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Plyometric exercise combined with high-intensity interval training improves metabolic abnormalities in young obese females more so than interval training alone

Running title: Plyometric exercises plus high-intensity interval training and obesity

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Abstract

The aim of this study was to compare the effects of 12 weeks of high intensity interval training (HIIT) *vs* plyometric exercise combined with HIIT (P+HIIT) on anthropometric, biochemical and physical fitness data in young obese females. Sixty-eight participants (age: 16.6±1.3 y, body mass: 82.8±5.0 kg, body fat: 39.4±3.3%, body mass index *Z*-score: 2.9±0.4) were assigned to one of three groups: HIIT (2 blocks per session of 6-8 bouts of 30-s runs at 100% velocity at peak oxygen uptake: $v\dot{V}O_{2peak}$, with 30-s active recovery between bouts at 50% $v\dot{V}O_{2peak}$; n=23), P+HIIT (2 blocks per session of 3 different 15-s plyometric exercises with 15-s passive recoveries, totaling 2 min for each plyometric exercise + the same HIIT program; n=26) or control (no exercise; n=19). Anthropometric (body mass, body mass index *Z*-score, body fat, lean body mass and waist circumference), biochemical (plasma glucose, insulin, leptin and adiponectin concentrations, leptin/adiponectin ratio and homeostasis model assessment-insulin resistance: HOMA-IR), physical fitness (peak oxygen uptake, $v\dot{V}O_{2peak}$, squat jump and countermovement jump performances), and energy intake data were collected. Both training programs improved the anthropometric, biochemical and physical fitness variables. However, the P+HIIT program induced greater improvements than the HIIT program in lean body mass (+3.0±1.7%), plasma glucose and leptin concentrations (-11.0±4.7% and -23.8±5.8%, respectively), plasma leptin/adiponectin ratio (-40.9±10.9%), HOMA-IR (-37.3±6.2%) and squat jump performance (22.2±7.5%). Taken together, these findings suggest that adding plyometric exercises to a HIIT program may be more beneficial than only HIIT in obese female adolescents.

Keywords: obese children, intermittent exercise, strength training program, lean body mass, adipocytokines.

Introduction

The rising prevalence of adulthood overweight and obesity is a risk factor for many chronic diseases and death (Zhou 2002). In addition, childhood and adolescent obesity have reached unprecedented levels (Lobstein et al. 2015), and studies show that obese children and adolescents are more likely to become obese adults (Serdula et al. 1993; Witaker et al. 1997). The prevention and treatment of obesity in young people is therefore crucial.

Several strategies have been recommended to treat obesity. One of the commonest strategies is regular physical exercise. However, as Boutcher (2011) pointed out, most exercise recommendations to induce weight loss have focused on steady-state exercise (or continuous exercise). Yet the beneficial effects of this type of exercise are often disappointing over the long run because of poor program adherence. Indeed, the monotony of this type of exercise seems be an obstacle to breaking the vicious circle of the sedentary lifestyle (Coquart et al. 2008). Other types of exercise have therefore been proposed, like interval training (*i.e.,* exercise during which the intensity varies regularly) (Coquart et al. 2008; Racil et al. 2015), which obese patients reported as being less difficult than steady-state exercise (Coquart et al. 2008). Moreover, its beneficial effects on anthropometric, physiological and physical fitness variables in obese adults were demonstrated (Coquart et al. 2008). More recently, Racil et al. (2013) compared the effects of moderate- *vs* high-intensity interval training (HIIT) on the anthropometric, biochemical and physical fitness variables in obese female adolescents. Their results indicated that both interval training programs had numerous beneficial effects in this age group, although anthropometric (*i.e.*, body fat and body mass index *Z*-score: BMI *Z*-score) and biological (*i.e.*, total cholesterol, low-density lipoprotein cholesterol and insulin concentrations) improvements were significantly better with HIIT. Therefore, HIIT can be recommended for young (Racil et al. 2013) and adult obese populations (Paoli et al. 2013).

On the other hand, plyometric is a type of training where muscles undergo a rapid elongation followed by an immediate shortening (stretch-shortening contraction), utilizing the elastic energy stored during the stretching phase (Cavagna, 1977). It has been demonstrated that explosive-type resistance training is efficient in improving vertical jump and has been shown to improve muscle strength (Mcbride et al. 2002).

Therefore, plyometric exercise may be considered an important component of exercise programs for the obese. Russell et al. (2014) recently examined the effects of a resistance training program including plyometric exercises on fasting plasma glucose concentration. The results showed a significant decrease in glucose concentration and increased strength, which were inversely correlated ($P \leq 0.05$; $r = -0.52$). Moreover, Shabi et al. (2006) reported that male adolescents with high obesity risk were able to significantly increase insulin sensitivity after 16 weeks of resistance training. These authors suggested indeed that the qualitative changes in skeletal muscle have contributed to this enhancement. Further, it appears that the impact of resistance training on muscle mass and strength in both young and older individuals is more pronounced with high training intensities (Fielding, 1995), which can result significant effects on insulin sensitivity (Miller et al. 1994; Ryan et al. 1996).

According to the previous studies, it has been indicated that muscle growth largely explain the disparity between sexes, especially for absolute measures of muscular strength and power (Neu et al. 2002; O'Brien et al. 2009). In this context, it is interesting to note that the sex-related differences in muscular strength are more evident as children enter adolescence, with males consistently outperforming females (O'Brien et al. 2010). However, to the best of the authors' knowledge, no study has yet examined the effects of plyometric exercise combined with HIIT (*i.e.*, P+HIIT) in the young obese population.

The adipocytokines, mainly leptin and adiponectin, are biologically active proteins that are significantly correlated (negatively for adiponectin) with the body mass index percentile in children (Chi-Jen et al. 2015). Moreover, leptin and adiponectin have been associated with insulin resistance (Yamamoto et al. 2002), which is frequently observed in obese patients. HIIT was demonstrated to significantly decrease plasma leptin concentration (Sartor et al. 2010) and increase plasma adiponectin concentration (Racil et al. 2013). However, no study has yet compared HIIT with P+HIIT to determine which would be the optimal exercise protocol to beneficially affect adipocytokines in the obese population. Therefore, the main aim of the present study was to analyze the effects of HIIT and P+HIIT on anthropometric, biochemical and physical fitness variables in obese female adolescents.

We hypothesized that the participants in the P+HIIT program would exhibit significantly greater insulin sensitivity which decreases the plasma glucose concentration compared with HIIT program.

Materials and methods

Participants

Seventy-five obese female adolescents, recruited from five secondary schools of the same region, volunteered to take part in this study. All participants were classified according to BMI which was calculated in the standard way, using the algorithm provided by the Centers for Disease Control and Prevention (CDC). Firstly, BMI was calculated from following equation: BMI (in $kg.m^{-2}$) = body mass (in kg) ÷ $height^2$ (in m). Then, the BMI scores were transformed to produce age- and sex-adjusted BMI percentiles using the CDC growth chart. None of the participants was involved in systematic exercise training at the time of data collection. Prior to data collection, all participants and parents provided written informed consent in accordance with the international ethical standards and the 1964 Helsinki Declaration and its later amendments. This study was approved by the local research ethics committee.

Anthropometric measures

During a preliminary session, the height of each participant was measured using a wall stadiometer, and body mass and percentages of body fat and lean body mass were assessed with a calibrated bioelectrical impedance scale (TBF-300, Tanita®, Tokyo, Japan). As recommended for children and adolescents (Rolland-Cachera et al. 1991), BMI *Z*-scores were calculated. Waist circumference was measured at the mid-point between the bottom of the rib cage and the iliac crest. All measurements were conducted on the same morning between 8:30 a.m. and 12:30 p.m. by the same evaluator.

Biochemical analysis

Twelve-hour fasting blood samples were taken from an antecubital vein before the intervention program; between 7:00 and 9:00 a.m. Samples were collected and then centrifuged for 15 min at 3000 rpm. Plasma samples were stored at -80°C until assayed. Plasma glucose concentration was measured by the hexokinase method using an automated device (Architect c8000, Abbott®, Quebec, Canada). Plasma insulin concentrations were measured by radioimmunoassay kits (Immunotech A, Beckman Coulter Company®, Marseille, France). Insulin resistance was assessed using the homeostasis model assessment-insulin resistance (HOMA-IR), computed as follows:

$$\text{HOMA-IR} = [\text{fasting insulin } (\mu\text{U.mL}^{-1}) \times \text{fasting glucose } (\text{mmol.L}^{-1})] \div 22.5$$

Plasma leptin and adiponectin were evaluated in duplicate runs using an enzyme-linked immunosorbent assay (ELISA) kit (Quantikine: human total adiponectin/acrp 30 immunoassay and human leptin immunoassay). From these plasma concentrations, the adiponectin/leptin ratio was also calculated. This ratio is important since it has been proposed as biological and potential index of insulin sensitivity during growth (Koebnick et al. 2007).

Physical fitness evaluation

Before the intervention period, all participants performed a graded exercise test until exhaustion (Cazorla, 1990). This maximal test was carried out on 200-m outdoor track calibrated with cones. The test starts at a running speed of 8.5 $km.h^{-1}$ and increases by 0.5 $km.h^{-1}$ every minute until exhaustion. During the test, respiratory gas exchange was measured breath-by-breath using a calibrated portable telemetry system (K_4b^2, Cosmed®, Rome, Italy). Moreover, heart rate was monitored using a heart rate monitor (S-610, Polar®, Kempele, Finland). Exhaustion was verified based on the following criteria: 1) a plateau in oxygen uptake, 2) respiratory exchange ratio $\geq$ 1.1, 3) peak heart rate ± 10 bpm of the predicted maximal heart rate (220 - age), and 4) apparent voluntary exhaustion. At least three of the four criteria were met or the test was repeated. Once exhaustion was confirmed, peak oxygen uptake ($\dot{V}O_{2peak}$) and velocity at $\dot{V}O_{2peak}$ (*i.e.*, $v\dot{V}O_{2peak}$) were identified.

The squat jump (SJ) and countermovement jump (CMJ) were performed using an infrared jump system (Optojump, Microgate®, Bolzano, Italy) interfaced with a microcomputer. Participants were asked to perform the SJ with feet parallel and shoulder-width apart, good balance in an upright position with the trunk remaining as vertical as possible, and hands on the hips throughout the test with a knee angle around 90°. The trial was not considered valid if any movement was perceived with the increased knee flexion at the start of the jump. For the CMJ, participants started from an upright standing position and made a preliminary downward movement by flexing the knees and hips, with a knee angle around 90° at the end of the countermovement. The trial was not considered valid if the knees did not bend quickly and to the maximum. The best of three trials was recorded for SJ and CMJ.

Energy intake

All participants completed a 4-day dietary questionnaire (3 weekdays and 1 weekend day) in the week prior to the intervention program. The questionnaire responses were then analyzed with Bilnut 2.01 software (Nutrisoft®, Cerelles, France) to determine energy intake ($kcal.day^{-1}$).

Intervention protocol

After the evaluations of baseline anthropometric, biochemical, physical fitness and energy intake data, the participants were randomly assigned to one of the three following groups: high-intensity interval training only (HIIT group, n = 23), combined plyometric exercise and high-intensity interval training (P+HIIT group, n = 26), or no-exercise control (n = 19).

The high-intensity interval exercises in both training groups (*i.e.*, HIIT and P+HIIT) were composed of two blocks of six (in the first 4 weeks) or eight bouts of 30-s runs at 100% velocity at $\dot{V}O_{2peak}$ ($v\dot{V}O_{2peak}$) with 30 s of active recovery between bouts at 50% $v\dot{V}O_{2peak}$, on an 200-m outdoor track. The two blocks were separated by a 4-min passive recovery period. The exercise intensities were increased by 5% $v\dot{V}O_{2peak}$ at the start of each consecutive 4-week period. The training sessions were held 3 days per week for 12 weeks (*i.e.*, Monday, Wednesday and Friday).

In the P+HIIT group, the high-intensity interval exercises were preceded by plyometric exercises. Those exercises were based on findings from previous investigations (Chu et al.

2006; Myer et al. 2005). Two blocks of three different plyometric exercises : weeks 1-4: double-leg jump, medicine ball overhead throw, and medicine ball single-leg dip; weeks 5-8: hurdle hops, zig-zag jump drill, and medicine ball backward throw; weeks 9-12: single-leg cone hops, single-leg zig-zag drill, and medicine ball partner push pass were performed in each training session. It is worth noting that participants performed basic plyometric movements in the first training period (weeks 1-4), which could provide the occasion to participants to gain confidence in their abilities before progressing to more advanced drills at second (weeks 5-8) and at the third training periods (weeks 9-12) (Myer et al. 2005). Each plyometric exercise was maintained for 2 min (15 s of plyometric exercise *vs* 15 s of passive recovery). Between each block and between each new exercise, the passive recovery periods lasted 1 min and 30 s, respectively.

All training sessions (HIIT and P+HIIT) started with a standardized warm-up (*i.e.*, 10 min of jogging at 50% $v\dot{V}O_{2peak}$ and then 5 min of dynamic stretching exercises and 5 accelerations over 20 m with 1 min of recovery between) and ended with a cool-down at 50% $v\dot{V}O_{2peak}$ for 10 min followed by 5 min of static stretching. Throughout the study period and prior to each test commencement, an experienced physical education teacher demonstrated the proper exercise technique. All participants were consistently encouraged to maintain proper technique performance for as long as possible.

General information

Whatever the group, all participants were instructed to maintain their usual physical activity level and their usual diet. After the 12-week intervention period, all anthropometric, biochemical, physical fitness and energy intake data were collected again, in the same conditions and by the same evaluators.

Statistical analysis

Data are reported as mean and standard deviation. The Shapiro-Wilk test was applied to examine normality, whereas homogeneity of variance was assessed using Levene's test. Once the assumption of normality was confirmed, parametric tests were performed. Data were analyzed using a two-way analysis of variance with repeated measures (3 groups: HIIT *vs* P+HIIT *vs* control × 2 times: before *vs* after the intervention program). Whenever significant differences in values occurred, a pairwise multiple comparisons test was performed using a Bonferroni *post-hoc* test.

Percentage changes in the variables from pre- to post-intervention were calculated, and a one-way ANOVA was conducted to identify the differences between groups. When data were not normally distributed, the nonparametric Kruskal–Wallis test was used.

All statistical analysis was performed using SPSS version 20.0 (SPSS®, Chicago, IL, USA). The level of statistical significance was set at $P < 0.05$.

Results

During the 12 weeks intervention period no injuries were reported but seven subjects were unable to complete the training program or achieve all the tests at post-intervention for personal reasons: two from (HIIT group), one from (P+HIIT group) and four from control group, and their data are thus excluded from all analyses. Therefore, 68 obese female adolescents (age: 16.6 ± 1.3 y, height: 1.63 ± 0.05 m, body mass: 82.8 ± 5.0 kg, body fat: 39.4 ± 3.3%, BMI *Z*-score: 2.9 ± 0.4) have fully completed the current study. The values of all anthropometric, biochemical, and physical fitness variables and energy intake, measured before and after the intervention period, are presented in Table 1. Moreover, the percentage changes in these data are presented in Table 2.

Significant decreases were noted in body mass, BMI *Z*-score, body fat and waist circumference in both training groups (*i.e.*, HIIT and P+HIIT; $P < 0.05$; Table 1), but only the P+HIIT group showed a significant increase in lean body mass ($P = 0.021$). This increase was significantly different from that of the other groups ($P = 0.012$; Table 2).

The plasma glucose and insulin concentrations were significantly decreased in the HIIT and P+HIIT groups after the training program, resulting in a significant decrease in HOMA-IR in both groups ($P < 0.05$; Table 1). The decreases in plasma glucose concentration and HOMA-IR were significantly greater in the P+HIIT group than in the other groups ($P < 0.05$; Table 2). The HIIT and P+HIIT groups also showed a significant decrease in plasma leptin concentration ($P = 0.033$ and $P = 0.019$, respectively) and an increase in plasma adiponectin concentration ($P = 0.029$ and $P = 0.012$, respectively; Table 1). Moreover, the plasma leptin/adiponection ratio was significantly reduced in both training groups ($P < 0.01$; Table 1).

In the between-group comparison, P+HIIT showed a significant decrease in plasma leptin concentration and the plasma leptin/adiponection ratio, which were greater than in the other groups ($P < 0.05$; Table 2).

$\dot{V}O_{2peak}$, v$\dot{V}O_{2peak}$ and SJ and CMJ performances were significantly increased in both trained groups ($P < 0.05$; Table 1). The improvement in SJ was significantly greater in the P+HIIT group compared with the other groups ($P = 0.035$ Table 2).

No significant change in energy intake was noted in any group ($P > 0.05$; Tables 1 and 2).

Discussion

The main aim of the present study was to analyze the effects of HIIT and P+HIIT on anthropometric, biochemical and physical fitness data in obese female adolescents. The results indicate that 12 weeks of HIIT or P+HIIT training (without dietary restriction) improved these data in the adolescents (Table 1). However, the P+HIIT program induced significantly greater improvements in lean body mass, plasma glucose and leptin concentrations, HOMA-IR, the plasma leptin/adiponectin ratio and SJ performance (Table 2).

According to numerous studies (Boutcher 2011; Paoli et al. 2013; Racil et al. 2013), HIIT (with or without plyometric exercises) is especially efficient to reduce body mass and fat in the obese population. Consequently, adding to the fact that this training modality increases insulin sensitivity (Racil et al. 2013), the plyometric exercises place significant stress on the musculoskeletal system (Fowler et al. 1995). It is important to mention that following intense exercises, a metabolic stress on active muscle fibers occurs, leading to increases in glucose uptake resulting in enhanced insulin sensitivity (DiPietro et al. 2006; Rose and Richter, 2005).

However, to increase lean body mass, the recommendation is to associate HIIT with resistance exercises (Table 2). Some authors have suggested that aerobic exercise is the optimal training mode to reduce body mass and fat, whereas a training program including resistance exercise (such as plyometric exercises) is advised to increase lean body mass (Ghahramanloo et al. 2009; Willis et al. 2012). Thus, to further increase the beneficial effects of HIIT on lean body mass, resistance exercise should be associated (Table 2). This latter type of exercise is essential because it increases muscle mass, and skeletal muscle is the major site of insulin-stimulated glucose utilization in the body (Joseph and Hood, 2014). Indeed, an increase in muscle mass suggests an enhanced number of mitochondria, which improves the ability of muscle to oxidize substrates (*i.e.*, glucose and free fatty acids), thus reducing plasma glucose concentration, which we suppose was the case in our study in the P+HIIT group. In fact, results have shown that glucose concentration was significantly lower in the P+HIIT group compared with the HIIT and control groups (Table 2). In the same context an increase in muscle mass suggests also an enhanced free fatty acid concentration and insulin resistance as shown in our study with a significantly lower HOMA-IR in the P+HIIT group (Table 2). This may prevent complications linked to obesity (*e.g.*, metabolic syndrome, type 2 diabetes, myocardial infarction).

Furthermore, it is likely that the greater effect on insulin sensitivity may be the result of type of training (*i.e.,* P+HIIT) and the intensity which induces the metabolic responses that predominantly depend on carbohydrates as the main fuel source (*i.e.,* phosphocreatine and anaerobic glycolysis systems). In fact, other studies have demonstrated that resistance training at high intensity was safe and well tolerated by older patients with type 2 diabetes, was effective in improving glycemic control (Dunstan et al. 2002), and has improved insulin action in healthy young women (Poehlman et al. 2000).

On the other hand, leptin and adiponectin, two hormones secreted by adipocytes, are counter-regulated *in vivo* and exert opposing effects on glucose metabolism, fat oxidation, and insulin sensitivity (Ceddia 2005; Yamauchi et al. 2002). In this context, some authors have proposed the leptin/adiponectin ratio as a potential marker for the comorbidities of childhood obesity (Diamond et al. 2004). More recently, this hypothesis seems to have been confirmed because the number of metabolic syndrome alterations was found to be correlated with the leptin/adiponectin ratio in obese adolescents (Masquio et al. 2015). We therefore assume that the significant decrease in this ratio in the present study indicated an improvement in the health status of our obese female adolescents after participation in an interval training program, and this was remarkably so in the P+HIIT group (Table 2).

The significantly greater decrease in the leptin/adiponectin ratio in the P+HIIT group seemed mainly linked to a significantly greater reduction in the plasma leptin concentration (Table 2). This latter decrease is important in obesity treatment because leptin increases the rate of insulin-stimulated glucose uptake and glucose oxidation, and normalizes the rate of glycogen synthesis (Yaspelkis et al. 2004), thus suggesting a reduction in plasma glucose concentration (which decreased more in the P+HIIT group than the HIIT group; Table 2). Theoretically, these responses might be due in part to the normalization of glucose transporter type-4 protein (GLUT4) concentration in the muscle (Yaspelkis et al. 2004). However, since Donges et al. (2013) recently showed an increase in insulin sensitivity after a training program (*i.e.*, aerobic and/or resistance exercise) and did not note a change in GLUT4 muscle content in untrained middle-aged men, further studies are needed to better understand the mechanisms linked to the reduction in plasma glucose concentration in obese adolescents.

After the intervention period, HOMA-IR was reduced to 3.2 ± 0.4 and 2.7 ± 0.3 in the HIIT and P+HIIT groups, respectively (Table 1). The HOMA-IR cut-off point for a diagnosis of insulin resistance was reported to be 3.16 in adolescents (Keskin et al. 2005). As such 14 (*i.e.*, 60.8%) and 23 (*i.e.*, 88.5%) adolescents were below this threshold value after the HIIT and P+HIIT programs, respectively. According to present results, it seems that this training modality (*i.e.,* P+HIIT) can provide an opportunity for all youth, regardless of body mass and fitness level, to experience success and feel good about their body. On the other hand, as overweight/obese children and adolescents seem to demonstrate significantly lower motor coordination than youth with 'normal' body mass index (D’hondt et al. 2011; Nunez-Gaunaurd et al. 2013), it is possible that HIIT associated to coordination exercises and/or conventional resistance exercise would provide higher benefits to P+HIIT. Therefore, an additional work is also required to assess even more the appropriateness of such programs for obese female adolescents.

While both training groups (*i.e.*, HIIT and P+HIIT) improved SJ and CMJ performances (Table 1), SJ improvement was greater in the P+HIIT group (Table 2). Recently, Russell et al. (2014) showed strength improvement after a resistance training program including plyometric exercise. Moreover, the authors reported that the strength changes were inversely correlated with fasting plasma glucose concentration. The current study also suggests this because both variables were significantly higher in the P+HIIT group than in the other groups (Table 2). Consequently, to optimize strength gains, it seems necessary to include resistance exercises in interval training programs.

Last, Coquart et al. (2008) proposed interval training as a way to increase adherence to exercise programs and limit the monotony of steady-state exercise (or continuous exercise), which is frequently offered in intervention programs. However, it now remains to be seen whether the P+HIIT program confers more long-term adherence benefits for obese female adolescents than HIIT alone.

Some limitations of this study are acknowledged. Firstly, cycling rather than running on the track may be a more appropriate exercise modality, given orthopaedic issues that may occur in obese population. However, the running exercise may be performed without ergometer and thus in the daily life.

On the other hand, since the sex-related (anthropometric and physiological) differences begin from the adolescence, and since the boys spend more time in physical exercise with vigorous- or moderate-intensity than girls (Belsky et al. 2003), we opted in the current study to focus only on obese adolescent females in order not to have any confounding effects of sex on the collected results. Further study in obese male adolescents would also be useful.

Conclusion

The current study findings demonstrate that the HIIT appears to be an efficient strategy to combat obesity. Moreover, as HIIT is less monotonous (because of intensity variation) than traditional aerobic exercise (in which the exercise intensity is continuous), HIIT may be recommended to improve the adherence in training program. Furthermore, to optimize the taking over, P+HIIT must be preferred to only HIIT. Indeed, this training modality produces better physiological adaptations (*e.g.*, management of glycemic control) than HIIT in obese female adolescents. Additional studies are nevertheless needed to elucidate the mechanisms of these specific adaptations.

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	HIIT group (n = 23)		P+HIIT group (n = 26)		Control group (n = 19)	
	Pre-	Post-	Pre-	Post-	Pre-	Post-
Age (y)	16.6 ± 0.9		16.5 ± 1.2		16.9 ± 1.0	
Height (m)	1.63 ± 0.05	1.63 ± 0.05	1.63 ± 0.02	1.64 ± 0.02	1.64 ± 0.06	1.64 ± 0.06
Body mass (kg)	83.9 ± 4.5	80.7 ± 5.7*	82.5 ± 5.4	80.8 ± 5.0*	81.8 ± 5.2	81.3 ± 4.9
Body mass index *Z*-score	2.9 ± 0.2	2.4 ± 0.3*	2.9 ± 0.3	2.6 ± 0.2*	2.8 ± 0.3	2.7 ± 0.3
Body fat (%)	39.3 ± 1.7	36.5 ± 1.3*	41.7 ± 3.6	38.8 ± 3.7*	36.7 ± 2.0	37.0 ± 1.9
Lean body mass (kg)	50.9 ± 2.9	51.2 ± 3.8	48.2 ± 5.6	49.6 ± 5.7*§	51.7 ± 3.1	51.3 ± 3.2
Waist circumference (cm)	93 ± 5	90 ± 6*	94 ± 5	90 ± 4*	93 ± 4	92 ± 3
Plasma glucose (mmol.l^{-1})	4.8 ± 0.5	4.6 ± 0.4*	4.6 ± 0.5	4.1 ± 0.4$^{\#\S}$	4.7 ± 0.3	4.8 ± 0.4
Plasma insulin (µU.ml^{-1})	21.1 ± 2.4	15.6 ± 1.2$^{\#}$	20.8 ± 1.8	14.6 ± 1.0$^{\#£}$	19.2 ± 2.0	18.6 ± 1.6
Homeostasis model assessment-insulin resistance	4.5 ± 0.7	3.2 ± 0.4$^{\#}$	4.3 ± 0.6	2.7 ± 0.3$^{\Phi\S}$	4.1 ± 0.6	4.0 ± 0.5
Plasma leptin (ηg.ml^{-1})	20.2 ± 2.6	17.3 ± 1.8*	17.6 ± 2.3	13.5 ± 2.0*§	18.5 ± 2.0	18.9 ± 1.8
Plasma adiponectin (µg.ml^{-1})	7.5 ± 1.5	9.4 ± 1.7$^{*£}$	8.0 ± 1.3	10.5 ± 1.7$^{*£}$	7.1 ± 1.1	7.4 ± 0.7
Plasma leptin/adiponectin ratio	2.8 ± 0.6	1.9 ± 0.4$^{\#}$	2.3 ± 0.5	1.3 ± 0.3$^{\Phi\S}$	2.7 ± 0.6	2.6 ± 0.3
Peak oxygen uptake (ml.kg^{-1}.min^{-1})	36.7 ± 1.1	39.2 ± 1.0$^{\#}$	36.0 ± 1.7	39.4 ± 1.8$^{\#}$	38.3 ± 1.4	38.8 ± 1.5
Velocity at peak oxygen uptake (km.h^{-1})	10.1 ± 0.8	11.2 ± 0.9*	9.8 ± 0.7	10.9 ± 0.7*	10.2 ± 0.4	10.4 ± 0.7
Performance in squat jump (cm)	17.9 ± 2.3	19.7 ± 2.4*	17.1 ± 2.5	20.8 ± 2.2$^{\#£}$	18.1 ± 1.5	18.4 ± 1.4
Performance in countermovement jump (cm)	18.9 ± 2.7	21.2 ± 2.9*	18.8 ± 2.7	22.5 ± 2.6$^{\#}$	20.2 ± 2.0	20.6 ± 2.6
Energy intake (kcal.d^{-1})	3002 ± 107	2900 ± 93	2888 ± 96	2812 ± 92	2945 ± 96	2904 ± 99

Table 1. Anthropometric, biochemical, and physical fitness data and energy intake (mean ± standard deviation) pre- and post-intervention program, in HIIT (high-intensity interval training), P+HIIT (plyometric exercises combined with HIIT) and control groups.

Significantly different within each group before *vs* after the intervention program *: $P < 0.05$, $^{\#}$: $P < 0.01$, $^{\Phi}$: $P < 0.001$. Significantly different from control $^{£}$: $P < 0.05$. Significantly different from the other groups §: $P < 0.05$.

	HIIT group (n = 23)	P+HIIT group (n = 26)	Control group (n = 19)
Body mass	-3.8 ± 3.9$^{£}$	-2.0 ± 1.0$^{£}$	-0.6 ± 1.6
Body mass index *Z*-score	-15.9 ± 4.8$^{£}$	-9.6 ± 2.6$^{£}$	-3.7 ± 2.3
Body fat	-7.1 ± 1.7$^{£}$	-7.2 ± 1.8$^{£}$	0.6 ± 0.9
Lean body mass	0.6 ± 4.4	3.0 ± 1.7§	-0.9 ± 1.5
Waist circumference	-3.2 ± 2.2$^{£}$	-4.0 ± 1.0$^{£}$	-0.6 ± 1.0
Plasma glucose	-3.4 ± 1.2$^{£}$	-11.0 ± 4.7§	1.3 ± 3.5
Plasma insulin	-25.8 ± 5.9$^{£}$	-29.5 ± 5.6$^{£}$	-3.2 ± 3.2
Homeostasis model assessment-insulin resistance	-28.3 ± 5.8$^{£}$	-37.3 ± 6.2§	-2.0 ± 2.8
Plasma leptin	-14.0 ± 5.4$^{£}$	-23.8 ± 5.8§	3.0 ± 10.3
Plasma adiponectin	27.3 ± 20.7$^{£}$	32.8 ± 20.6$^{£}$	5.7 ± 12.1
Plasma leptin/adiponectin ratio	-31.3 ± 8.9$^{£}$	-40.9 ± 10.9§	-0.8 ± 18.8
Peak oxygen uptake	7.0 ± 2.2$^{£}$	9.5 ± 3.0$^{£}$	1.2 ± 1.5
Velocity at peak oxygen uptake	10.9 ± 4.8$^{£}$	11.7 ± 6.0$^{£}$	2.1 ± 3.2
Performance in squat jump	10.4 ± 3.8$^{£}$	22.2 ± 7.5§	1.4 ± 1.9
Performance in countermovement jump	11.8 ± 4.2$^{£}$	20.0 ± 10.2$^{£}$	1.7 ± 3.6
Energy intake	-3.4 ± 2.4	-2.6 ± 1.7	-1.4 ± 1.6

Table 2. Percentage changes in anthropometric, biochemical, physical fitness data and energy intake (mean ± standard deviation) after the intervention program, in HIIT (high-intensity interval training), P+HIIT (plyometric exercises combined to HIIT) and control groups. Significantly different from control $^{£}$: $P < 0.05$. Significantly different from the other groups §: $P < 0.05$.

Captions of tables.

Table 1. Anthropometric, biochemical, and physical fitness data and energy intake (mean ± standard deviation) pre- and post-intervention program, in HIIT (high-intensity interval training), P+HIIT (plyometric exercises combined with HIIT) and control groups. Significantly different within each group before *vs* after the intervention program *: $P < 0.05$, $^{\#}$: $P < 0.01$, $^{\Phi}$: $P < 0.001$. Significantly different from control $^{£}$: $P < 0.05$. Significantly different from the other groups §: $P < 0.05$.

Table 2. Percentage changes in anthropometric, biochemical, physical fitness data and energy intake (mean ± standard deviation) after the intervention program, in HIIT (high-intensity interval training), P+HIIT (plyometric exercises combined to HIIT) and control groups. Significantly different from control $^{£}$: $P < 0.05$. Significantly different from the other groups §: $P < 0.05$.