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ORIGINAL ARTICLE

The effects of high-intensity intermittent exercise training on fat loss and fasting insulin levels of young women

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Objective: To determine the effects of a 15-week high-intensity intermittent exercise (HIIE) program on subcutaneous and trunk fat and insulin resistance of young women.
Design and procedures: Subjects were randomly assigned to one of the three groups: HIIE ($n=15$), steady-state exercise (SSE; $n=15$) or control (CONT; $n=15$). HIIE and SSE groups underwent a 15-week exercise intervention.
Subjects: Forty-five women with a mean BMI of $23.2\pm2.0\,kg\,m^{-2}$ and age of 20.2 ± 2.0 years.
Results: Both exercise groups demonstrated a significant improvement ($P<0.05$) in cardiovascular fitness. However, only the HIIE group had a significant reduction in total body mass (TBM), fat mass (FM), trunk fat and fasting plasma insulin levels. There was significant fat loss ($P<0.05$) in legs compared to arms in the HIIE group only. Lean compared to overweight women lost less fat after HIIE. Decreases in leptin concentrations were negatively correlated with increases in VO_{2peak} ($r=-0.57$, $P<0.05$) and positively correlated with decreases in TBM ($r=0.47$; $P<0.0001$). There was no significant change in adiponectin levels after training.
Conclusions: HIIE three times per week for 15 weeks compared to the same frequency of SSE exercise was associated with significant reductions in total body fat, subcutaneous leg and trunk fat, and insulin resistance in young women.
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Keywords: intermittent sprinting; body fat; insulin

Introduction

Overweight and obesity levels have escalated worldwide, and these trends are occurring in both developed and developing countries. It has been estimated that the current level of 250 million obese (7% of world population), is likely to significantly increase in future.[1] As being overweight is associated with long-term ill health and reduced life quality, it has been recommended that effective weight loss strategies be developed.[2] Although caloric restriction has been the major weight loss strategy, it has been shown that exercise programs designed for fat loss result in an increase in cardiorespiratory fitness[3] and a preservation of fat-free mass.[4–6] Most exercise programs designed for weight loss have focused on steady-state exercise (SEE) of around 30 min at a moderate intensity on most days of the week. Disappointingly, these kinds of exercise programs have led to little or no fat loss.[7] Thus, what is needed is an exercise protocol that can be carried out by overweight, inactive individuals that more effectively induces fat loss.

One such exercise protocol may be high-intensity intermittent exercise (HIIE). HIIE involves brief high-intensity, anaerobic exercise followed by brief but slightly longer bouts of very low-intensity (aerobic) exercise. Prior research has demonstrated that HIIE enhances capacity for fat oxidation and mitochondrial enzyme activity;[8–10] however, the ability of chronic HIIE to induce fat loss has only been examined by one study. Tremblay *et al.*[11] compared exercising intermittently at high-intensity and continuous moderate intensity exercise five times per week for 20 weeks. At the end of the intervention, despite a significantly lower exercise-induced energy deficit, the high-intensity group had lost significantly more fat as measured by change in skinfold thickness relative to energy expenditure. A characteristic of this study was that the HIIE protocol was of a long duration (45 min) and involved exercising five times per week. Thus, it is likely that

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sedentary, overweight individuals would have difficulty in adhering to such a program. Because of the ability of this program to induce fat loss, it would be beneficial to find a less demanding version of this protocol that would reduce body fat but would be more acceptable to sedentary individuals.

Therefore, the purpose of this study was to examine the effects of 20-min bouts of HIIE repeated three times weekly on body composition and fasting insulin levels. Relatively normal weight individuals with a range of adiposity were chosen to determine the effects of HIIE in a population range. It was hypothesized that 15 weeks of HIIE compared to 15 weeks of 40-min bouts of SSE would result in significantly greater reductions in body fat and insulin resistance in young, premenopausal women.

Subjects and methods

Subjects

Subjects were nonsmoking and inactive but otherwise healthy women aged between 18 and 30 years. Ethnically, there were 12 Chinese, 18 European, 3 Southeast Asian and 1 African subject. Subjects were screened using the PAR-Q,[12] which is a standard pre-exercise questionnaire and approval for the study was granted by a University Research Ethics Committee. Subjects were randomly allocated into one of the three groups: HIIE, SSE or control (CONT; Table 1). Forty-five volunteers underwent initial testing. However, for various reasons, seven withdrew from the SSE and four from the HIIE group. Age (22.4 ± 0.7, 21.0 ± 0.8, 22.2 ± 0.1.2 years) and BMI (24.4 ± 1.5, 22.4 ± 1.0, 23.8 ± 1.4 kg m^{-2}) were similar for the HIIE, SSE and CONT groups (Table 1). There was no significant difference on any measured variable between the non-adherents and those women who stayed in the study.

Procedures

Subjects came into the laboratory after an overnight fast after avoiding caffeine the morning of the test. All women were tested in the follicular stage of the menstrual cycle. Pretraining testing included anthropometric measures and a determination of VO_{2peak} on a cycle ergometer (Table 1). A cannula was inserted into an antecubital vein followed by a supine rest of 30 min. Baseline blood samples were taken and whole blood was placed in 10 ml EDTA and 3 ml fluoride vacutainers. Samples from the fluoride tubes were assayed immediately for lactate and glucose using a YSI analyzer (2300 STAT; Yellow Springs, Ohio, USA). Blood lipid profiles (Cholestech LDX) were also assayed immediately using blood from the EDTA tubes. Whole blood was spun immediately in a chilled centrifuge at 4 °C 3000 r.p.m. for 10 min and then aliquots of plasma were immediately frozen at −86 °C for later analysis. Exercise was carried out on an electrically braked, computer controlled Monark 839 cycle ergometer and VO_{2peak} was assessed using a ParvoMedics TrueMax 2400 metabolic cart. All tests were carried out between 700 and 900 hours.

The pretraining exercise assessment was a ramp test with 2-min stages following a 3-min warm-up. Subjects started cycling at 30 W and maintained a cycling speed of 90 r.p.m. throughout. The work increments for each stage were 15 W. The test ceased when the standard criteria of attainment of VO_{2peak} or volitional exhaustion was reached.[13] The test was followed by a 5-min cooldown. Because these volunteers were untrained and unused to cycling exercise, they typically ceased cycling before achieving a true VO_{2max}, thus VO_{2peak} was accepted as an indicant of aerobic power. Venous blood samples were taken in the last 30 s of every second stage of the test and at the end of the cooldown. Heart rate (HR) was recorded at the end of each stage. Blood samples were centrifuged and frozen as described previously.

Body composition

Each subject underwent a dual-energy X-ray absorptiometry (DEXA) scan on a Lunar Prodigy (GE Corporation, Fairfield, Connecticut, USA), software enCORE 2003 GE Medical Systems version 7.51. Total body and central abdominal fat and lean tissue mass and percentage of total tissue were measured as previously described.[14] DEXA has been validated as a measure of body fat in obese and normal weight individuals,[15–17] and central abdominal fat measurement by DEXA has been shown to correlate strongly with insulin resistance.[14] DEXA gives two measures of central adiposity. The trunk measurement includes the area distal to the neck and superior to the pelvis without the upper limbs. In this cohort, the mean fat mass (FM) in this area was

Table 1 Changes in body composition and aerobic power after 15 weeks of training (mean and s.e.)

Group	VO_{2peak} (l min^{-1})	VO_{2peak} (ml kg^{-1} min^{-1})	TBM (kg)	FM (kg)	% BF
HIIE pretraining	1.79 ± 0.1	28.8 ± 2.1	63.3 ± 3.8	22.2 ± 3.0	35.1 ± 2.7
HIIE post training	2.22 ± 0.2[a]	36.4 ± 2.5[a]	61.8 ± 3.6[a]	19.7 ± 2.6[a,b]	32.4 ± 2.3[a,b]
SSE pretraining	1.83 ± 0.1	30.9 ± 2.1	59.8 ± 2.4	18.4 ± 2.2	31.7 ± 3.0
SSE post training	2.18 ± 0.1[a]	36.9 ± 1.5[a]	59.7 ± 2.3	18.8 ± 2.1	32.3 ± 2.9
CONT pretraining	2.0 ± 0.1	31.4 ± 1.5	65.1 ± 4.3	22.6 ± 3.3	35.6 ± 2.8
CONT post training	2.0 ± 0.1	30.7 ± 1.6	66.5 ± 4.4	22.9 ± 3.0	35.7 ± 2.6

Abbreviations: CONT, control; HIIE, high-intensity intermittent exercise; SSE, steady-state exercise; TBM, total body mass; FM, fat mass; BF, body fat. [a]HIIE significantly different from CONT, $P < 0.05$. [b]HIIE significantly different from SSE, $P < 0.05$.

10.3 kg with a lean mass of 18.4 kg. The central abdominal measurement covered a section between T12 and L4 and had a typical FM of 1.2 kg and lean mass of 2.5 kg.

Diet monitoring
Subjects were asked to retain their normal eating patterns during the course of the training program. On their initial and final visit to the laboratory, subjects provided a 3-day diet inventory, and analysis was performed using SERVE dietary analysis software.

High-intensity intermittent exercise training
Monark cycle ergometers were used for training. For the HIIE protocol, each subject performed 8 s of sprinting and 12 s of turning the pedals over slowly (between 20 and 30 r.p.m.) for a maximum of 60 repeats a session. At the beginning of the 15-week training period, subjects started with a resistance of 0.5 kg and worked as hard as they could during the sprinting phase. Subjects started with as little as 5 min in the conditioning phase and gradually increased work time to a maximum of 20 min. Once an individual could complete 20 min of intermittent sprinting at 0.5 kg, resistance was increased by increments of 0.5 kg. A decrease in the subject's HR at the current workload presaged an increase in resistance. The women adapted to the training stimulus rapidly so that by the end of 2 weeks (six exercise sessions), all women were able to complete the full 20 min of exercise.

Each training session consisted of a 5-min warm-up at a workload chosen by each subject. At the end of warm-up, subjects followed a prerecorded tape, which included prompts to start and stop cycling with a work/rest ratio of 8 s:12 s. At the end of this conditioning phase, subjects reduced their workload and cooled down for 5 min followed by standard stretches for the quadriceps, hamstrings and posterior calf muscles. HR was recorded during the exercise and cooldown. If an individual missed a session, she would make it up later so that 45 exercise sessions were completed within the 15-week period.

Steady-state exercise training
For SSE training, subjects completed a 5-min warm-up at a comfortable workload after which each individual exercised at 60% VO_{2peak}. At the end of the conditioning phase, a 5-min cooldown and stretching in the same manner as the HIIE group was completed. Subjects started the 15-week program exercising at this intensity for 10–20 min. The duration of the exercise was gradually increased to a maximum of 40 min of exercise per session. When subject's fitness improved, as indicated by a decrease in HR, the resistance was increased by 0.5 kg increments.

Control group
The CONT group was asked to maintain their current physical activity levels and dietary habits for the 15 weeks of the experimental period. They supplied a record of their dietary intake at week 1 and 15 weeks later.

Assays
Insulin levels were assessed using an enzyme-linked immunosorbent assay kit (DSL 10–1600). The homeostasis model assessment of insulin sensitivity (HOMA-IR) was calculated for each individual.[18] HOMA-IR is calculated by dividing the product of insulin (in $\mu IU\,ml^{-1}$) and glucose (in $mmol\,l^{-1}$) concentrations by 22.5. Adiponectin analysis was undertaken using an enzyme-linked immunosorbent assay kit (DRP 300; R&D Systems, Minneapolis, Minnesota, USA). Similar enzyme-linked immunosorbent assays were performed for leptin (DSL-10-23100i). All samples were assayed in duplicate as internal controls.

Statistical analysis
SPSS 14.0. software was used to examine pre–post group changes and *post hoc* analyses were used to identify significant between-group differences. Also Pearson's Product–Moment correlation coefficient was used to examine relationships between variables.

Results

There were no significant differences between the three groups on any measured variable prior to the training program (Table 1).

Energy expenditure associated with training
Energy expenditure for the SSE group was estimated by converting the workload for each session (kp*r.p.m. = W) into oxygen consumption in $l\,min^{-1}$.[19] Energy expenditure for one session of HIIE was assessed in a previous study,[20] and this data was used to estimate energy expenditure for the 15 weeks of HIIE of the present study. Using this method, there was no significant difference between SSE (36.3 ± 3.4 MJ) and HIIE (41.5 ± 0.81 MJ) in estimated total energy expenditure over the 15-week training period. The average energy expenditure for each HIIE session was 834.5 ± 11.3 kJ and for SSE was 809.7 ± 74.0 kJ. In terms of % VO_{2peak} power during the exercise bouts (exercise watts relative to peak watts), each HIIE session averaged 53.2% peak power output, whereas each SSE session averaged 73.9% peak power output.

Exercise heart rates
There was a significant difference in training HR between the two exercise groups ($P < 0.007$). The HIIE group recorded a mean training HR of 168.6 beats min^{-1}, whereas the SSE had an HR of 155.7 beats min^{-1}.

Peak aerobic power
Both HIIE and SSE resulted in a significant increase ($P<0.0001$) in post versus pretraining peak absolute oxygen uptake. VO_{2peak} increased by 23.8% after HIIE and by 19.3% after SSE training (Table 1).

Total body mass and body fat
There was a significant decrease in total body mass (TBM) for the HIIE compared to the CONT group ($P<0.01$). No significant change occurred for the SSE or CONT groups (Table 2).

There was significant FM loss ($P<0.05$) for the HIIE group of 2.5 ± 0.83 kg compared to the other two groups. The SSE group had a mean FM gain of 0.44 ± 0.88 kg and the CONT group had a gain of 0.33 ± 0.47 kg (Figure 1). Fat loss and initial adiposity levels were moderately correlated ($r=-0.58$, $P<0.02$), indicating that subjects possessing greater initial fat levels tended to lose more fat.

Responders versus nonresponders
Four moderate fat loss responders (women who had a 3% or less decrease in total fat) in the HIIE group, possessed significantly lower ($P<0.05$) initial FM than the other women (14.3 versus 22.2 kg). These four women were the leanest in the HIIE group with an average weight of 52.9 kg and a BMI of 21.1 $kg\,m^{-2}$. With the four lean women removed, the mean fat loss in the HIIE group was 3.94 ± 0.91 kg, resulting in a 4.3% decrease in body mass and a 14.7% decrease in total FM.

Central abdominal fat
High-intensity intermittent exercise led to a significant decrease ($P<0.05$) in central abdominal fat (−0.15 ± 0.07 kg), whereas the SSE and CONT groups had nonsignificant increases in central abdominal fat (SSE group, +0.1 ± 0.08 kg; CONT group, +0.03 ± 0.04 kg; Figure 2).

Lean body mass
There were no significant pre- and posttraining differences in total lean body mass.

Regional differences in fat and lean mass
All three groups increased fat deposits in the arms ($P<0.01$) with no between-group differences. There was a trend ($P=0.06$) for the HIIE group to lose more fat from the legs compared to the other groups (Table 2). The HIIE group lost 1.40 ± 0.17 kg of trunk fat, the SSE group gained 0.11 ± 0.51 kg and the CONT group lost 0.05 ± 0.42 kg. When these changes in fat tissue were calculated as percentage of fat, there were significant differences between the HIIE and CONT group for percentage of fat in the lower limbs ($P<0.05$) and trunk ($P<0.05$).

Changes in lean tissue mass in the legs were not significant. The HIIE group gained 0.11 ± 0.14 kg, the SSE lost 0.92 ± 0.18 kg, and the CONT lost 0.13 ± 0.15 kg (Table 2). There was a significant increase in trunk lean tissue for the HIIE compared to the SSE group ($P<0.05$) (Table 2).

Fasting insulin and glucose
Both HIIE (31%) and SSE (9%) groups decreased fasting insulin; however, only HIIE was significantly different from CONT ($P<0.05$) (Figure 3). Similarly, both HIIE (33%) and SSE (11%) subjects decreased fasting HOMA-IR scores;

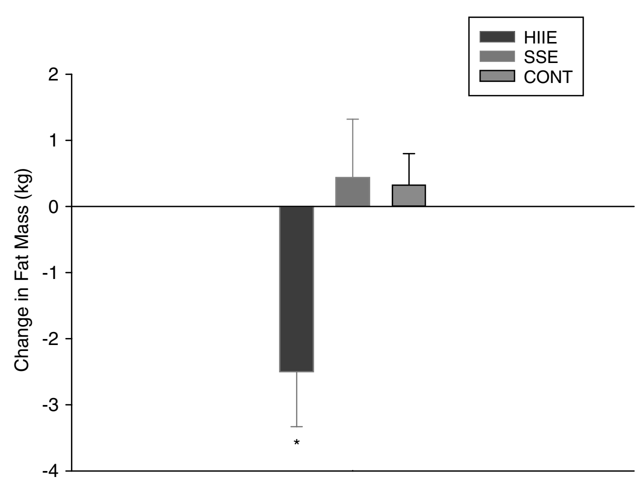

Figure 1 Total fat change for the high-intensity intermittent exercise (HIIE), steady-state exercise (SEE) and no exercise control groups. *Significantly different from control and SSE groups ($P<0.05$).

Table 2 Regional changes in body composition (mean and standard error)

Group	*Leg fat (kg)*	*Leg lean (kg)*	*Leg, % fat*	*Trunk fat (kg)*	*Trunk lean (kg)*	*Trunk, % fat*
HIIE pretraining	8.0 ± 1.2	13.1 ± 0.5	36.6 ± 3.0	11.4 ± 2.0	18.3 ± 0.8	36.5 ± 3.4
HIIE post training	6.8 ± 0.8	13.2 ± 0.5	33.2 ± 2.2[a]	10.0 ± 1.6[b]	18.8 ± 0.8[b]	33.2 ± 2.9[a,b]
SSE pretraining	7.3 ± 0.7	13.2 ± 0.6	35.4 ± 2.4	8.6 ± 1.3	18.6 ± 0.8	30.9 ± 3.7
SSE post training	7.0 ± 0.5	13.1 ± 0.6	34.8 ± 2.0	8.8 ± 1.2	18.3 ± 0.8	31.8 ± 3.6
CONT pretraining	8.9 ± 1.2	13.3 ± 0.5	38.1 ± 2.4	11.0 ± 1.5	18.3 ± 0.6	35.3 ± 2.9
CONT post training	8.7 ± 1.1	13.2 ± 0.5	38.1 ± 2.1	11.0 ± 1.3	18.0 ± 0.5	36.1 ± 2.6

Abbreviations: CONT, control; HIIE, high-intensity intermittent exercise; SSE, steady-state exercise. [a]HIIE significantly different from CONT, $P<0.05$. [b]HIIE significantly different from SSE, $P<0.05$.

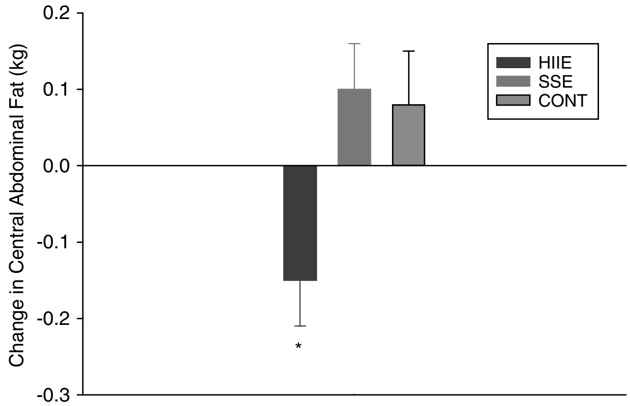

Figure 2 Central abdominal fat change for the high-intensity intermittent exercise (HIIE), steady-state exercise (SEE) and no exercise control groups. *Significantly different from control and SSE groups ($P<0.05$).

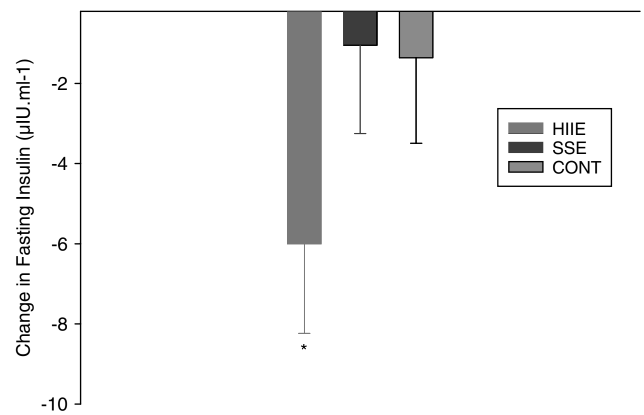

Figure 3 Fasting insulin change for the high-intensity intermittent exercise (HIIE), steady-state exercise (SEE) and no exercise control groups. *Significantly different from control ($P<0.05$).

however, these levels were not significantly different from CONT. There was a significant correlation between central abdominal fat loss and change in insulin concentration with training ($r=0.46$, $P<0.05$) so that individuals who lost more abdominal fat had a greater decrease in fasting insulin concentration. Fasting glucose concentrations were $<5\,\text{mmol}\,l^{-1}$ in all groups pre- and post training. There were no between-group differences and no significant change after the intervention for glucose concentration.

Leptin and adiponectin

There was a significant decrease ($P<0.05$) in leptin concentration for the HIIE group after training (Table 3). Improvement in VO_{2peak} ($r=-0.57$, $P<0.001$), and change in TBM ($r=0.47$, $P<0.001$) were significantly correlated with change in leptin. No significant correlations existed ($P>0.05$) between leptin and change in FM. Change in adiponectin was not significantly different between groups, but change in adiponectin was associated with change in FM ($r=-0.40$, $P<0.05$) and percentage of BF ($r=-0.40$, $P<0.05$).

Diet

There were no significant changes in either the macro- or micronutrient content of pre- and posttraining diet as assessed by 3-day diet diaries (Table 4).

Discussion

The major finding of this study was that both HIIE and SSE significantly increased VO_{2peak}, but only HIIE resulted in a significant loss in total and abdominal fat. There was significant loss in leg compared to arm fat in the HIIE group. Both exercise protocols decreased fasting insulin levels; however, the effect was significantly greater in HIIE compared to CONT. Fat loss to HIIE was variable with leaner women losing less fat. Fat loss induced by HIIE was achieved with half the time commitment, but with a similar energy expenditure to that of SSE.

Both HIIE and SSE exercise increased absolute VO_{2peak} by 23.8 and 19.3%, respectively. This large increase in VO_{2peak} after HIIE is surprising given that the volume of the aerobic component was significantly less than that of SSE. The aerobic component of the HIIE amounted to 36 min per week (ignoring warm-up and cooldown) compared to 120 min per week of aerobic component in the SSE condition. Talanian *et al.*[9] have also found that an intermittent sprinting exercise program significantly elevated aerobic power; in this study, the oxidative enzyme β-hydroxyacyl-CoA dehydrogenase was used as an indicant of mitochondrial volume and was found to increase by 31%, suggesting that intermittent sprinting enhances mitochondrial capacity. Other studies have also shown increases in aerobic power to differing forms of intermittent sprinting,[21–23] whereas Tabata *et al.*[23] found that intermittent sprinting also resulted in significant increases in anaerobic capacity. Collectively, these data show that intermittent sprinting results in significant improvements in both aerobic and anaerobic fitness.

That HIIE produced a greater fat reduction effect compared to SSE supports the results of Tremblay *et al.*[11] Despite exercising half the time, HIIE subjects in the present study lost 11.2% of total FM with SSE subjects experiencing no fat loss. Collectively, these results demonstrate that intermittent sprinting compared to SEE is a more effective and efficient way of controlling body composition. However, our estimates of energy expenditure and intake lack sufficient precision to comfortably conclude that energy balance was unaffected in the HIIE condition. Thus, it is feasible that the change in FM that occurred in HIIE may have been influenced by unreported changes in diet. Indeed, HIIE-induced suppressed diet intake may be one of a number of

Table 3 Adiponectin, leptin, insulin, HOMA-IR and glucose levels (mean and s.e.)

Group	HIIE	SSE	CONT
Adiponectin ($\mu g\,ml^{-1}$) pretraining	6.8 ± 1.3	11.2 ± 1.8	8.4 ± 1.2
Adiponectin ($\mu g\,ml^{-1}$) post training	6.7 ± 1.3	8.1 ± 2.0	7.4 ± 1.0
Leptin ($ng\,ml^{-1}$) pretraining	34.8 ± 5.8	29.5 ± 6.5	37.2 ± 6.4
Leptin ($ng\,ml^{-1}$) post training	30.5 ± 8.5[a,b]	29.1 ± 5.0	52.4 ± 11.1
Insulin ($\mu IU\,ml^{-1}$) pretraining	19.4 ± 3.4	11.1 ± 3.4	13.8 ± 3.1
Insulin ($\mu IU\,ml^{-1}$) post training	13.4 ± 3.7[a]	10.1 ± 2.8	12.4 ± 2.9
Glucose ($mmol\,l^{-1}$) pretraining	4.2 ± 0.1	4.2 ± 0.2	4.3 ± 0.1
Glucose ($mmol\,l^{-1}$) post training	4.0 ± 0.1	4.1 ± 0.2	3.9 ± 0.1
HOMA-IR pretraining	3.6 ± 0.7	2.2 ± 0.7	2.6 ± 0.7
HOMA-IR post training	2.4 ± 0.7	1.9 ± 0.6	2.2 ± 0.4

Abbreviations: CONT = control; HIIE, high-intensity intermittent exercise; HOMA-IR, homeostasis model assessment of insulin sensitivity; SSE, steady-state exercise. [a]HIIE significantly different from CONT, $P<0.05$. [b]HIIE significantly different from SSE, $P<0.05$.

Table 4 Fat, protein and carbohydrate levels before and after training (mean and s.e.)

Group	Fat ($g\,day^{-1}$)	Saturated fat ($g\,day^{-1}$)	CHO ($g\,day^{-1}$)	Protein ($g\,day^{-1}$)	Energy intake ($kJ\,day^{-1}$)
HIIE pretraining	69.2 ± 8.8	27.7 ± 6.1	182.7 ± 19.1	83.4 ± 10.1	7115.5 ± 724.0
% intake	36.3 ± 2.6	13.9 ± 1.9	43.1 ± 2.2	19.4 ± 1.3	
HIIE post training	77.2 ± 9.4	31.8 ± 5.6	209.3 ± 22.0	86.2 ± 7.0	7955.6 ± 800.4
% intake	35.6 ± 2.6	13.1 ± 1.9	44.3 ± 2.2	18.8 ± 1.4	
SSE pretraining	100.9 ± 19.1	35.1 ± 7.0	291.7 ± 50.8	100.3 ± 18.4	10 350.37 ± 1702.4
% intake	36.3 ± 1.8	14.2 ± 1.6	44.7 ± 2.9	16.9 ± 1.5	
SSE post training	96.35 ± 12.0	29.5 ± 5.7	229.3 ± 36.6	78.6 ± 11.0	8400.8 ± 880.0
% intake	38.5 ± 4.7	13.4 ± 2.1	45.4 ± 5.2	15.5 ± 1.9	
CONT pretraining	81.2 ± 8.4	31.0 ± 3.7	258.5 ± 18.2	99.3 ± 11.4	9122.9 ± 637.7
% intake	31.2 ± 2.4	12.0 ± 1.1	48.7 ± 2.5	17.7 ± 1.1	
CONT post training	72.7 ± 12.6	29.8 ± 4.6	207.9 ± 23.0	74.9.4 ± 11.4	7595.5 ± 811.4
% intake	35.2 ± 3.6	12.0 ± 1.5	46.7 ± 4.0	16.4 ± 1.4	

Abbreviations: CONT = control; HIIE, high-intensity intermittent exercise; SSE, steady-state exercise.

possible factors underlying the fat loss effect of HIIE.[11] For example, HIIE may have suppressed appetite or decreased attraction for energy-dense foods.[24,25] Another explanation for the HIIE fat loss effects is that this type of exercise may result in enhanced lipid utilization. Prior research in our laboratory has shown that lipid release, as indicated by blood glycerol levels, gradually increased over 20 min of HIIE.[20] Catecholamine levels in this study were also found to be significantly elevated after HIIE.[20] With regard to SSE, the FM and aerobic fitness response was typical of that reported in the literature in that there were no significant changes in TBM, FM or trunk fat, but there was a significant increase in aerobic fitness.[26–32]

Central adiposity diminished in the HIIE compared to the SSE and CONT groups. The HIIE group decreased central abdominal fat by 9.5%, in contrast to the SSE group, which had a 10.5% increase. Total trunk FM reflected these changes (Table 2). This is an important finding because of the effect of excess visceral fat on metabolic dysfunction.[26,33,34] Although these changes may appear minor in these young women, their central abdominal FM before the intervention was relatively small (mean = 1.27 kg). Thus, it is likely that HIIE would have an even greater fat-reducing effect on individuals possessing larger abdominal fat stores. DEXA does not directly measure visceral fat, but there is a relationship between DEXA measured abdominal FM and visceral fat. For example, Bertin *et al.*[15] found a significant correlation ($r = 0.60$) between visceral fat determined by computed tomography (CT) scan and abdominal FM measured by DEXA, indicating that changes in abdominal fat reflect to some degree, changes in visceral fat. Moreover, the DEXA technique used in this study has been shown to have a strong correlation with insulin resistance.[14]

Changes in lean tissue mass in the legs were not significant, but a trend was apparent in that the HIIE group gained, whereas the SSE and CONT lost lean tissue. In the HIIE group, there was also a significant increase in abdominal fat-free mass, suggesting that the trunk musculature was recruited during HIIE. These data suggest that HIIE compared to SSE provides greater loading of the trunk and leg musculature. This characteristic may be important for weight loss programs, as it has been shown that the decrease in muscle mass that typically accompanies dietary restriction usually results in lowered resting metabolic rate.[35]

It is considered that spot reduction (that is, deliberately reducing fat stores in specific areas of the body) is not possible, and the body will mobilize preferentially those stores with the highest concentrations of adipose cells.[36–38]

There is evidence in the current study that this principle may not apply to every exercise modality. In HIIE, where work is done primarily by the musculature of the legs and the trunk muscles act as stabilizers, there was a decrease in FM and an increase in lean mass, which summated to a significant change in percentage of fat in these two regions. This was not the case with the SSE group.

Both exercise groups reduced fasting insulin levels and HOMA-IR scores, although only the insulin level of the HIIE group was statistically significant. The HIIE group had a 31% decrease in fasting insulin concentrations compared to 9% for the SSE group. The 9% decrease of the SSE is typical compared to results of other studies using similar exercise protocols.[39] The significantly larger effects of HIIE on fasting insulin suggests that this form of exercise may be a more effective way of normalizing endocrine dysfunction. If the training continued for a longer period (6 months to a year), it is possible that the decrease in insulin concentrations would lead to greater fat oxidation,[40] and hence, greater fat loss in the longer term.[41] Supporting this notion is the significant inverse relationship found between loss of trunk fat and decrease in insulin concentration. This is in keeping with a significant correlation between loss of abdominal fat and improvements in insulin sensitivity in response to calorie restriction.[42]

High-intensity intermittent exercise training had a marked effect on fat levels for some individuals and a moderate effect for others. The correlation ($r = 0.58$, $P < 0.01$) between fat loss and initial FM supports prior research that has shown that fat loss is typically related to initial FM.[43,44] The four moderate fat loss responders in the HIIE group (women who had a 3% or less decrease in total fat) possessed significantly lower initial FM than the other women. With the four lean women removed, the mean fat loss in the HIIE group was 3.94 ± 0.91 kg resulting in a 4.3% decrease in body mass and a 14.7% decrease in total FM. This 3.94-kg fat loss compares favorably to the 1.15-kg weight loss reported in a recent meta-analysis of the effects of SEE on weight loss.[7]

In conclusion, 20 min of HIIE, performed three times per week for 15 weeks compared to the same frequency of 40 min of SSE exercise was associated with significant reductions in fasting insulin, total body fat, subcutaneous leg fat and abdominal fat.

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