412. doi:10.2165/00007256-200535050-00003
40. Eliakim A, Nemet D, Zaldivar F, McMurray RG, Culler FL, Galassetti P, Cooper DM (2006) Reduced exercise-associated response of the GH-IGF-I axis and catecholamines in obese children and adolescents. J Appl Physiol 100(5):1630–1637. doi:10.1152/japplphysiol.01072.2005
41. Lazzer S, Bedogni G, Lafortuna CL, Marazzi N, Busti C, Galli R, De Col A, Agosti F, Sartorio A (2009) Relationship between basal metabolic rate, gender, age, and body composition in 8,780 white obese subjects. Obesity 28:28
42. Lazzer S, Boirie Y, Bitar A, Montaurier C, Vernet J, Meyer M, Vermorel M (2003) Assessment of energy expenditure associated with physical activities in free-living obese and nonobese adolescents. Am J Clin Nutr 78(3):471–479
43. Stiegler P, Cunliffe A (2006) The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss. Sports Med 36(3):239–262
44. Smith J, Mc Naughton L (1993) The effects of intensity of exercise on excess postexercise oxygen consumption and energy expenditure in moderately trained men and women. Eur J Appl Physiol Occup Physiol 67(5):420–425
45. Phelain JF, Reinke E, Harris MA, Melby CL (1997) Postexercise energy expenditure and substrate oxidation in young women resulting from exercise bouts of different intensity. J Am Coll Nutr 16(2):140–146
46. Saris WH, Schrauwen P (2004) Substrate oxidation differences between high- and low-intensity exercise are compensated over 24 hours in obese men. Int J Obes Relat Metab Disord 28(6):759–765
47. Melanson EL, Sharp TA, Seagle HM, Horton TJ, Donahoo WT, Grunwald GK, Hamilton JT, Hill JO (2002) Effect of exercise intensity on 24-h energy expenditure and nutrient oxidation. J Appl Physiol 92(3):1045–1052