Effects of supervised exercise training at the intensity of maximal fat oxidation in overweight young women

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Abstract

The purpose of this study was to investigate the effects of 8 weeks of supervised exercise training at the exercise intensity at which the maximal fat oxidation occurred (Fatmax intensity) on body composition and cardiorespiratory function in overweight young women. Fifty sedentary female university students [aged 20–23 years, body mass index (BMI) >25 kg/m²] were enrolled in the study. The maximal fat oxidation rate was measured using a graded treadmill running test; the average result of the participants was 0.43 ± 0.01 g/minute, which occurred at the exercise intensity of 54.0 ± 4.0% maximal oxygen consumption (VO2max), and the corresponding heart rate was 134 ± 3 beats per minute. The individualized heart rate at the Fatmax intensity was applied in the exercise training program. The trained individuals decreased their body mass, BMI, fat mass, waist–hip ratio, fasting plasma triglycerides, and total cholesterol concentrations and increased their VO2max and heart rate index in a step test. There were no changes in these variables in the control group. In conclusion, exercise training at the Fatmax intensity is an evidence-informed and safe exercise prescription for overweight young women.

Keywords: Body composition; Exercise training; Fat oxidation rate; Overweight young women

Introduction

Overweight and obesity are multifactor physical disorders. The health hazards associated with these disorders are strongly linked with the development and progression of heart diseases, hypertension, type 2 diabetes, respiratory diseases, certain types of cancer, reproductive abnormalities, and osteoarthritis. The most common risk factor for such disorders, from the viewpoint of exercise physiology, is the combination of lack of physical activities and excessive intake of dietary calories. In the literature, exercise training has been reported to improve the body composition and cardiorespiratory fitness level of obese or overweight individuals. All these studies applied the so-called “moderate exercise intensity” as, at least, one of the exercise intensities in their physical activity programs. These exercise intensities were usually determined by a certain percentage of the individuals’ maximal oxygen consumption (VO2max) or maximal heart rate (HR), but little evidence is available on why the exercise intensity was chosen and what energy substrates were used during exercise training at these intensities.

As for the degree of intensity of exercise training, it is well evidenced that the absolute rate of fat oxidation increases from low to moderate intensities of exercise and then decreases as exercise becomes even more intense. The peak rate of fat oxidation measured over the entire range of exercise intensities has been defined as the maximal fat oxidation. The exercise intensity at which the maximal fat oxidation occurs has been specified as the Fatmax. Some previous studies have shown that the Fatmax intensity usually occurs between 39%
and 65% of VO$_{2\max}$ and varies according to gender, body composition, training status, VO$_{2\max}$, and diet of the study participants.\textsuperscript{17–21}

It is logical to hypothesize that application of the Fat$_{\text{max}}$ intensity in exercise training programs would burn body fat more efficiently and cause improvements in body composition for obese or overweight individuals. A few studies have investigated the effects of exercise training programs at the Fat$_{\text{max}}$ intensity on obese adolescents,\textsuperscript{22} middle-aged individuals with metabolic syndrome,\textsuperscript{23} and obese men.\textsuperscript{24} It has been found that such exercise training programs produced beneficial effects on fat oxidation during moderate-intensity exercise, body composition, and insulin sensitivity of the study participants. To the best of our knowledge, there have been no previous reports on the application of the Fat$_{\text{max}}$ intensity in exercise training programs for young women who are overweight. Therefore, the main purpose of the present study was to investigate the effects of an 8-week supervised exercise training program with individualized Fat$_{\text{max}}$ intensity on the body composition and cardiorespiratory fitness level of a group of overweight young women.

Methods

Participants

Fifty female university students, aged 20–23 years, were enrolled in this study. The inclusion criteria were females who had body mass index (BMI) >25 kg/m$^2$, had percentage body fat >30%, did not engage in regular exercise training, had normal menstrual cycle, and were not pregnant, lactating, or taking oral contraceptives at the time of their enrolment. Students who were afflicted with heart diseases, hypertension, pulmonary diseases, and diabetes; who needed orthopedic treatments; and who had neurological limitations to physical exercise were excluded. The exact details of the study were described to the participants prior to the baseline test, while a written informed consent to the study was obtained from each of them. This study was approved by the Ethics Committee of Tianjin University of Sport, China.

Study design

Following the baseline test, the participants were randomly allocated into two groups: the Fat$_{\text{max}}$ exercise training group ($n = 30$) and the sedentary control group ($n = 20$). Those in the Fat$_{\text{max}}$ group underwent 8 weeks of supervised exercise training according to the specific requirements (see the “Exercise training program” section later). Participants in the control group were required to maintain their individual habits of physical activities and to refrain from engaging in any other forms of prescribed exercise training during the period of experimentation. Each participant’s body mass, height, waist and hip girths, body composition, VO$_{2\max}$, blood pressure (BP), HR responses to a step test, and fasting plasma triglycerides and total cholesterol concentrations were measured at the baseline, as well as after 8 weeks of the experimental period. All these measurements and tests were carried out from the early phase up to the mid-follicular phase of each participant’s menstrual cycle. The post-training tests and the last training session were separated by at least 2 days. Under the complete supervision of the researchers, all tests and training sessions were conducted in the exercise physiology laboratory and the sports grounds of Tianjin University of Sport. Meanwhile, all the participants were required to maintain their normal diet during the period of experimentation.

Anthropometric measures

Each participant’s body mass was assessed with a balance scale and her height (without shoes) was measured with a stadiometer. The BMI was calculated by dividing body mass in kilograms by height in meters squared (kg/m$^2$). The waist girth was measured at the level of the umbilicus horizontally without clothing, while the hip girth was measured at the level of the greatest protrusion of the gluteal muscles with underwear. Waist–hip ratio (WHR) was calculated by dividing the waist girth by the hip girth. All these measurements were conducted by the same researcher. Each of these measurements was taken three times and the average was reported.

Body composition

After 10–12 hours of fasting, the total body composition of each participant was measured using the GE Prodigy direct digital DEXA bone densitometry (GE Healthcare, USA), when she was lying supinely. By means of the standard soft tissue analysis provided by that company, the non-bone fat-free soft tissue, fat tissue, and bone mineral content were measured. The total body fat (%) was determined as a portion of the total amount of fat in the entire body mass. Fat mass and fat-free mass were also calculated.

BP measurement

After the participant had remained seated for 10 minutes, her BP was measured at the brachial artery using the auscultatory method. The first Korotkoff sound registered the systolic BP and the last one was considered as the diastolic BP. All these measurements were carried out by the same researcher.

Blood tests

A 5-mL fasting blood sample was taken for the analysis of serum lipid. The serum total cholesterol and triglycerides concentrations were measured by a Cobas Integra bioanalyzer (Roche, USA) using the standard kits.

Step test

The HR response to the step test was used as an index of cardiovascular fitness level. The height of the step was 25 cm.
After a warm-up exercise, the participants performed a 3-minute step test with a frequency of 30 complete step-ups per minute, regulated by a metronome set at 120 beats per minute. Postexercise HR at minutes 1, 2, and 3 were measured for 30 seconds each (i.e., HR from postexercise 30 seconds to 1 minute, from 1 minute 30 seconds to 2 minutes, and from 2 minutes 30 seconds to 3 minutes). HR was measured using a PE-4000 HR monitor (Polar Electro, Finland). The HR index was calculated as follows:

\[
\text{HR index} = \frac{\text{exercise time (seconds) \times \sum \text{30-second postexercise HR}}}{2 \times 100}
\]

Maximal oxygen uptake

Each participant’s VO2max was measured by a graded treadmill walking/running test (Pulsar cosmos treadmill, Germany). After a warm-up period, the initial workload was set at the speed of 3.3 km/hour at a 0% incline for 3 minutes. The second workload was executed at the speed of 6.3 km/hour at a 0% incline for 1 minute; the speed was then increased by 0.8 km/hour per minute. When the speed was increased up to 10 km/hour, the incline was simultaneously increased by 1% per minute as the speed still continued to increase by 0.8 km/hour per minute. This procedure continued until the participant had reached exhaustion, at which time the test was terminated. The criteria for measuring VO2max were the following: a leveling off of VO2 despite increased workload, a respiratory exchange ratio (RER) equal to or higher than 1.05, and an exercise HR higher than 180 beats per minute. VO2 and carbon dioxide production (VCO2) were measured by an open-circuit indirect gas analyzer (Cortex Metalyzer II gas analyzer, Germany), which was calibrated with the standard gas prior to each test. HR was recorded continuously by an electrocardiogram.

Fatmax measurement procedure

After 10—12 hours of fasting, the Fatmax was measured in a modified graded treadmill running test. Briefly, after a warm-up exercise of walking or running at 5.5 km/hour for 3 minutes, the first stage of exercise was set at a speed of 7 km/hour with an incline of 1% for 3 minutes. The incline was increased by 1% every 3 minutes until the RER of 1.0 was reached, and then the speed was increased by 0.8 km/hour per minute until the participant reached exhaustion. VO2 and VCO2 were measured using the same gas analyzer as used in the VO2max test. The values toward the end of each exercise stage, prior to the RER reaching 1.0, were used to calculate the fat oxidation rate. The Fatmax tests were always performed in the morning (8—10 AM) to avoid circadian variance.

Calculation of fat oxidation

To identify the exercise intensity of the Fatmax, total fat oxidation was calculated using the following stoichiometric equation, with the assumption that the urinary nitrogen excretion rate was negligible:

\[
\text{Total fat oxidation} = 1.67 \times \text{VO}_2 - 1.67 \times \text{VCO}_2
\]

where VO2 and VCO2 are expressed in liters per minute. The value of 1.67 was derived from the volume of oxygen consumed and carbon dioxide produced in the oxidation of 1 g of fat. The exercise intensity at which the highest rate of fat oxidation occurred was defined as the Fatmax (Fig. 1). HR was recorded continuously by an electrocardiogram. The corresponding HR at the Fatmax intensity was recorded individually and then applied to control the intensity of exercise training during the experimental period.

Exercise training program

The participants of the Fatmax group underwent five exercise training sessions per week on an outdoor track for 8 weeks. The training session consisted of a 10-minute warm-up period, which included walking and jogging, as well as muscle stretches. This was followed by 40 minutes of running, with the intensity being controlled at the individualized HR of the Fatmax intensity. There was a 10-minute cool-down period when the participants walked slowly and stretched their muscles. Each training session lasted for 1 hour. All these training sessions were supervised by the researchers and every participant wore an HR monitor during the training so as to maintain the correct training intensity.

Statistical analyses

All the values were presented as mean ± SD. The paired Student t test was applied to test the changes in the measured variables within the groups. To evaluate the effects of exercise training, unpaired Student t test was used to compare the baseline data, as well as the changes in the measured variables after the interventions between the groups. A p value of <0.05 was regarded as statistically significant. All analyses were
performed using the SPSS Version 11.5 for Windows (SPSS Inc., Chicago, IL, USA).

Results

The results were based on the observations of 29 participants in the Fatmax group and 19 in the control group who completed the study. Eight participants of the Fatmax group missed two to five training sessions for various reasons, but no catch-up sessions were given; all other participants of the group took part in all 40 sessions. Two participants (one from each group) dropped out of the study due to personal reasons. As for those who successfully completed the training program, there were no reported physical injuries that were caused by physical activities during the training sessions.

With increasing exercise intensity, the fat oxidation rate increased to 0.43 ± 0.01 g/minute (range 0.28–0.59 g/minute) at the absolute VO2 of 18.33 ± 3.35 mL/kg/minute, which was at 54.0 ± 4.0% VO2max (range 44.7–67.7% VO2max); after this point the fat oxidation rate decreased (Fig. 1). The average HR corresponding to the Fatmax intensity was 134 ± 3 beats per minute.

The participants in the Fatmax group decreased markedly their body mass, BMI, body fat, fat mass, and WHR, while their fat-free mass was not changed after the exercise training. There were no significant differences in the variables between the two groups at the baseline test. However, the changes in body mass, BMI, fat mass, and WHR were significantly different between the groups. There was no obvious change in these variables for the participants of the control group (Table 1).

The VO2max of the participants in the Fatmax group increased significantly following the exercise training. Evidently, changes in the VO2max were significantly different between the two groups, although there were no significant differences in this variable between the groups at the baseline test. HR response to the step test was greatly improved in the participants of the Fatmax group, but not in those of the control group. Changes in the HR index were significantly different between the two groups. Both systolic and diastolic BP of the participants of the Fatmax group were not changed following the exercise training. Serum total cholesterol and triglyceride concentrations were significantly decreased in the Fatmax group and 19 in the control group who performed using the SPSS Version 11.5 for Windows (SPSS Inc., Chicago, IL, USA).

Discussion

Based on the investigation of this group of homogeneous individuals, we have found that the maximal fat oxidation rate of overweight young women was 0.43 ± 0.01 g/minute, which occurred at the exercise intensity of 54.0 ± 4.0% VO2max. In the literature, there are few studies on the effects of Fatmax intensity on obese or overweight women. One study of overweight women has reported that the Fatmax intensity was at 39.5 ± 2.3% VO2max and with a maximal fat oxidation rate of 0.20 ± 0.02 g/minute. Those results were dramatically different from our present results. The use of different testing models (they used a walking protocol) and the age of the participants (age of their participants: 36.6 ± 1.8 years) might be the major reasons that led to the difference. This comparison confirmed the observation that the Fatmax intensity is affected by many factors. Hence, the present results from Chinese young women cannot simply be applied to other ethnic populations. Consistent with the previous studies, we also noticed large variations in the Fatmax intensity and maximal fat oxidation rate among the participants of the present study, even though they belonged to a highly homogenous group (i.e., young, sedentary, and overweight). Therefore, this interindividual variability has to be considered when designing an exercise training program based on the Fatmax concept.

In the present study, we found improvements in body composition of the trained group, while the untrained control individuals did not show any changes in these variables. This outcome was supported by a previous study in which an 8-week exercise training program at the Fatmax intensity was applied to people with metabolic syndrome, but not by another two exercise studies at the Fatmax intensity conducted in obese men or adolescents. Small sample size and short training duration of these two studies might be responsible for this outcome. The decrease in WHR in our present study indicated that the higher portion of body fat loss might come from the abdominal fat depot. This was an encouraging result as

Table 1
Changes in body composition prior to and after exercise training.

<table>
<thead>
<tr>
<th></th>
<th>Fatmax (n = 29)</th>
<th>Control (n = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Post-test</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>70.4 ± 5.3</td>
<td>66.4 ± 5.4**</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>27.48 ± 1.91</td>
<td>25.89 ± 2.00**</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>43.94 ± 5.65</td>
<td>40.62 ± 4.92**</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>31.0 ± 4.6</td>
<td>27.0 ± 4.0**</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>39.5 ± 4.9</td>
<td>39.4 ± 4.4</td>
</tr>
<tr>
<td>WHR</td>
<td>0.86 ± 0.04</td>
<td>0.83 ± 0.03*</td>
</tr>
</tbody>
</table>

All data are presented in mean ± SD.

*p < 0.05; **p < 0.01, between the pre- and post-tests within the groups.

†p < 0.05; †p < 0.01, comparison of the changes between the groups.

BMI = body mass index; Fatmax = intensity at which the maximal fat oxidation occurs; SD = standard deviation; WHR = waist–hip ratio.
Changes in cardiorespiratory function and lipid profile prior to and after exercise training.

<table>
<thead>
<tr>
<th></th>
<th>Fatmax (n = 29)</th>
<th>Control (n = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Post-test</td>
</tr>
<tr>
<td><strong>Systolic BP (mmHg)</strong></td>
<td>116 ± 10</td>
<td>115 ± 11</td>
</tr>
<tr>
<td><strong>Diastolic BP (mmHg)</strong></td>
<td>78 ± 4</td>
<td>77 ± 4</td>
</tr>
<tr>
<td>Heart rate index</td>
<td>41.9 ± 4.3</td>
<td>46.7 ± 5.0**</td>
</tr>
<tr>
<td>VO2max (mL/kg/min)</td>
<td>34.1 ± 2.6</td>
<td>36.9 ± 2.6*</td>
</tr>
<tr>
<td>Triglycerides (mmol/L)</td>
<td>2.09 ± 0.79</td>
<td>1.61 ± 0.52**</td>
</tr>
<tr>
<td>Total cholesterol (mmol/L)</td>
<td>5.19 ± 0.53</td>
<td>4.74 ± 0.55**</td>
</tr>
</tbody>
</table>

All data are presented in mean ± SD.

* $p < 0.05$; ** $p < 0.01$, between the pre- and post-tests within the groups.
† $p < 0.05$; †† $p < 0.01$, comparison of the changes between the groups.

BP = blood pressure; Fatmax = intensity at which the maximal fat oxidation occurs; SD = standard deviation; VO2max = maximal oxygen consumption.

The decrease in the concentrations of serum total cholesterol and triglycerides of the Fatmax group suggested that more fat was consumed as fuel. This result has been supported by the literature, in which lipid oxidation rates increased after exercise training at the Fatmax intensity and plasma triglyceride concentration decreased after low-intensity exercise training. However, another exercise training study at the Fatmax intensity did not show any changes in the lipid profile.

The exercise training program in that study was a combination of 2 weeks of supervised training followed by 6 weeks of home-based training. The authors did not report the quality control of the home-based training.

The current study had certain limitations. With the major purpose of testing the effect of exercise training at the Fatmax intensity on body composition and cardiorespiratory fitness, we did not have a second exercise group training at a different intensity. Therefore, the current outcomes cannot directly be compared with the effects of exercise program at other intensities. As the Fatmax intensity has a large interindividual variation dependent on gender, age, body composition, and training status, the target exercise HR of 134 ± 3 beats per minute should be used only for overweight young women.

In conclusion, with significant improvements in body composition, VO2max, and the HR index of the trained individuals, the present results demonstrated that the exercise training program at the Fatmax intensity is an effective option for the treatment of obesity. The exercise training program used in our study is an evidence-informed as well as a safe exercise prescription for overweight young women.

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References