Minimal Resistance Training Improves Daily Energy Expenditure and Fat Oxidation

ERIK P. KIRK1, JOSEPH E. DONNELLY2, BRYAN K. SMITH2, JEFF HONAS2, JAMES D. LECHEMINANT1, BRUCE W. BAILEY3, DENNIS J. JACOBSEN2, and RICHARD A. WASHBURN2

1Department of Kinesiology & Health Education, Southern Illinois University, Edwardsville, IL; 2Center for Physical Activity and Weight Management, Energy Balance Laboratory, University of Kansas, Lawrence, KS; and 3Department of Exercise and Health Sciences, University of Massachusetts, Boston, MA

ABSTRACT

KIRK, E. P., J. E. DONNELLY, B. K. SMITH, J. HONAS, J. D. LECHEMINANT, B. W. BAILEY, D. J. JACOBSEN, and R. A. WASHBURN. Minimal Resistance Training Improves Daily Energy Expenditure and Fat Oxidation. Med. Sci. Sports Exerc., Vol. 41, No. 5, pp. 1122–1129, 2009. Long-term resistance training (RT) results in chronic increases in energy expenditure (EE) and substrate oxidation likely due to adaptations in resting metabolic rate (RMR) and sleep metabolic rate (SMR). However, the majority of investigations designed to determine the effect of short-term (e.g., 6 months) training on energy expenditure and substrate oxidation have been limited to acute responses to RT and have not assessed chronic adaptations. To address this gap in the literature, we aimed to evaluate the effect of 6 months of supervised minimal RT in previously sedentary, overweight young adults (mean ± SD: BMI = 27.7 ± 0.5 kg·m–2) on 24-h EE, RMR, SMR, and substrate oxidation using whole-room indirect calorimetry 72 h after the last RT session. Participants were randomized to RT (one set, 3 d·wk–1; three to six repetition maximums, nine exercises; N = 22) or control (C, N = 17) groups and completed all assessments at baseline and at 6 months. Results: There was a significant (P < 0.05) increase in 24-h EE in the RT (527 ± 220 kJ·d–1) compared with C during these periods. SMR (8.4 ± 8.6%) and RMR (7.4 ± 8.7%) increased significantly in RT (P < 0.001) but not in C, resulting in significant (P < 0.001) between-group differences for SMR with a trend for significant (P = 0.07) increase in RMR. Conclusion: A minimal RT program that required little time to complete (11 min per session) resulted in a chronic increase in energy expenditure. This adaptation in energy expenditure may have a favorable impact on energy balance and fat oxidation sufficient to assist with the prevention of obesity in sedentary, overweight young adults. Key Words: WHOLE-ROOM INDIRECT CALORIMETER, STRENGTH TRAINING, OBESITY, EXERCISE, RESTING METABOLIC RATE

The continued increase in the development of overweight and obesity, combined with the difficulty in treating these conditions, suggests that innovative strategies for obesity prevention need to be developed and evaluated (17). The college age population represents an important group of individuals at high risk of developing obesity (43,45). Reports by many health organizations have recommended resistance training (RT) as an integral part of adult fitness programs (4,12,17,33,42). Nevertheless, despite the plethora of investigations that have examined the acute effects of RT on energy expenditure and substrate oxidation, there have been limited investigations of long-term (e.g., 6 months or longer) RT on the chronic adaptations of energy expenditure and substrate oxidation in young adults.

Unlike aerobic exercise, which results in significant increases in energy expenditure during and, for a short time, after cessation of the activity, the energy expenditure during RT is relatively low (29,31), but the increase in energy expenditure after the cessation of the activity may be elevated (7,29,38). To this end, although there is a plausible basis for using RT as a weight control strategy, results from investigations designed to determine the effect of low-volume RT on RMR (2,5,22,36,39), 24-h energy expenditure (24-h EE) (16,32) and substrate oxidation (40) are scarce and inconsistent. Because resting metabolic rate (RMR) accounts for the largest proportion of total daily energy expenditure, small changes in RMR could have long-term benefits for weight management (6,16,25,34). However, RT studies that measured energy expenditure and substrate oxidation within 24 h after the last RT session determined an acute response to RT. Using this method reduces our understanding if an adaptation to RT resulting in a chronic elevation of energy expenditure and fat...
oxidation has occurred. Because many organizations (4,12, 17,33,42) recommend performing RT sessions 48–72 h apart, it is important to determine the chronic effect of RT on energy expenditure and fat oxidation. In addition, previous studies have used a greater volume of RT consisting of multiple sets (two to four sets) than recommended by the American College of Sports Medicine (ACSM; one set, 8–12 repetitions, 8–10 exercises) to develop and maintain muscular fitness in untrained individuals (13,21). Higher-volume multiple-set RT programs may not be attractive or adhered to by sedentary overweight individuals in need of weight management.

Another consideration is that few studies have controlled both premeasurement energy intake and exercise. This is important for ensuring that subjects are in a similar state of energy balance and fuel repletion at the time of testing, because over- and underfeeding have profound effects on energy expenditure and substrate oxidation. The most effective method to evaluate the chronic effects of RT on energy expenditure and substrate oxidation is to study subjects during a 24-h period by using whole-room indirect calorimetry, with the application of suitable premeasurement dietary and exercise controls.

The primary objective of this investigation was to evaluate the impact of a supervised 6-month minimal RT program [one set, 3-d-wk⁻¹, nine exercises, three to six repetition maximums (RM)] in sedentary young adults on 24-h EE, RMR, sleep metabolic rate (SMR), and substrate oxidation assessed by whole-room indirect calorimetry 72 h after the last RT session. We hypothesized that the minimal RT program would result in an increase in 24-h EE, RMR, SMR, and fat oxidation compared with the nonexercising controls.

SUBJECTS AND METHODS

Participants/Design

Sixty-three overweight (BMI > 25 kg·m⁻²), young adult men and women volunteered to participate in this study after providing written informed consent. Participants were monetarily compensated for participation. Potential participants who used tobacco products, had a history of chronic disease (i.e., diabetes, heart disease, etc.), elevated blood pressure (>140/90 mm Hg), lipids (cholesterol > 240 mg·L⁻¹, triglycerides >500 mg·L⁻¹) (9), fasting glucose (>126 mg·dL⁻¹) (11), or were physically active (>2100 kJ·wk⁻¹ on the Minnesota Leisure Time Physical Activity Questionnaire) (35) were excluded from the study. Participants were matched for fat-free mass (FFM; ±0.5 kg) and randomized at approximately a 1.5:1 ratio to RT (n = 37) or nonexercise control (C, n = 26). This assignment ratio was in anticipation of greater attrition in the RT group compared with the C group. Both groups were instructed to maintain their normal ad libitum diet and normal activities of daily living. Eight participants failed to complete the study protocol (RT, n = 5; C, n = 3). Of the 55 participants who completed the study (RT, n = 32; C, n = 23), 39 participants volunteered to complete the whole-room calorimeter protocol (RT, n = 22; C, n = 17), and these data are reported in this article. Twenty-four-hour EE, RMR, SMR, substrate oxidation, muscular strength, and body composition were assessed at baseline and after completion of a 6-month supervised RT program. In addition, dietary intake was assessed monthly throughout the RT program. The study protocol was approved by the Institutional Review Board at the University of Kansas–Lawrence.

Procedures

Resistance training protocol. RT was performed on three nonconsecutive days per week for 6 months using Paramount weight stack resistance equipment (Paramount Fitness Corporation, Los Angeles, CA) in the Energy Balance Laboratory at the University of Kansas–Lawrence. To ensure compliance with the RT protocol, all sessions were supervised on a one-on-one basis by experienced laboratory technicians. Participants were informed that an adherence rate of greater than 90% of scheduled sessions was required to remain in the study. Detailed records regarding attendance, number of repetitions performed, resistance used, and the total amount of weight lifted per session were maintained by the training supervisor. Participants performed one set of nine exercises designed to train all major muscle groups (chest press, back extension, lateral pull-down, triceps extension, shoulder press, leg press, calf raise, leg curl, and abdominal crunch) using a resistance of three to six 1RM, approximately equal to 85%–90% of 1RM. We selected the higher-intensity RT program to maximize the potential effect on fat-free mass (FFM) and therefore also RMR, SMR, and 24-h EE. During the first training session, participants were familiarized with the equipment and instructed on proper lifting techniques for all exercises using minimal resistance (~12–15 RM). On the fourth training day, a resistance eliciting three to six RM was determined on the basis of the participant’s performance during the initial three training periods. All lifts were conducted at 2-s concentric and 4-s eccentric movements (33) to decrease the likelihood that momentum was being used to perform the lift and to ensure loading throughout the full range of motion. When more than six repetitions were completed using good form for two consecutive exercise sessions, the resistance was increased by approximately 2.25 kg to reduce the maximum number of repetitions to between three and six. The order of exercises (as listed previously) was the same for all training sessions. Each exercise was preceded by 5-min upper and lower body stretching and followed by a 5-min cool-down/stretching period.

Assessments. With the exception of dietary intake, all assessments were conducted at the same time of day in both RT and C groups at baseline and after the 6-month
intervention period. Posttraining assessments for the RT group were conducted 72 h after completion of the final RT session.

**Body mass/BMI.** Body mass was assessed at baseline and at 6 months between the hours of 7 and 9 a.m. using a digital scale accurate to ±0.1 kg (Model No. PS6600; Befour, Inc., Saukville, WI). The participants were weighed before breakfast and after attempting to void and wore a standard hospital gown at the time of weighing. Height was assessed using a wall-mounted stadiometer (Model PE-WM-60-84; Perspective Enterprises, Portage, MI). BMI was calculated as weight per height (kg m⁻²).

**Body composition.** Fat-free mass (FFM), fat mass (FM), and percent body fat were assessed using dual-energy x-ray absorptiometry (DXA, Lunar DPX-IQ; Lunar Radiation Corp., Madison, WI). DXA examinations were performed during the afternoon with the participants clothed in a hospital gown. All females completed a pregnancy test before DXA evaluations. DXA is capable of detecting changes in fat-free mass of approximately 1.6%–3.8% (20).

**Maximal strength testing.** Before beginning the 4th training session, a 1RM strength test for the chest press and leg press, was performed according to the protocol described by Lemmer et al. (25). Briefly, participants performed a light warm-up of 10 repetitions of the exercise to be evaluated, against minimal resistance. A resistance estimated to be just below the subject’s 1RM strength was chosen, and the participant was asked to lift the weight once. If the lift was completed successfully through the full range of motion, the resistance was increased (minimum increment of 1.1 kg) and another attempt made after a rest period of at least 1 min. This process was continued until the subject was unable to lift the prescribed resistance. The highest weight lifted was recorded as the 1RM. The 1RM was determined within five attempts for each exercise. The test–retest reliability (intraclass correlation) for maximal strength assessment was 0.95 for chest press and 0.94 for leg press.

**Twenty-four-Hour Energy Expenditure—Room Calorimeter**

**Room description.** The calorimeter is a small room measuring 2.6 m wide, 3.4 m long, and 2.58 m high, with a total volume of 17,500 L and is equipped with a couch that folds into a bed, a desk, toilet, entertainment facilities (TV, VCR, computer), telephone, and a stationary bicycle, reducing the volume to 16,300 L. An airlock (78.1 × 33.7 cm) allows for the passage of food and materials to the subject while inside the room.

**Dietary control for calorimeter stay.** Three days before the calorimeter stay, participants were provided a diet (three meals and two snacks per day) estimated to meet free-living energy requirements to maintain weight stability and standardize macronutrient intake. Twenty-four-hour energy requirements (kJ d⁻¹) were estimated as 2065.16 – (12.90 × height (cm)) + (13.49 × body mass (kg)) + (0.03418 × grams of lean tissue measured from DXA) × 4.186 (8). The energy composition of the diet was as follows: 30% from fat, 15% from protein, and 55% from carbohydrate. All menus were planned by a registered dietitian, and all food were prepared and served at the university cafeteria. Weigh and measure techniques (41) were used to document the macronutrient and energy composition of the diet. The two daily between-meal snacks contained the same macronutrient composition as the three meals. To confirm weight stability (±1 kg), individuals were measured in a standard hospital gown, after voiding and before consumption of breakfast, 3 d before the calorimeter stay, and immediately before entering the calorimeter. During the 3 d before the calorimeter stay, participants were instructed to maintain their normal daily physical activity patterns and to refrain from performing any RT or aerobic exercise 72 h before entering the calorimeter. This protocol was done specifically to reduce the effect of the last RT session on posttraining assessments of energy expenditure and substrate oxidation in the RT group (28). Participants spent the night before the calorimeter stay in our laboratory dormitory under supervision of the research staff.

**Calorimeter stay.** Participants entered the calorimeter at 8:00 a.m. and exited at 7:00 a.m. the following day. Data were extrapolated to 24-h values. During each stay in the calorimeter, participants consumed a diet with a caloric content designed to achieve energy balance and with the same macronutrient composition as described above. Participants were provided breakfast (8:30 a.m.), lunch (12:30 p.m.), snack (3:00 p.m.), dinner (5:30 p.m.), and a second snack (8:00 p.m.) during the 23-h stay. All food for the calorimeter stay were prepared in the metabolic kitchen by registered dietitians. To account for energy expended in normal activities of daily living, an individualized cycle ergometer protocol (75 W) designed to expend ~837 kJ per session was performed at 10:30 a.m., 4:00 p.m., and 7:00 p.m. The number of minutes of exercise required to expend ~837 kJ was calculated using the ACSM metabolic equations (1). Participants were free to move out of the calorimeter during other times of the day. However, free time was primarily spent in sedentary activities such as reading, writing, watching TV, or using the computer. Participants were instructed to remain awake and not to nap or perform any exercise other than the cycle ergometer exercise prescribed by the protocol. Participants went to bed at the same time (±30 min) during each calorimeter stay.

**Assessments/calibration.** Total 24-h EE, RMR, SMR, and substrate oxidation were determined from oxygen consumption and carbon dioxide production. Gas volumes (SPTD) were assessed from the flow rate and the differences in carbon dioxide and oxygen concentrations between air entering and exiting the calorimeter using Siemens Ultrimat/Oxymat 6 (Siemens, Karlsruhe, Germany) oxygen and carbon
dioxide analyzer that is calibrated before each test. The oxygen and carbon dioxide analyzers were calibrated with gases of known concentration before each calorimeter stay.

The accuracy and precision of the whole-room calorimeter was evaluated monthly by burning propane at variable rates. We consistently observed 97%–98% recovery of the predicted values for oxygen consumption and carbon dioxide production. Repeated measures under identical conditions during a short period have not been previously completed in our calorimeter. However, in a separate study, when examining repeated measures performed under separate but similar conditions approximately 6 wk apart, intraclass correlations for 24-h EE, SMR, and RMR were 0.804, 0.718, and 0.70, respectively. Coefficients of variation (CV) for 24-h EE, SMR, and RMR were 4.1, 7.9, and 7.3, respectively. Although the CV values are slightly higher than what have been previously reported, the sample size is considerably larger (n = 26), and the time between tests is ~6 wk. Both of which could possibly explain the larger CV for our repeated measures.

The operation of the calorimeter was computer-controlled. Data were collected continuously, averaged during 15-min intervals, and recorded to a data file. Sleeping metabolic rate was assessed as the average metabolic rate obtained for 1:00 to 5:00 a.m. Resting metabolic rate was measured between 6:00 and 6:45 a.m. with the participant awake, lying quietly on their back. All participants were monitored by research assistants during the calorimeter stay. Urine was collected throughout the calorimeter stay for the determination of total nitrogen concentration (37), which was used to assess 24-h protein oxidation (27). Energy expenditure and substrate oxidation were calculated from measured oxygen consumption and respiratory quotient (RQ) using the equations of Jequier et al. (18).

Dietary intake. Dietary intake was assessed monthly during the course of the intervention using 24-h dietary recalls and 3-d food records (15) performed on one randomly selected day each month. Research assistants were trained by a registered dietitian to conduct standardized, structured interviews using neutral probing questions (10). To promote accurate reporting of portion sizes, subjects were given three-dimensional food models (10). Nutrient calculations were performed using the Nutrition Data System for Research software (Food and Nutrient Database 31, released 2000, Version 4.03; Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN).

Statistics and data analysis. A two-factor (group × time) repeated-measures (time) ANOVA was used for main effects. If there was a significant interaction effect of group or time, we used the Tukey’s post hoc test. Student’s t-test was used to determine differences for change scores. Statistical significance was defined at P < 0.05 for all tests. All values are expressed as mean ± SEM. Data were analyzed using SAS (8.2, Cary, NC). Using an α level of 0.05 and a sample size of 22 in the RT and 17 in the C group, the results provided a 72% statistical power for the interaction effects in 24-h EE and 82% in RMR.

RESULTS

Thirty-nine overweight (BMI = 27.7 ± 0.5 kg·m⁻²) adults [RT, N = 22 (16 males, 6 females); C, N = 17 (11 males, 6 females)], 85% white, and with mean age of 21.0 ± 0.5 yr completed the 6-month study and all baseline and end-study assessments. Adherence to the RT protocol was excellent, with participants completing 96 ± 1% of the total prescribed exercise sessions. No participant fell below the 90% adherence rate required to be considered compliant with the RT protocol. The average time to complete each exercise session was 11 ± 1 min. No major adverse events occurred during the study in either of the RT or the C groups. There were no significant baseline differences between groups for any variables assessed. Also, there was no difference between subjects who dropped out of the study and those who completed the study.

Strength (1RM). As expected, significant between-group differences for change in both chest (RT = +47.5 ± 4.9%) and leg press strength (RT = +53.7 ± 8.5%) were observed (P < 0.001). No change was observed in the C group.

Body mass and composition. During the 6-month intervention, body mass and BMI increased significantly (P < 0.05) in both RT (weight = 2.9%, BMI = 2.9%) and C groups (weight = 2.9%, BMI = 2.5%); however, differences in the change in body mass and BMI between groups were not statistically significant (Table 1). RT had a significant impact on body composition. The increase in FFM was significantly greater (P < 0.01) in RT (+2.7%) compared with that in C (–0.6%). Although the between-group difference for change in FM was not statistically significant, we observed a significant increase in FM (8.8%, P < 0.05) in C and a nonsignificant increase (3.3%) in RT. The combination of similar increases in body mass, greater increases in FFM, and reduced increase in FM favoring RT compared with C resulted in a significant between-group difference (P < 0.05) for change in percent body fat (RT = 0.9%, C = 6.3%).

Table 1. Body weight and composition at baseline and at 6 months between the controls (C, n = 17) and resistance training (RT, n = 22) groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Baseline</th>
<th>6 Months</th>
<th>Change</th>
<th>P for Group × Time Interaction*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td>C</td>
<td>82.2 ± 2.8</td>
<td>84.6 ± 3.1</td>
<td>2.4 ± 0.6*</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>86.7 ± 2.8</td>
<td>89.2 ± 2.6</td>
<td>2.5 ± 0.7*</td>
<td></td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>C</td>
<td>27.6 ± 0.6</td>
<td>28.3 ± 0.7</td>
<td>0.7 ± 0.9*</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>27.8 ± 0.7</td>
<td>28.7 ± 0.7</td>
<td>0.8 ± 1.6*</td>
<td></td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>C</td>
<td>26.0 ± 1.8</td>
<td>28.3 ± 1.7</td>
<td>2.3 ± 0.6*</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>27.2 ± 1.9</td>
<td>28.2 ± 1.7</td>
<td>0.9 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>C</td>
<td>52.7 ± 2.6</td>
<td>52.4 ± 2.5</td>
<td>–0.3 ± 0.2</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>55.3 ± 1.9</td>
<td>56.8 ± 2.0</td>
<td>1.5 ± 0.5*</td>
<td></td>
</tr>
<tr>
<td>% body fat</td>
<td>C</td>
<td>33.2 ± 2.2</td>
<td>35.3 ± 1.8</td>
<td>2.1 ± 0.6*</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>32.7 ± 1.8</td>
<td>33.0 ± 1.7</td>
<td>0.3 ± 0.5</td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SEM.
* Group by time interaction from baseline to 6 months between the C and RT groups.
* Significantly different within group, P < 0.05.
Twenty-four-hour EE, RMR, and SMR. There was no between-group difference for the change in 24-h EE (P = 0.30); however, the increase in 24-h EE in RT (P < 0.05) was double that of the increase in the C group (Table 2). RT resulted in a significant increase (P < 0.001) in RMR, with a trend for time × group interaction for RMR (P = 0.07). SMR increased significantly in RT (P < 0.001) but not in C resulting in a significant between-group difference (P < 0.05). Change in FFM was positively associated with change in 24-h EE (ρ = 0.44, P = 0.04), RMR (ρ = 0.37, P = 0.08), and SMR (ρ = 0.29, P = 0.18) in the RT group. Likewise, the regression approach (24) was also used to examine the effects of the change in FFM with 24-h EE and RMR, and the results of these analyses were similar to those using the ratio method.

There were no significant within- or between-group differences for the change in 24-h EE per kilogram FFM. RT resulted in significant increases (P < 0.05) in both RMR per kilogram FFM and SMR per kilogram FFM; however, the between-group differences in the change for both of these outcomes were not statistically significant (Fig. 1).

Substrate oxidation. There were no significant between- or within-group differences for the change in protein, fat, or carbohydrate oxidation (g d⁻¹; Table 3 and Fig. 2). However, changes in RQ assessed during both rest and sleep suggested increased fat oxidation in RT compared with control. SMR–RQ increased slightly in C (0.5%) and decreased significantly (P < 0.05) in RT (−1.7%) resulting in a significant difference between groups (P < 0.05; Fig. 2). RMR–RQ was not significantly different between groups; however, RMR–RQ decreased in RT (−1.5%, P = 0.15) and increased in C (0.4%) suggesting a favorable trend for increased fat oxidation as a result of RT.

Dietary intake. Differences in reported dietary intake (total energy, carbohydrate, fat, protein) were not significant between the baseline and the intervention periods for either RT or C or between the two groups during the intervention. The mean intake for total energy and the percent of dietary carbohydrate, fat, and protein were 9538 kJ d⁻¹, 50%, 34%, and 16%, respectively. There was no difference for either group at baseline and at 6 months between energy and macronutrient intake during the 3 d of standardized food before or during the calorimeter stay.

**DISCUSSION**

To our knowledge, this is the first study to use a whole-room indirect calorimeter to measure changes in 24-h EE, RMR, SMR, and substrate oxidation 72 h after the last RT session in response to a long-term (6 months), low-volume RT program in young overweight adults. Results showed a favorable impact of RT on body composition corresponding to a chronic adaptation of both energy expenditure and fat oxidation.

The favorable results for 24-h energy expenditure suggests that a 6-month minimal RT may have a significant impact on daily energy expenditure. In fact, increases in 24-h EE may potentially result in a negative energy balance of sufficient magnitude to prevent increases in fat.

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**TABLE 2.** Twenty-four-hour, rest, and sleep energy expenditure at baseline and 6 months between the controls (C, n = 17) and resistance training (RT, n = 22) groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Baseline</th>
<th>6 Months</th>
<th>Change</th>
<th>P for Group × Time Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>24-h EE (kJ d⁻¹)</td>
<td>C</td>
<td>12.835 ± 479</td>
<td>13.105 ± 479</td>
<td>270 ± 168</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>13.091 ± 358</td>
<td>13.618 ± 383</td>
<td>527 ± 220*</td>
<td></td>
</tr>
<tr>
<td>RMR (kJ d⁻¹)</td>
<td>C</td>
<td>9448 ± 571</td>
<td>9683 ± 432</td>
<td>235 ± 168</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>9236 ± 1337</td>
<td>9915 ± 268</td>
<td>679 ± 173†</td>
<td></td>
</tr>
<tr>
<td>SMR (kJ d⁻¹)</td>
<td>C</td>
<td>9166 ± 522</td>
<td>9258 ± 340</td>
<td>92 ± 177</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>9143 ± 283</td>
<td>9844 ± 234</td>
<td>701 ± 162†</td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SEM.  
† Significantly different within group, P < 0.05.  
* Significantly different within group, P < 0.001.

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**TABLE 3.** Substrate oxidation at baseline and at 6 months between the controls (C, n = 17) and resistance training (RT, n = 22) groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Baseline</th>
<th>6 Months</th>
<th>Change</th>
<th>P for Group × Time Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate oxidation (g d⁻¹)</td>
<td>C</td>
<td>473.1 ± 21.8</td>
<td>502.1 ± 25.3</td>
<td>28.9 ± 19.6</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>463.1 ± 14.1</td>
<td>488.9 ± 20.9</td>
<td>25.8 ± 17.3</td>
<td></td>
</tr>
<tr>
<td>Fat oxidation (g d⁻¹)</td>
<td>C</td>
<td>85.4 ± 9.0</td>
<td>74.4 ± 7.1</td>
<td>11.0 ± 8.5</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>91.9 ± 38.5</td>
<td>93.1 ± 8.2</td>
<td>1.2 ± 8.2</td>
<td></td>
</tr>
<tr>
<td>Protein oxidation (g d⁻¹)</td>
<td>C</td>
<td>66.1 ± 4.7</td>
<td>77.1 ± 6.5</td>
<td>11.0 ± 5.4</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>75.3 ± 5.1</td>
<td>77.3 ± 5.3</td>
<td>2.0 ± 6.1</td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SEM.  
* Group by time interaction from baseline to 6 months between the C and RT groups.
may be responsible for weight gain

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**FIGURE 2**—Relative change in respiratory quotient measured during assessment of resting (RMR–RQ) and sleeping metabolic rate (SMR–RQ). Values are means ± SE. *Significantly different within group, P < 0.05. #Significantly different between groups, P < 0.05.

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mass (25,34,40). Hill et al. (14) estimated that an “energy gap” of only 420 kJ may be responsible for weight gain in 90% of the population. Reduction or elimination of this energy gap could prevent or reduce body fat gain in the majority of Americans. In the current study, subjects in the RT group increased their 24-h EE by ~500 kJ, and although both groups gained a similar amount of body mass, fat mass increased in C but not in RT. These results suggest that a minimal RT program, such as the one performed in the current study, may increase 24-h EE sufficiently to prevent gains in body fat despite an increase in body mass resulting from increased FFM. It is also encouraging that the increase in 24-h EE, measured more than 72 h after the last RT session, suggests a chronic adaptation rather than an acute effect of RT. Because RT is routinely recommended by health organizations to be performed every other day, the fact that even a low-volume RT program can provide a sustained increase in energy expenditure may be important for weight management.

Despite the fact that the increase in 24-h EE in the RT group was double that of the increase in the C group, the lack of significance between groups may be attributable to the individual variable response to RT for both RT (range = −1547 to 3009 kJ d−1) and C (range = −1117 to 1356 kJ d−1) groups. These results may suggest that individuals respond differently to RT and that some individuals may require greater volumes of RT to increase energy expenditure. Further, studies evaluating these individual responses to RT are warranted. Another consideration for the lack of difference between groups may be due to the increased energy expenditure in the C group as a result of an increase in fat mass. Nevertheless, the fact that a minimal amount of RT can have a meaningful impact on energy expenditure, which translates to favorable improvements in body composition, supports recommendations by various health organizations to include RT as part of a healthy lifestyle. In addition, subjects gained weight despite a ~4000-kJ difference between reported energy intake (9538 kJ d−1) and measured energy expenditure (~13,330 kJ d−1). These results support previous research (23,26) that overweight subjects underreport their energy intake.

The minimal RT protocol described in this study may provide an attractive alternative to either aerobic exercise or multiple-set RT programs for weight management in busy young adults, owing to the minimal time commitment (11 min per session) and the fact that participants did not need to change clothes or shower. In fact, compared with the energy expenditure of the American College of Sports Medicine–recommended 30-min endurance exercise (~1500 kJ) (8), a session of RT is relatively low (~650 kJ) (30). However, the long-term adaptation to RT through increases in FFM and reductions in FM as seen in the current study provide an alternative approach to managing fat mass gain often seen in the college-aged population, a group at high risk for developing obesity.

The ~7% increase in RMR and SMR are in agreement with other studies using single (25,34) and multiple (3,6,16) sets. Further, increased energy expenditure as a result of RT observed in this study is at least partially a function of increased FFM, as indicated by the positive correlation for change in FFM and change in 24-h EE, RMR, and SMR. However, RMR and SMR both increased as a result of RT after adjustment for FFM, suggesting that other factors may also be contributing to the increase. Although not measured in this study, myofibrillar protein turnover (19) could increase both SMR and RMR and has been shown to account for as much as 20% of RMR (44). In addition, sympathetic nervous system activity may be related to changes in SMR and RMR. For example, low-volume RT has been shown to increase muscle sympathetic nerve activity (34) and to elevate rates of muscle protein synthesis and breakdown up to 48 h after exercise.

Twenty-four-hour fat oxidation (g d−1) increased slightly with RT (1.3%) and decreased in C (~12.9%); however, neither between- nor within-group differences were statistically significant. The lack of significant change may be due to the smaller number of subjects or to a need for a greater volume of exercise. In addition, changes in fat oxidation may be affected by the energy and macronutrient balance in the indirect calorimeter. Every attempt was made to keep subjects in energy balance by having subjects eat a standardized diet 3 d before the chamber stay and during the chamber stay. Both groups were underfed ~8% at baseline and at the end of study, although the macronutrient oxidation rates in the chamber for fat (26%), carbohydrate (~65%), and protein (~10%) were slightly different than standardized diet of 30% fat, 55% carbohydrates, and 15% protein. These differences are most likely due to the underfeeding. Nevertheless, because both groups were fed identical standardized diets before and during the chamber with no difference between groups, then the differences for energy expenditure and substrate oxidation between groups are most likely due to the intervention rather than composition of the diet. It is important to note, however, that the changes in both RMR–RQ and SMR–RQ (i.e., increased in C and decreased in RT) are consistent with the 24-h fat oxidation data. Increased fat oxidation with RT
may also be a result of increased sympathetic nervous system activity because plasma norepinephrine has been shown to increase after RT in men (34). The positive influence of even a small amount of RT on fat oxidation suggests an important role of RT on body mass management.

In conclusion, a minimal RT program, performed for 6 months, produced significant increases in the components of 24-h EE (RMR and SMR) and a favorable increase in 24-h EE. In addition, observed changes in both RMR–RQ and SMR–RQ suggested a potential for increased fat oxidation as a result of RT. Together, these findings suggest that a minimal RT program may provide a sufficient stimulus to impact energy balance and to prevent long-term weight or body fat gain in sedentary, overweight, young adults. Further, the minimal RT protocol described in this study may provide an attractive alternative to either aerobic exercise or multiple-set RT programs for weight management in busy young adults because of the minimal time commitment. Studies with larger samples of both men and women are needed to assess potential gender differences in the energy expenditure and substrate oxidation response to minimal RT and to elucidate the impact of such programs on substrate oxidation and total and free-living physical activity energy expenditure perhaps by using doubly labeled water.

REFERENCES

to a weight-loss dietary regimen and exercise programs in women. 


