Effect of Acute Resistance Exercise on Postexercise Oxygen Consumption and Resting Metabolic Rate in Young Women

Kristin L. Osterberg and Christopher L. Melby

This study determined the effect of an intense bout of resistive exercise on postexercise oxygen consumption, resting metabolic rate, and resting fat oxidation in young women (N = 7, ages 22–35). On the morning of Day 1, resting metabolic rate (RMR) was measured by indirect calorimetry. At 13:00 hr, preexercise resting oxygen consumption was measured followed by 100 min of resistive exercise. Postexercise oxygen consumption was then measured for a 3-hr recovery period. On the following morning (Day 2), RMR was once again measured in a fasted state at 07:00. Postexercise oxygen consumption remained elevated during the entire 3-hr postexercise recovery period compared to the pre-exercise baseline. Resting metabolic rate was increased by 4.2% (p < .05) from Day 1 (morning prior to exercise: 1,419 ± 58 kcal/24 hr) compared to Day 2 (16 hr following exercise: 1,479 ± 65 kcal/24 hr). Resting fat oxidation as determined by the respiratory exchange ratio was also significantly elevated on Day 2 compared to Day 1. These results indicate that among young women, acute strenuous resistance exercise of the nature used in this study is capable of producing modest but prolonged elevations of postexercise metabolic rate and possibly fat oxidation.

Key Words: weight lifting, metabolism, energy expenditure, females

The magnitude of the elevation of metabolic rate above resting values during recovery from exercise, often referred to as excess postexercise oxygen consumption, depends primarily on the intensity of exercise, and to a lesser extent on exercise duration (1–3, 8–10, 14, 17–19). Bahr et al. (2) found that postexercise oxygen consumption remained significantly elevated for several hours even when duration of exercise was short (2, 4, and 6 min) but intensity was equivalent to 108% VO2 max.

The duration and intensity of most exercise sessions for nonathletes (e.g., 30 min at 50–60% of VO2 max) results in only a small contribution to total energy expenditure beyond the net energy cost of the exercise itself. However, there remains the possibility that high intensity, strenuous exercise may produce a prolonged elevation of postexercise metabolic rate above true basal values, which

The authors are with the Dept. of Food Science and Human Nutrition, Colorado State University, Fort Collins, CO 80523. Direct correspondence to Dr. Chris Melby.
could make a meaningful contribution to daily energy expenditure (5, 14, 16). For example, Maehlum et al. (14) found that excess postexercise oxygen consumption persisted for at least 12 hr in subjects exercised for 80 min at 70% VO\textsubscript{2}\text{max}. Furthermore, it is possible that exercise of high intensity and prolonged duration may even affect resting metabolic rate (RMR) when measured up to 24 hr after the exercise bout (7). A study from our laboratory (5) showed that resting metabolic rate (RMR) measured the morning after 3 consecutive days of exercise for 90 min at 75% VO\textsubscript{2}\text{max} was significantly higher than RMR measured the morning after 3 consecutive days of no exercise.

Few studies have examined the effects of resistance exercise on postexercise and resting metabolic rate, and most have focused on men (10, 16). The growing interest in weight training for improving athletic performance, for weight control, and for prevention of such degenerative diseases as osteoporosis has led to increased interest in the physiological effects of weight training. In two studies from our laboratory (10, 16) we found strenuous resistive exercise to acutely increase resting metabolic rate measured approximately 15 hr following exercise in young men. It is unclear whether such strenuous resistive exercise will produce the same effects on postexercise metabolic rate in young women. The muscle mass of women and the volume of weight lifted by them during a resistance exercise session is typically less than that of their male counterparts, and it is important to characterize the postexercise response following such exercise in women. Therefore the purpose of this study was to determine the effects of a bout of strenuous weight lifting exercise on oxygen consumption during the 3 hr immediately after exercise, and on resting metabolic rate measured 16 hr following exercise in healthy, weight-trained young women.

**Methods**

Seven young women, ages 22–35 and in apparently good health, were recruited by word of mouth from among the staff and students at Colorado State University. All were informed of the testing procedure. This study was approved by the Human Research Committee at Colorado State University. Prior to testing, all subjects were required to complete a health-screening questionnaire to identify potential risks that would preclude participation. All the women denied using any performance-enhancing drug or medication that would affect resting metabolic rate. Two of the 7 reported use of oral contraceptives. All subjects were physically active and lifted weights 3 or 4 times a week in addition to regular cardiovascular exercise. Subjects were required to meet the following criteria for participation in the study: (a) no prior experience as a competitive body-builder; (b) body fat mass values less than 25% of total body weight; and (c) body weight stability defined as no gain or loss of weight > 2.0 kg within the 6 months prior to testing. Individual physical characteristics are listed in Table 1.

**Experimental Protocol**

On Day 0, subjects refrained from any exercise and were fed a standardized evening meal at 18:00 hr. The next morning (Day 1) they reported to the laboratory at 7:00 for measurement of resting metabolic rate following a 12-hr fast. At 8:00 they were fed a standardized breakfast. They were then given a small snack to consume at 10:00 and allowed to leave the laboratory with instructions to remain sedentary and to
Table 1  Physical Characteristics of Subjects

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Age</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Body mass index</th>
<th>% Body fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32</td>
<td>175.5</td>
<td>77.2</td>
<td>25.1</td>
<td>17.7</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>170.4</td>
<td>72.5</td>
<td>25.0</td>
<td>24.7</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>177.6</td>
<td>77.6</td>
<td>24.6</td>
<td>17.9</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>159.2</td>
<td>50.5</td>
<td>19.9</td>
<td>16.8</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>161.8</td>
<td>52.8</td>
<td>20.2</td>
<td>11.7</td>
</tr>
<tr>
<td>6</td>
<td>23</td>
<td>169.2</td>
<td>60.7</td>
<td>21.2</td>
<td>22.1</td>
</tr>
<tr>
<td>7</td>
<td>26</td>
<td>159.7</td>
<td>57.2</td>
<td>57.2</td>
<td>17.2</td>
</tr>
<tr>
<td>Mean ± SEM</td>
<td>27.0±1.8</td>
<td>167.6±2.8</td>
<td>64.2±4.4</td>
<td>22.6±0.9</td>
<td>18.3±1.6</td>
</tr>
</tbody>
</table>

Note. Body mass index = weight (kg)/height (m)^2; % Body fat based on 4-site skinfold analysis.

refrain from consuming any food or beverages except the provided snack and water. At 12:45 the subjects returned to the laboratory and a pre-exercise VO_2 measurement was made for 30 min beginning at 13:00 hr. At 13:30 hr they began a 100-min session of resistance exercise, followed by a 3-hr measurement of postexercise VO_2. Subjects then ate their evening meal, the same as on Day 1, finishing by 19:00 hr. Then they left the laboratory with instructions to refrain from any consumption of food or beverages except for water, to get at least 8 hr sleep, and not to exercise. The subjects reported on Day 2 at 7:00 for a second RMR measurement. Because we used a within-subjects comparison of RMR, with before and after measurements occurring over a time interval in which menstrual cycle changes would not affect RMR (i.e., only 24 hr), we did not attempt to test all subjects during the same phase of the menstrual cycle.

Anthropometric Measurements

Upon acceptance into the study, each subject’s height and weight was measured using a standard balance beam scale and a stadiometer. Weight was measured to the nearest 0.1 kg and height to the nearest 0.5 cm. Skinfold thicknesses for each subject were measured at four sites—abdomen, suprailiac, tricep, and thigh—using a Lange skinfold caliper in order to evaluate body fat % (12).

Resting Metabolic Rate

Subjects were told not to exercise for at least 36 hr prior to their first RMR test, the morning of Day 1. Using a ventilated canopy system, RMR was measured by indirect calorimetry for 45 min in a 12-hr fasted state. The subject was placed in a semi-dark, private room and lay supine on a comfortable bed with her head enclosed in a clear plexiglass canopy. Room temperature was kept at a constant 22–23 °C. The canopy was connected to the metabolic cart (Horizon MMC, SensorMedics,
Yorba Linda, CA) by a hose. The metabolic cart was calibrated prior to each measurement and respiratory gas measurements were standardized for standard temperature, pressure, and humidity (STPD). The oxygen and carbon dioxide analyzers were calibrated before each test using known gas concentrations. The reliability of repeated measures in our laboratory has been previously reported with an average coefficient of variation or 3.1 ± 1.3% for RMR and 5.3 ± 2.4% for RER (6). Heart rate was monitored and recorded via 3-lead ECG.

Subjects were checked after 12 min to make sure they were awake and comfortable. For purposes of subject habituation to the testing procedure, the respiratory gas measurements during the first 15 min of the test were discarded, and only the last 30 min of measurements were used to determine RMR. The Weir equation (22) was used to convert VO₂ and VCO₂ values to energy expenditure values. The second RMR measurement obtained on Day 2 at approximately 16 hr postexercise followed the same protocol as the first RMR measurement.

Using these RER values as well as the VO₂ values from the RMR measures, the rates of resting fat oxidation were calculated according to the formula of Jequier et al. (13): Fat oxidation (g/min) = \(1.689 \times VO₂ - 1.689 \times VCO₂\).

**Exercise Protocol and Oxygen Consumption**

On Day 1, following the measurement of RMR and consumption of breakfast and a snack, baseline pre-exercise VO₂ was measured for 30 min beginning at approximately 13:00. At 13:30 the subjects began exercising. After the exercise session they consumed water and voided if needed, then underwent measurement of 3 hr of postexercise VO₂ using the ventilated canopy described above. The time lag between completion of the last set of resistance exercise and the actual measurement of postexercise VO₂ was approximately 5 min.

**Weight Lifting.** The weight-lifting session consisted of 5 sets of 10 different exercises (lifts), 10–15 repetitions per set, with the last 2 sets of each exercise performed until failure. The 10 lifts were performed in groups of 2. For example, beginning at minute 0:00, the first set of 10–15 reps for the bench press, military press, and leg exercises, and for the other was performed, followed immediately by 10–15 reps of bent-over rows. At minute 4:00 the subjects began the second set of bench press/bent-over rows. Weights were added or removed to ensure maximal effort while remaining in the 10–15-rep range. The exercise groupings consisted of bench press/bent-over row, leg extension/leg curl, military press/sit-up, biceps curl/triceps extension, and lunges followed by lateral raises. Opposing muscle groups were grouped together as much as possible to avoid premature failure due to muscle fatigue.

Subjects were closely supervised to prevent injury and to ensure proper lifting technique. They were allowed to perform the concentric and eccentric contractions required of each lift at their own pace. Typically, 1 to 2 min of each 4-min period was spent performing the lifts and the remainder was spent resting between sets. The weight lifted for each exercise represented approximately 70% of the individual’s one-repetition maximum (RM) for the bench press and the leg exercises, as determined at least 1 week prior to the exercise testing, by the progressive addition of weight until the subject’s 1-RM was obtained. The weight for the other lifts represented each subject’s estimated 12-RM.
**Meals**

Attempts were made to keep the subjects in energy balance during the testing days. Each subject consumed a standardized meal the evening prior to the measurement of RMR on Day 1, and an identical meal was consumed the evening prior to the measurement of RMR on Day 2. Total energy intake was based on individual RMR \* 1.5. All subjects were fed identical dinners and snacks, with calorie manipulation occurring at breakfast using the following formula as in previous studies (16): \[ \text{RMR} \* 1.5 - \text{(dinner kcals + snack kcals)} = \text{breakfast kcals} \]. The macronutrient composition of the diet was 62% energy as carbohydrate, 23% energy as fat, and 15% energy as protein.

All food was provided for each subject and eaten at the laboratory, except the midmorning snack, which was sent with each subject along with instructions to consume the snack at 10:00. Participants finished dinner prior to Day 1 (testing day) by 19:00 hr to ensure a 12-hr fast before RMR was measured. Breakfast was finished before 8:00, the snack was eaten at 10:00, and again, dinner prior to Day 2 was finished before 19:00 hr.

**Statistical Analyses**

The mean VO\(_2\) and RER values were averaged for the 30-min pre-exercise period and for each 30-min period during the 3-hr recovery. The data were analyzed using a repeated measures ANOVA. Post hoc comparisons were then made for each of the means for the six 30-min postexercise periods versus the pre-exercise values. Metabolic rate, RER, and fat oxidation measured under resting conditions on Day 1 (prior to the exercise bout) were compared to those same variables on Day 2 (approximately 16 hr following exercise) using paired \(t\) tests. Alpha was set at .05.

## Results

Table 1 shows the physical characteristics of all 7 subjects. These values indicate that the study sample was composed of young women of average height and body weight, with a lower than average percent body fat as estimated from the sum of skinfold analyses. Postexercise VO\(_2\) values (30-min averages during the 3-hr postexercise period) were compared to pre-exercise 30-min mean VO\(_2\) using a repeated measures ANOVA (7 timepoints: pre-exercise + 6 recovery data points) (Figure 1). The \(F\)-ratio for the ANOVA was significant (\(F = 8.017, p < .001\)), and post hoc analyses using the least significant differences test revealed a significantly higher VO\(_2\) value at all 6 of the 30-min periods during the 3-hr recovery compared to pre-exercise VO\(_2\) (\(p < .05\)). As shown in Figure 1, VO\(_2\) decreased rapidly during the initial stages of recovery but leveled off approximately 60 min postexercise and remained elevated above pre-exercise values for the entire 3-hr postexercise period. During the final 30 min of the 3-hr recovery, VO\(_2\) was 13% higher than pre-exercise baseline VO\(_2\) (248.9 vs. 220.3 ml O\(_2\) - min\(^{-1}\)) (\(p < .05\)).

The RER measured during the 3-hr recovery from exercise was significantly lower at all six 30-min time intervals during the postexercise period compared to pre-exercise baseline RER (Figure 2). During the first hour of recovery, mean RER values fell below 0.70 for some subjects, most likely due to conservation of metabolically produced CO\(_2\) in order to restore bicarbonate stores to their pre-exercise
Figure 1 — Postexercise oxygen consumption (mean of each 30-min period ± SEM) during the 3-hr recovery from acute resistance exercise compared to 30-min pre-exercise baseline VO₂ value. Mean VO₂ values for each 30-min timepoint during the postexercise period were significantly higher (p < .05) than baseline VO₂.

Figure 2 — Postexercise respiratory exchange ratio (mean of each 30-min period SEM) during the 3-hr recovery from acute resistance exercise compared to pre-exercise baseline RER value. Mean RER for each 30-min timepoint during the postexercise period were significantly lower (p < .05) than baseline RER.
values. Because of the disturbances in the bicarbonate pool, the rates of substrate oxidation during the 3-hr recovery were not calculated from respiratory gas exchange measures.

Figure 3 depicts each subject's changes in RMR values from Day 1 (prior to exercise) to Day 2 (approx. 16 hr post). The mean increase was 4.2% ($p < .05$). The mean value for Day 2 RMR ($1,479 \pm 65$ kcal/24 hr) was significantly higher than Day 1 RMR ($1,419 \pm 58$ kcal/24 hr). These values represent $102.4 \pm 1.7\%$ (mean $\pm$ SEM) and $98.3 \pm 1.6\%$, respectively, of predicted RMR values based on the revised Harris-Benedict equation (21).

The respiratory exchange measurements were used to determine the rate of fat oxidation during RMR measurements on Days 1 and 2. The mean RER when RMR was measured on Day 2 (RER = 0.807 $\pm$ 0.02) at approximately 16 hr postexercise was significantly lower ($p = .05$) than the mean RER for Day 1 the morning prior to exercise (RER = 0.841 $\pm$ 0.02). There was a 62% increase in resting fat oxidation at the time RMR was measured on Day 2 following the resistance exercise (0.071 g · min$^{-1}$) compared to when measured on Day 1 prior to exercise (0.044 g · min$^{-1}$ ($p = .015$).

**Discussion**

The results of this investigation indicate that in young women, metabolic rate remains elevated for an extended period following strenuous resistive exercise. The rate of oxygen consumption (VO$_2$) remained elevated throughout the 3-hr postexercise period, and RMR was significantly higher 16 hr following exercise compared to RMR measured the morning prior to exercise. Also, we found the rate of resting fat oxidation to be higher 16 hr following exercise. These data indicate that resistance exercise such as this results in significant postexercise metabolic perturbations that influence both energy expenditure and substrate oxidation.
In a previous experiment from our laboratory (16) in which male subjects followed a similar exercise protocol, but with a shorter rest interval (3 min between paired sets), there was a significant elevation of metabolic rate during the 2 hr immediately following exercise, and elevated RMR (9.4%) when measured the next morning 15–16 hr postexercise. In a second experiment in the same report, a longer rest interval between exercise sets (4 min vs. 3 min) resulted in a less pronounced increase in RMR (4.7%). The present study indicates that women respond to this same resistive exercise protocol in a similar fashion (a 4.2% increase in RMR, compared to a 4.7% increase for men).

**Methodological Issues**

Several aspects of this study merit attention. Pre-exercise VO₂ values were used to establish baselines rather than utilizing a separate control day. We did not use a separate control day because of the possible influence of menstrual cycle on metabolic rate. Using a control condition separated from the exercise condition by at least several days for an appropriate washout period would have increased the likelihood of the subject completing the control and experimental conditions during different phases of her menstrual cycle. We could have handled this issue by examining the exercise treatment during a specific phase of the cycle, and then studying the subjects under control conditions during the same phase of the next cycle occurring approximately 1 month later. However, many women have irregular menstrual cycles, particularly athletes. Therefore, predicting phases of the menstrual cycle when metabolic rate would be equivalent to that of the control day would prove difficult.

Although individuals vary in their physiological responses, basal metabolic rate generally begins to rise 7–10 days prior to menstruation, with a drop at the beginning of the menstrual period. This is followed by a gradual return to normal values 7–10 days following cessation of menses (20). Because of the difficulties associated with conducting the study over two menstrual cycles, pre-exercise VO₂ values were used to establish the baseline rather than using a separate nonexercise control day, and the pre- and postexercise RMR measurements were performed just 24 hr apart, a time period during which any changes in menstrual-phase-induced energy expenditure and substrate oxidation rates would be minimal.

Because we used a within-subjects comparison of RMR, with before and after measurements occurring over a time interval that would not affect RMR (i.e., it is doubtful that a detectable change in RMR would occur over a single day due to menstrual cycle changes), it was unnecessary for subjects to all be tested during the same phase of the menstrual cycle, and thus we made no attempt to do so.

It might be argued that due to diurnal variations in metabolic rate (i.e., increases in resting VO₂ from morning to evening), determination of the magnitude of postexercise VO₂ values by using a pre-exercise baseline VO₂ rather than a control condition on a separate day could contribute to “artificially” high calculated values of postexercise VO₂. In other words, due to diurnal variations, metabolic rate could be elevated in late afternoon vs. early afternoon, even without an intervening exercise bout. However, several lines of evidence suggest that postexercise VO₂ was elevated due to exercise and not due to diurnal variations in metabolic rate: (a) the magnitude of the elevation of VO₂ 3 hr following exercise was 13%, much higher
than could be attributed to diurnal variation; (b) it is possible that without exercise, the subjects' metabolic rate would have actually decreased in the afternoon as the time interval from their last meal increased (i.e., lower contribution of postprandial thermogenesis to their late afternoon vs. early afternoon VO\textsubscript{2} values); and (c) prior research in our laboratory (15) has shown that the magnitude of elevations in postexercise VO\textsubscript{2} values were similar whether using a separate control day or a preexercise baseline to determine excess postexercise oxygen consumption.

The RER values were depressed below baseline for the entire 3-hr postexercise period and remained significantly lower approximately 16 hr postexercise. The RER values in the early part of the recovery period, below the "physiologic" value for fat oxidation (0.707), are likely indicative of conservation of CO\textsubscript{2} used for replenishment of bicarbonate stores. Bicarbonate is used to buffer lactic acid, which accumulates during intense anaerobic exercise. Because of the disturbances in the bicarbonate pool that accompany such exercise, we made no attempts to estimate substrate oxidation rates during and immediately after exercise using the RER values observed. It is possible that toward the end of the recovery period, at which time the bicarbonate pool would likely be restored, the lower RER values are a true reflection of greater fat oxidation. However, because we did not measure pre- and postexercise bicarbonate levels, no conclusions about postexercise fat oxidation should be made.

During measurement of RMR the subjects were in steady state, and shifts in bicarbonate ion would have been unlikely. The RER values obtained during the measurement of RMR on both days are then appropriate to use for estimation of substrate oxidation rates. Therefore, the lower resting RER on Day 2 compared to Day 1 most likely reflects greater fat oxidation. The calculated rate of fat oxidation was 62% higher on Day 2 compared to Day 1.

Maintenance of energy balance is important in any study that examines energy expenditure and substrate oxidation rates. Acutely overfeeding a mixed diet can increase metabolic rate and decrease the rate of fat oxidation (11), while the opposite would occur with underfeeding (15). The increase in resting fat oxidation on Day 2 could potentially be due to the effect of underfeeding in which fat is mobilized from adipose stores and used for energy. However, subjects were fed an average of 2,170 kcal per day, thus any caloric deficit is likely to be fairly small. Also, as stated earlier, acute underfeeding lowers RMR (15), yet our subjects had an increase in RMR from Day 1 to Day 2. One might argue that the energy intake set at 1.5 times the measured RMR was inadequate to maintain energy balance on the day that subjects engaged in such exercise. While it is possible that their actual energy requirements were somewhat higher, we did not want to risk overfeeding them on the exercise day. Had the subjects been overfed in our study, it would have been unclear whether the elevation in RMR 16 hr following the exercise bout was the result of the exercise or simply due to an excess energy intake.

It should be noted that members of general public are unlikely to engage in such rigorous resistance exercise. Therefore we are making no extrapolations of these findings to individuals who are beginning an exercise program to lose weight and alter body composition. Further research must be undertaken to clarify the role of resistance exercise in weight regulation.

In conclusion, this investigation indicates that in young women, strenuous resistance exercise of the nature used in this study causes significant elevations of
(a) postexercise oxygen consumption when measured for 3 hr following cessation of exercise, (b) resting metabolic rate when measured 16 hr following cessation of exercise, and (c) resting fat oxidation when measured 16 hr following cessation of exercise. Application of these results to weight regulation in humans must be made with caution, because most individuals would be unable to complete the amount of work performed in the exercise session used in this study.

References


**Acknowledgments**

This study was supported by the Colorado Agricultural Experiment Station, Project #616 (CLM). An abstract of this paper was presented at the American College of Sports Medicine Meeting, Seattle, June 1999. The authors would like to thank the study participants for their cooperation, and Mr. Eric Reinke for his assistance in the laboratory.

*Manuscript received: May 7, 1998
Accepted for publication: July 20, 1999*