

# Resistance and aerobic exercise have similar effects on 24-h nutrient oxidation

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## ABSTRACT

MELANSON, E. L., T. A. SHARP, H. M. SEAGLE, W. T. DONAHOO, G. K. GRUNWALD, J. C. PETERS, J. T. HAMILTON, and J. O. HILL. Resistance and aerobic exercise have similar effects on 24-h nutrient oxidation. *Med. Sci. Sports Exerc.*, Vol. 34, No. 11, pp. 1793–1800, 2002. **Background:** Whether resistance exercise is as effective as aerobic exercise for body-weight management is debated. **Purpose:** To compare 24-h energy expenditure (EE) and macronutrient oxidation elicited by comparable bouts of stationary cycling (BK) and weightlifting (WTS). **Methods:** 24-h EE and macronutrient oxidation were measured in 10 nonobese male subjects on three occasions using whole-room indirect calorimetry. BK and WTS days were compared with a nonexercise control day (Con). **Results:** During BK, subjects exercised for  $49 \pm 7$  min (mean  $\pm$  SEM) at 70% of  $\dot{V}O_{2\max}$  and expended  $546 \pm 16$  kcal. During WTS, subjects performed a 70-min circuit consisting of four sets of 10 different exercises at 70% of exercise-specific 1-repetition maximum and expended  $448 \pm 21$  kcal ( $P < 0.001$  vs BK). 24-h EE on BK and WTS days ( $2787 \pm 76$  kcal·d<sup>-1</sup>,  $2730 \pm 106$  kcal·d<sup>-1</sup>, respectively,  $P > 0.05$ ) was elevated compared with Con ( $2260 \pm 96$  kcal·d<sup>-1</sup>,  $P < 0.001$ ), but 24-h respiratory exchange ratio (RER) was not different. 24-h carbohydrate oxidation was significantly elevated on the exercise days (BK =  $370 \pm 18$  g·d<sup>-1</sup>, WTS =  $349 \pm 23$  g·d<sup>-1</sup>,  $P > 0.05$ ) compared with Con ( $249 \pm 29$  g·d<sup>-1</sup>,  $P = 0.04$ ). 24-h fat and protein oxidation were the same on BK, WTS, and Con days. EE and macronutrient oxidation in the periods after exercise also did not differ across conditions. **Conclusion:** In men, resistance exercise has a similar effect on 24-h EE and macronutrient oxidation as a comparable bout of aerobic exercise. Neither exercise produced an increase in 24-h fat oxidation above that observed on a nonexercise control day. **Key Words:** WHOLE-ROOM CALORIMETER, FAT OXIDATION, BODY-WEIGHT REGULATION

The effects of low- versus high-intensity exercise on postexercise energy expenditure (EE) and macronutrient oxidation have been an area of intense interest with regards to body-weight regulation. Using acute measurements of respiratory gas exchange, several studies reported that compared with low-intensity exercise, postexercise EE and fat oxidation are acutely increased by high-intensity exercise (1,9,22,24). However, most of these studies only measured EE and substrate oxidation for a few hours after exercise. Using whole-room indirect calorimetry, we recently reported that 24-h EE or macronutrient oxidation is not different on days when isocaloric bouts (400 kcal) of low- (40% of maximal aerobic capacity,  $\dot{V}O_{2\max}$ ) or high-intensity (70% of  $\dot{V}O_{2\max}$ ) exercises are performed (19), suggesting that the postexercise effects on EE and substrate metabolism are not affected by exercise intensity.

Although exercise intensity appears to have no effect on 24-h EE and substrate oxidation, it still remains to be dem-

onstrated whether the type of exercise could have an effect. Specifically, we were interested in comparing the effects of aerobic exercise and resistance exercise on postexercise and 24-h EE and substrate oxidation. Postexercise resting EE has been reported to remain elevated for several hours after resistance exercise (3,7,9,20,21). It has previously been reported that resting metabolic rate (RMR) is increased and respiratory exchange ratio (RER) is decreased on the day after a bout of resistance exercise in male (20) and female subjects (21), suggesting that resistance exercise may offer additional benefits with regards to body-weight control. Additionally, resistance exercise has been reported to result in a greater excess postexercise oxygen consumption (EPOC) compared with aerobic exercise (7). To our knowledge, however, no studies have directly compared the effects of aerobic and resistance exercises on metabolic responses over 24 h.

The primary aim of this investigation was to compare the effect of aerobic and resistance exercises on postexercise and 24-h EE and substrate oxidation to test the hypotheses that postexercise and 24-h EE and fat oxidation are greater on a day on which resistance exercise is performed. To achieve these aims, we measured 24-h EE and substrate oxidation during three stays in a whole-room calorimeter. During one day in the calorimeter, subjects expended 1670 kJ (400 kcal) during stationary cycling at workloads corresponding to 70% of their maximal aerobic capacity. On another day in the calorimeter, subjects performed a 60-min

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resistance-training circuit, which was estimated to produce a similar level of energy expenditure. These data were compared with a sedentary day on which no exercise was performed.

## METHODS

### Subjects

Ten nonobese, healthy adult male subjects (mean  $\pm$  SD, age =  $31 \pm 7$  yr; weight =  $75.1 \pm 7.1$  kg, % body fat =  $19.4 \pm 4.6\%$ ,  $\dot{V}O_{2\max} = 43.9 \pm 5.0$  mL $\cdot$ kg $^{-1}\cdot$ min $^{-1}$ ) participated in the study. Subjects were moderately active (3–5 h $\cdot$ wk $^{-1}$  of exercise) as determined from self-report. Smokers or individuals reporting a history of diabetes, cardiovascular disease, or metabolic disorders known to affect intermediary metabolism were excluded. A health history and physical examination was performed to confirm that there were no medical reasons for exclusion from the study. Subjects provided informed written consent. The study protocol was approved by the Colorado Multiple Institutional Review Board and the Scientific Advisory Board of the General Clinical Research Center (GCRC) at the University of Colorado Health Sciences Center.

### Preliminary Assessments

**Aerobic capacity.** Maximal aerobic capacity was determined from  $\dot{V}O_{2\max}$  measured by using standard indirect calorimetry (model 2900, SensorMedics Metabolic Cart, Yorba Linda, CA) during a graded exercise test using a stationary cycle ergometer. Subjects pedaled at a cadence of 70 RPM beginning at a workload of 50 W. The workload was increased by 25 W every minute until volitional exhaustion. Heart rate (monitored using a 12-lead electrocardiogram), blood pressure, and perceived exertion were measured every minute.  $\dot{V}O_{2\max}$  was determined from the average of the highest three measurements during the final stage of exercise. To be accepted as valid, the test was required to meet two of the following three criteria: 1) a respiratory quotient  $> 1.1$ , 2) heart rate within 10 beats $\cdot$ min $^{-1}$  of age predicted maximum, and 3) an increase in  $\dot{V}O_2$  in response to the final workload of  $< 2.0$  mL $\cdot$ kg $^{-1}\cdot$ min $^{-1}$ .

**Body composition.** Body composition was determined by hydrodensitometry, with residual volume measured simultaneously using the open-circuit nitrogen-dilution technique (10). Nitrogen was measured using a Med-Science 505-D Nitralizer (St. Louis, MO). Percent body fat was estimated from body density (average of 7–10 repeat measurements) using the revised equation of Brozek et al. (6).

**Resting metabolic rate.** RMR was measured by using indirect calorimetry (model 2900, SensorMedics Metabolic Cart). Measurements were made in the morning after a 12-h fast and 24-h abstention from exercise. After 30 min of rest, RMR was measured for 15–20 min using a ventilated canopy. Oxygen consumption and carbon dioxide production were used to calculate RMR according to the formula of Weir (29). Criteria for valid RMR was a minimum of 15 min

of steady state, determined as  $< 10\%$  fluctuation in oxygen consumption and  $< 5\%$  fluctuation in respiratory quotient.

### Experimental Protocol

Twenty-four-hour EE and substrate oxidation were measured on four occasions, using whole-room, indirect calorimetry. The first calorimeter day served as a baseline day, during which 24-h EE was measured without any exercise performed. This allowed us to produce a state of energy balance with greater precision during the experimental days. Subjects were then studied on three additional calorimeter days within a 4-wk period performed in random order: 1) a nonexercise control day (Con), 2) an aerobic-exercise day (BK), and 3) a resistance-exercise day (WTS). For 3 d before each calorimeter stay, subjects were provided a diet estimated to meet free-living energy requirements (RMR  $\times$  1.5–1.8, depending on self-reported physical activity level) and maintain weight stability. The composition of the diet was 30% of energy from fat, 15% of energy from protein, and 55% of energy from carbohydrate. Breakfast was consumed each day in the GCRC, with other food packaged and taken with the subject to be consumed off-site. No other food was permitted, and subjects were required to consume all food provided. Two optional food modules (200 kcal each, with the same macronutrient composition as the total diet) were provided that could be consumed in case subjects experienced hunger. All food was prepared in the GCRC metabolic kitchen at the University of Colorado Health Sciences Center. To confirm weight stability, a gowned body weight was measured daily, after subjects voided and before consumption of breakfast. Subjects were instructed to maintain their normal physical activity and exercise patterns but refrained from exercise on the day before each of the calorimeter stays.

**Calorimetry days.** Subjects entered the calorimeter at 0800 and exited at 0700 the following day. The data were extrapolated to 24-h values. During each stay in the calorimeter, subjects consumed a diet designed to achieve energy balance, as determined from the baseline day. The composition of the diet was 30% of energy fat, 15% of energy protein, and 55% of energy carbohydrate. The energy values of the diets on the exercise days were adjusted (+500 kcal) for the estimated increased EE due to the exercise bouts (400 kcal for exercise + 100 kcal for elevated postexercise EE). Across conditions, meals were provided at the same time of day. On the exercise days, exercise was performed at 1000. In an attempt to account for energy expended in activities of daily living, a standardized walking and stepping protocol was performed each day between 1420 and 1630. This protocol consisted of 10-min periods alternating between either walking or stepping at prescribed paces and sitting quietly. Subjects were free to move about the calorimeter during other times of the day, but primarily this time was spent in sedentary behavior (reading, writing, watching TV). Subjects were instructed to remain awake and not to nap or perform any exercise other than that

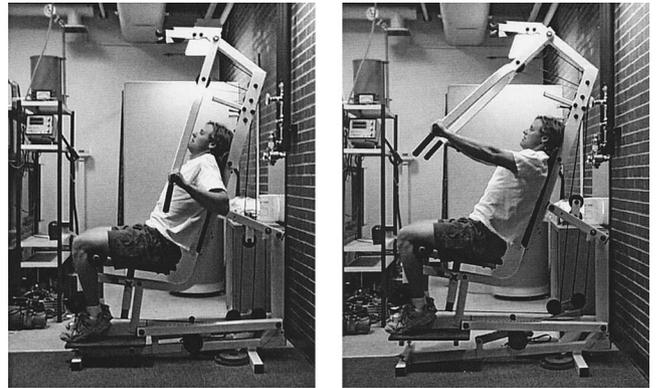
prescribed by the protocol. Subjects went to bed ( $\pm 30$  min) at the same time during each calorimeter stay.

During exercise in the calorimeter, the target energy expenditure was approximately 400 kcal (1670 kJ) above resting levels. All exercise sessions were supervised by a technician. During BK, subjects exercised at a workload corresponding to 70% of  $\dot{V}O_{2\max}$  on a stationary electronically braked bicycle ergometer (Pedal Mate, Warren E. Collins, Braintree, MA). Before the calorimeter stay, subjects performed a submaximal stationary cycling test at a workload corresponding to 70% of maximal aerobic capacity. The steady-state  $\dot{V}O_2$  observed at this workload was used to calculate the amount of time required to achieve a net energy expenditure of 400 kcal. While in the calorimeter, workloads were controlled via a work integrator external to the calorimeter.

Resistance exercises were performed using a Body Lift 1000 (Pacific Fitness Corporation, Cypress, CA) exercise machine (Fig. 1). Resistance is established by adjusting the length of a cantilevered arm, permitting the subject to lift a percentage of their body weight through the range of the exercise. The length of the lever arm is established based on the pivot position, established using a pin at 15 equally spaced hole positions. The resistance in each position is specific to each exercise and is proportional to the subject's body mass, e.g., at pin position 10, the resistance while performing biceps curl is equivalent to 55% of the subjects' body weight. A higher pin position produces a shorter lever arm and therefore a greater resistance. This was the most practical means of performing weight-lifting exercises in the whole-room calorimeter, as the Body Lift did not require "spotting" and could remain in the whole-room calorimeter throughout the 24-h stay without major intrusion on the subjects' "living space."

One-repetition maximum (1 RM) for each exercise was predetermined during a single session. For each exercise, subjects performed a warm-up set of 8–10 repetitions at a light resistance. The 1-RM test began at a resistance corresponding to approximately 60–70% of estimated 1 RM. After execution of one repetition with that weight, the resistance was increased by changing the pin position. After a period of rest ( $\sim 1$ – $2$  min), subjects performed a further single repetition trial with the new weight. This pattern continued until the subject was unable to complete a single repetition of the lift. The subject's 1 RM was considered to be the weight used on the last successful trial. On a separate day, subjects were familiarized with the circuit routine by performing a practice session identical to the routine prescribed for the calorimeter. During this session, final adjustments were made to the workloads. If subjects had difficulty achieving the prescribed number of lifts (10 per set on sets 1–3, at least 10 on set 4), the prescribed workload was decreased accordingly (i.e., position of the pin was decreased by one). However, if subjects executed more than 15 lifts on the fourth set, the pin position was increased by one.

During WTS, subjects performed a 60-min circuit consisting of four sets of 10 exercises at 70% of exercise-specific 1 RM. To determine the appropriate settings, the 1



**FIGURE 1**—Subject performing bench press on Body Lift 1000. Resistance is established by adjusting the length of a cantilevered arm, permitting the subject to lift a percentage of their body weight through the range of the exercise.

RM value was converted to weight (using a chart supplied by the manufacturer) and multiplied by 0.70. The pin position that best approximated this value was considered 70% of exercise specific 1 RM. Before the circuit, a 10-min warm-up set of eight repetitions of each exercise was performed at approximately 50% of the resistance used during the circuit. Thus, the length of entire resistance exercise session was 70 min. During sets 1–3, subjects performed 10 repetitions, but on the fourth set, subjects exercised to failure. Exercises were performed in pairs (bench press and standing mid-row; bilateral leg extension and unilateral leg curls; triceps extension and biceps curl; abdominal crunch and military press) and were repeated every 3 min. For example, during minutes 1–3, subjects performed 10 repetitions of bench-press and 10 repetitions of standing mid-rows. After completion of each exercise pair, subjects were permitted to rest until the next 3-min interval. Pilot testing suggested that this program would elicit a level of energy expenditure close to our target.

## Measurements

**24-h EE and substrate oxidation.** Total daily EE and substrate oxidation were determined from oxygen consumption and carbon dioxide production measured in a whole-room calorimeter. Gas concentrations were determined from the flow rate and the differences in  $CO_2$  and  $O_2$  concentrations between entering and exiting air using Hartman and Braun (Frankfurt, Germany) oxygen (Magnos 4 G) and carbon dioxide (Uras 3 G) analyzers. Values were corrected for temperature, barometric pressure, and humidity. Urine was collected for the duration of the calorimetry stay and analyzed for total nitrogen concentration, which was then used to determine 24-h protein oxidation (25). EE and substrate oxidation were calculated from oxygen consumption and the respiratory exchange ratio based on the equations of Jequier et al. (15). Values for all indices were averaged over 1-min intervals and recorded to a data file. The operation of the calorimeter was controlled and data collected minute-by-minute using a customized program operating on a personal computer. The accuracy and preci-

TABLE 1. Energy expenditure over 24 h and during different segments of the day; mean(SE).

	Con	BK	WTS
24 h (kcal)	2260 (96) <sup>a</sup>	2787 (77) <sup>b</sup>	2730 (105) <sup>b</sup>
Exercise (kcal · min <sup>-1</sup> )	1.68 (0.08) <sup>a</sup>	11.19 (0.41) <sup>c</sup>	6.05 (0.31) <sup>b</sup>
30 min postexercise (kcal · min <sup>-1</sup> )	1.59 (0.07) <sup>a</sup>	2.50 (0.20) <sup>b</sup>	2.63 (0.10) <sup>b</sup>
Lunch to bedtime (kcal · min <sup>-1</sup> )	1.85 (0.07) <sup>a</sup>	1.87 (0.06) <sup>a</sup>	1.94 (0.07) <sup>a</sup>
Standardized walk/step routine (kcal · min <sup>-1</sup> )	2.61 (0.09) <sup>a</sup>	2.56 (0.11) <sup>a</sup>	2.74 (0.17) <sup>a</sup>
Sleeping (kcal · min <sup>-1</sup> )	1.08 (0.06) <sup>a</sup>	1.06 (0.06) <sup>a</sup>	1.07 (0.07) <sup>a</sup>

Values with different superscripts are significantly different ( $P < 0.05$ ).

sion of the calorimeter is evaluated regularly by burning propane at a variable rate. Calibration tests consistently demonstrate a 97–98% recovery of the predicted values for oxygen consumption and carbon dioxide production. Further, quick response rates (in the order of 1–2 min) are observed, allowing for accurate determination of EE of short intervals (e.g.,  $\geq 30$  min).

EE and substrate oxidation were determined over 24 h and for the following segments of the 24-h period: 1) exercise, 2) immediately postexercise (30 min after completion of exercise), 3) the remainder of the day (from 1230 to bedtime), 4) during the standardized walking and stepping routine in the afternoon, and 5) during sleeping. On the control day, rates of energy expenditure to be compared with exercise periods were calculated between 1000 and 1130. EE and substrate oxidation during sleep were used as a surrogate for resting measurements to determine whether the acute exercise bouts exerted a prolonged effect on resting EE or substrate metabolism.

### Statistical Analysis

Statistical analyses were carried out using SAS (SAS/STAT User's Guide, Version 8, 2000, SAS Institute Inc, Cary, NC). Repeated-measures analysis of variance with within-subject factor condition (Con, BK, WTS) was carried out using linear mixed models and a random subject effect with SAS PROC MIXED. These methods provide valid handling of the occasional missing observations (28). Contrasts were used within these models to estimate overall condition effects. Statistical significance was set at  $P < 0.05$ . Results are presented as mean (SEM).

## RESULTS

During BK, subjects exercised for  $49 \pm 2$  min and expended  $546 \pm 16$  kcal. The net increase in EE during this period (EE during BK – EE during the same period on Con) was  $464 \pm 15$  kcal. During the 60-min weight-lifting circuit, subjects expended  $448 \pm 21$  kcal ( $P < 0.001$  vs BK), and the net increase in EE was  $322 \pm 19$  kcal. 24-h EE (Table 1) on BK and WTS days was not different ( $2787 \pm 77$  kcal·d<sup>-1</sup>,  $2730 \pm 105$  kcal·d<sup>-1</sup>, respectively), but on both exercise days was elevated compared with Con ( $2260 \pm 96$  kcal·d<sup>-1</sup>,  $P < 0.001$ ). Compared with the nonexercise Con day, the average increase in 24-h EE was  $528 \pm 42$  kcal·d<sup>-1</sup> on the BK day and  $470 \pm 66$  kcal·d<sup>-1</sup> on the WTS day ( $P > 0.05$ ).

During exercise, the rate of EE was greater during BK ( $11.19 \pm 0.41$  kcal·min<sup>-1</sup>) than during WTS ( $6.05 \pm 0.31$

kcal·min<sup>-1</sup>). Immediately postexercise (30 min after exercise), EE remained elevated after BK and WTS ( $2.50 \pm 0.20$ ,  $2.63 \pm 0.10$  kcal·min<sup>-1</sup>, respectively,  $P > 0.05$ ) above that observed during the same period on the nonexercise day ( $1.59 \pm 0.07$ ,  $P < 0.001$ ). EE during the remainder of the day (1230 to bedtime), during the standardized walk/step routine, and sleeping periods was unaffected by either BK or WTS.

Twenty-four-hour RER was not affected by type of exercise (Con =  $0.86 \pm 0.02$ , BK =  $0.89 \pm 0.01$ , WTS =  $0.88 \pm 0.01$ ,  $P > 0.05$ ). RER was higher during WTS ( $1.02 \pm 0.01$ ) compared with BK ( $0.96 \pm 0.01$ ,  $P < 0.01$ ) and Con ( $0.88 \pm 0.02$ ,  $P < 0.0001$ ). RER was higher during BK compared with the same period in the control condition ( $P < 0.001$ ). After exercise, there were no differences in RER. During the 30-min postexercise period, RER was not significantly different (Con =  $0.82 \pm 0.02$ , BK =  $0.86 \pm 0.04$ ; WTS =  $0.83 \pm 0.03$ ,  $P > 0.05$ ). Similarly, RER during the remainder of the day (Con =  $0.88 \pm 0.01$ , BK =  $0.89 \pm 0.01$ , WTS =  $0.86 \pm 0.01$ ,  $P > 0.05$ ), during the standardized walk/step routine (Con =  $0.87 \pm 0.02$ , BK =  $0.89 \pm 0.01$ , WTS =  $0.87 \pm 0.01$ ,  $P > 0.05$ ), and during sleep (Con =  $0.81 \pm 0.02$ , BK =  $0.83 \pm 0.01$ , WTS =  $0.84 \pm 0.01$ ,  $P > 0.05$ ) was unaffected by exercise.

Macronutrient oxidation and balance data are presented in Table 2. The main impact of both aerobic and resistance exercise was to increase 24-h carbohydrate oxidation. Twenty-four-hour carbohydrate oxidation was significantly elevated on the exercise days (BK =  $370 \pm 18$  g·d<sup>-1</sup>, WTS =  $349 \pm 23$  g·d<sup>-1</sup>,  $P > 0.05$ ) compared with Con ( $249 \pm$

TABLE 2. Macronutrient oxidation and balances; mean(SE).

	Con	BK	WTS
24-h macronutrient oxidation (g)			
Carbohydrate	249.3 (29.5) <sup>a</sup>	370.2 (17.9) <sup>b</sup>	349.4 (22.8) <sup>b</sup>
Fat	86.5 (16.7) <sup>a</sup>	87.0 (12.6) <sup>a</sup>	91.0 (10.4) <sup>a</sup>
Protein	85.1 (7.2) <sup>a</sup>	88.9 (7.5) <sup>a</sup>	86.6 (8.8) <sup>a</sup>
24-h macronutrient balances (g)			
Carbohydrate	61.7 (35.3) <sup>a</sup>	14.3 (37.0) <sup>a</sup>	45.4 (41.7) <sup>a</sup>
Fat	-5.6 (18.1) <sup>a</sup>	11.6 (13.5) <sup>a</sup>	8.8 (14.1) <sup>a</sup>
Protein	6.8 (9.5) <sup>a</sup>	23.8 (10.6) <sup>a</sup>	26.8 (12.8) <sup>a</sup>
Lunch-to-bedtime oxidation (mg · min <sup>-1</sup> )			
Carbohydrate	249.0 (26.2) <sup>a</sup>	246.0 (17.1) <sup>a</sup>	217.0 (17.7) <sup>a</sup>
Fat	60.0 (12.0) <sup>a</sup>	58.0 (9.8) <sup>a</sup>	79.0 (9.2) <sup>a</sup>
Sleeping oxidation (mg · min <sup>-1</sup> )			
Carbohydrate	62.0 (13.9) <sup>a</sup>	80.0 (9.5) <sup>a</sup>	82.0 (14.9) <sup>a</sup>
Fat	57.0 (10.1) <sup>a</sup>	46.0 (7.0) <sup>a</sup>	54.0 (6.0) <sup>a</sup>

Values with different superscripts are significantly different ( $P < 0.05$ ). 24-h macronutrient oxidation data calculated from energy expenditure and protein RQ value. Segment (lunch-to-bedtime, sleeping) macronutrient oxidation values calculated from energy expenditure and non-protein RQ.

29 g·d<sup>-1</sup>,  $P = 0.04$ ). Twenty-four-hour fat and protein oxidation were not different across conditions. Substrate oxidation was not different in the postexercise periods. Fat and carbohydrate oxidation during the period from lunch to bedtime and during sleep were unaffected by exercise condition. There were no significant differences in 24-h macronutrient balances between conditions.

## DISCUSSION

The main findings of this study are that in adult male subjects, resistance exercise has a similar effect on 24-h EE and macronutrient oxidation as a comparable bout of aerobic exercise. The increase in 24-h EE on the exercise days was primarily supported by an increase in the amount of carbohydrate oxidized. We observed no differences in 24-h fat oxidation across conditions. We therefore conclude that in men, resistance and aerobic exercise have similar effects on 24-h EE and fat oxidation. Our conclusions cannot be extended to women. Indeed, there is evidence that during exercise, women rely on more fat than men (13). In our previous study, female subjects sustained a slightly greater rate of fat oxidation during the postexercise period, and this gender difference appeared to be greater at the higher exercise intensity (19). Whether resistance exercise affects 24-h fat oxidation in female subjects remains to be addressed.

In contrast to our finding that postexercise energy expenditure did not differ between exercise conditions, it has been previously reported that EPOC is greater after heavy weight lifting than after aerobic exercise matched on duration and  $\dot{V}O_2$  response (7). However, the treadmill exercise in that study was performed at a much lower intensity (43.4% of  $\dot{V}O_{2max}$ ) than in the current study. Weight lifting performed at the same  $\dot{V}O_2$  as aerobic exercise probably represents a greater disturbance to homeostasis. Heart rate, ventilatory rate, blood lactate, and rating of perceived exertion are higher during the weight training exercise (7). The question addressed in the current study was whether there is a difference in 24-h EE if there is similar energy expenditure during weight lifting and aerobic exercise. It would be interesting to determine if EPOC differs between resistance and aerobic exercise of the same duration as time is often the limiting factor for those performing exercise.

Although RER tended to be lower after WTS ( $0.83 \pm 0.03$ ) compared with the same period on the nonexercise

control day ( $0.88 \pm 0.02$ ), we observed no significant difference between conditions in RER in the immediate postexercise period (30 min after the end of exercise). Previous studies have reported that RER is significantly decreased immediately after (3,20) or the day after (20,21) a bout of resistance exercise relative to a nonexercise control day. These data have been interpreted to suggest that fat oxidation is enhanced in the postexercise period as a result of resistance exercise. Although we only studied men, it is unlikely that this is a gender-related phenomenon, as a decline in RER after resistance exercise has been reported in both men (20) and women (9,21). A more likely explanation for these discordant results is the experimental conditions. In previous studies, subjects remained rested and fasted during the postexercise period. In the current investigation, postexercise measurements encompassed the lunch meal, and subjects were free to move about the calorimeter, although they participated in mainly sedentary activities during this time. It is possible, for example, that hormonal responses (e.g., elevated insulin levels) in the postprandial state attenuated fat oxidation by blunting lipolysis. Furthermore, the conclusion that fat oxidation is increased after resistance exercise has been based on the observation that RER tends to be lower compared with a nonexercise control period (3,20,21). However, carbon dioxide tends to be retained in the cells and body fluids after strenuous exercise in order to replenish bicarbonate pools (16). Thus, whether the fall in RER after weightlifting truly represents an increase in fat oxidation remains to be demonstrated.

We found that the type of exercise had no effect on EE over 24 h or during sleep. The effects of these acute bouts of exercise did not appear to last beyond a few hours. Our findings that sleeping metabolic rate were not elevated on the WTS compared with the CON day are similar to studies that demonstrated that after an acute bout of resistance exercise, metabolic rate returns to baseline within a couple of hours (3,26) but conflict with other studies reporting that RMR remains elevated 24–48 h after a moderate- to high-intensity acute bout of resistance exercise (20,21,23). Factors that may have contributed to these discrepant findings include 1) the use of a machine vs free weights; 2) training status of subjects; 3) volume or duration of exercise, as suggested by others (23); 4) intensity of effort (26); or 5) the work to rest ratio (11). Each of these factors is discussed below, and a comparison between studies that have exam-

TABLE 3. Comparison of studies that have examined acute effect of resistance training on metabolite.

	Subjects	Volume	Work:Rest	Intensity (% 1 RM)	Sets to Failure
Melby et al., (20)	$N = 7$ males; weight trained (3-4x-wk <sup>-1</sup> )	6 sets of 10 exercises (90 min)	3 min to complete paired set ( $\approx 1$ min rest)	70%	All
	$N = 6$ males; weight trained (3-4x-wk <sup>-1</sup> )	5 sets of 10 exercises (96 min)	4 min to complete paired set ( $\approx 1-2$ min rest)	70%	All
Osterberg and Melby (21)	$N = 7$ females; weight trained (3-4x-wk <sup>-1</sup> )	5 sets of 10 exercises (100 min)	4 min to complete paired set ( $\approx 1-2$ min rest)	70%	Last 2
Scheunke et al (23)	$N = 7$ males; weight trained (3-4x-wk <sup>-1</sup> )	4 sets of 3 exercises (duration not reported)	2 min between sets	70%–77%	All
Current study	$N = 10$ males; $N = 7$ weight trained (3-4x-wk <sup>-1</sup> )	4 sets of 10 exercises (60 min)	3 min to complete paired set ( $\approx 1$ min rest)	70%	Last

ined the acute effects of resistance exercise on metabolic rate at least 12 h after exercise is summarized in Table 3.

With regards to the use of a machine versus free weights, the observed level of EE during WTS in the current study compares favorably with previous investigations using adult male subjects where EE was measured during exercise. These studies have reported a range of EE during circuit-type resistance exercise training from 6.0 to 9.0 kcal·min<sup>-1</sup> (2,11,14,30). Moreover, in the current study, RER was greater than 1.0 during WTS, which is also consistent with previous investigations. These data suggest that the energy requirements of the Body Lift are similar to free weights.

In previous investigations, only weight-trained subjects were studied, i.e. self-reported participation in weight training 3–4 times per week (Table 3). In the current study, 7 of the 10 subjects studied reported similar levels of weight training. We do not believe this factor influenced our results, as exclusion of the three subjects whom did not report participation in weight training produced the same statistical outcomes. As demonstrated in Table 3, intensity and work to rest ratios were similar across studies, and the volume of exercise was either slightly higher (20,21) or much lower (23) than in the current study. That led us to consider other factors. After carefully reviewing these studies, we noticed that they did differ in the number of sets performed to failure. In the current study, only the last set was done to failure, as opposed to the last two in the study of Osterberg and Melby (21), and all sets in the studies of Melby et al. (20) and Schuenke et al. (23). Studies that have reported rapid return to baseline appear not to have exercised subjects to failure (3,26). Thus, the number of sets performed to failure, rather than volume or intensity, may be a more important factor in whether postexercise metabolic rate is elevated after exercise.

Differences in experimental design between the current and previous studies may also be a contributing factor. In the current study, subjects were confined to the calorimeter on the night after exercise. The advantage of whole-room calorimetry is that integrated responses can be measured over the course of 24 h and it enables measurement of responses that might not be detected in most study designs. We also employ stringent prestudy dietary controls for ensuring that subjects are in a similar state of energy balance and fuel repletion at the time of testing, as over- and under-feeding have profound effects on macronutrient oxidation (12). In all other studies, subjects were studied under free-living conditions; i.e., they left the laboratory and returned the next day for measurements. Schuenke et al. (23) suggested that the increased RMR measured in response to acute resistance exercise with all sets performed to failure would translate into a 404-kcal increase on the day after the exercise and 369 kcal 2 d after resistance exercise. Results of the current study, where subjects exercised to failure only on the last set, do not support this suggestion.

These results have some practical implications for using exercise for weight control. Lack of time is often listed as a limiting factor for participation in exercise (5). Thus, if the goal of exercise is weight maintenance or weight loss, more

total energy expenditure can be achieved in less time with aerobic compared with resistance exercise. Subjects expended  $11.19 \pm 0.41$  kcal·min<sup>-1</sup> during  $49 \pm 2$  min of cycling at 70%  $\dot{V}O_{2\max}$  and only  $6.05 \pm 0.31$  kcal·min<sup>-1</sup> during a 60-min resistance exercise circuit, therefore indicating that aerobic exercise such as that conducted in this study might be more time efficient for purposes of weight control. The difference in the rate of EE between modalities is largely due to the intermittent versus continuous nature of resistance compared with aerobic exercise. Although it is tempting to suggest that a greater EE can be achieved during resistance exercise with less rest between sets, this does not reflect the manner in which most individuals perform resistance exercise.

This study sought to determine whether resistance exercise acutely enhances EE, thereby providing an additional benefit to aerobic exercise with regard to weight control. Whether regular participation in resistance-exercise training promotes increases in EE was not addressed. Fitness practitioners often advocate resistance training as a means of promoting weight loss based on the assumption that the training will lead to increases in RMR mediated by increases in fat free mass (FFM), the major determinant of RMR. Supervised resistance training programs of 8- to 12-wk duration typically produce increases in FFM of 1–2 kg (17,18,27), although larger increases (3.0 kg) have been reported with more intense training in young adult male subjects (for example, see Brown et al. (4)). However, we contend that most healthy adults will not achieve substantial increases in FFM as a result of unsupervised resistance training. In support of this contention, Mazetti et al. (18) reported greater increases in FFM in young adult male subjects ( $24.6 \pm 1.0$  yr) participating in a 12-wk supervised training program ( $1.4 \pm 0.5$  kg) compared with those that were unsupervised ( $0.3 \pm 0.4$  kg).

Unfortunately, the effects of increases in FFM on RMR are not well understood. In a review of studies that examined the relationship between body composition determined from the two-compartment model and RMR, Cunningham (8) concluded that for each kg increase in FFM, RMR increases by approximately 22 kcal·d<sup>-1</sup> (8). Recent longitudinal data presented by Lemmer et al. (17) suggest that this value may be greater and, moreover, that the relationship may be gender dependent. In this study, older and younger men and women participated in a 24-wk resistance-training program. Examination of the data presented in Table 3 (17) suggests that compared with pretraining levels, RMR measured 24–48 h after the last strength training session (mean 35 h) was increased approximately 17 kcal·kg FFM<sup>-1</sup>·d<sup>-1</sup> in young women, 63 kcal·kg FFM<sup>-1</sup>·d<sup>-1</sup> in older women, 101 kcal·kg FFM<sup>-1</sup>·d<sup>-1</sup> in young men, and 131 kcal·kg FFM<sup>-1</sup>·d<sup>-1</sup> in older men. FFM significantly increased in all four groups [young men = 1.5 kg (2.3%); young women = 1.9 kg (4.4%); older men = 1.0 kg (1.8%); older women = 0.9 kg (2.1%)]. However, RMR (absolute and relative to FFM) was significantly increased in men but not women. These results were not affected by age; young

(20–30 yr) and older (65–75 yr) men increased absolute and relative RMR, whereas young and older women did not.

Thus, the available data suggest that increases in RMR will not occur without substantial gains in FFM. As weight gain likely occurs due to small degrees of positive energy balance over time, any increase in RMR would be meaningful in the long run. However, our concern is that the benefits of resistance training on RMR and body-weight control are being greatly overstated to the general public. We do not discount the many positive benefits from participation in resistance training (e.g., improved functionality, bone health, and joint integrity) but believe we should be more responsible in educating the exercising public and practitioners with regard to realistic expectations of the role of resistance training on body-weight regulation.

**Strengths and limitations.** A strength of this study was that subjects were maintained within a tight range of energy and macronutrient balance in the calorimeter (Table 2). Mean energy balance across conditions was  $-30 \pm 41$  kcal·d<sup>-1</sup> for Con,  $-87 \pm 27$  kcal·d<sup>-1</sup> for BK, and  $-23 \pm 52$  kcal·d<sup>-1</sup> for WTS ( $P > 0.05$ ). Thus, the impact of energy imbalance on substrate oxidation was minimal. A limitation of the current study was that the energy expended during exercise was not precisely matched for each exercise condition. Estimated EE was slightly higher than the targeted level (400 kcal above resting levels) during biking ( $464 \pm 15$  kcal) but lower than expected during WTS ( $322 \pm 19$  kcal). However, it is unlikely that a more precise matching of energy expenditure would have produced different results. Twenty-four-hour EE was  $57 \pm 51$  kcal·d<sup>-1</sup> higher on BK compared to WTS (NS). EE during the postexercise period and during sleep was not different between BK, WTS, and Con (Table 1). Therefore, any increases in 24-h

EE compared with the Con day are directly due to the increase in EE during exercise. Thus, we feel confident that interpretation would be the same if we had achieved our targeted level of energy expenditure during the resistance exercise circuit.

## CONCLUSION

We have found that in adult male subjects, similar increases in 24-h EE are achieved with aerobic and resistance exercise, with the increases occurring during the exercise and immediate postexercise periods. During the extended period after exercise (remainder of the day and into the sleeping period), neither exercise produced an increase in EE during above that observed on a nonexercise control day. Furthermore, the two types of exercise have similar effects on 24-h macronutrient oxidation, with the increased demand of exercise being primarily supported by increased carbohydrate oxidation. Neither exercise produced an increase in fat oxidation above that observed on a nonexercise control day. Our conclusions do not extend to resistance training programs geared toward power-lifting or body-building, where levels of energy expenditure may be greater than what we observed during circuit training, although to our knowledge, these comparisons have not been performed.

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