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Resistance training increases total energy expenditure and free-living physical activity in older adults

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Hunter, Gary R., Carla J. Wetzstein, David A. Fields, Amanda Brown, and Marcas M. Bamman. Resistance training increases total energy expenditure and free-living physical activity in older adults. *J Appl Physiol* 89: 977–984, 2000.—The purpose of this study was to determine what effects 26 wk of resistance training have on resting energy expenditure (REE), total free-living energy expenditure (TEE), activity-related energy expenditure (AEE), engagement in free-living physical activity as measured by the activity-related time equivalent (ARTE) index, and respiratory exchange ratio (RER) in 61- to 77-yr-old men ($n = 8$) and women ($n = 7$). Before and after training, body composition (four-compartment model), strength, REE, TEE (doubly labeled water), AEE (TEE − REE + thermic response to meals), and ARTE (AEE adjusted for energy cost of standard activities) were evaluated. Strength (36%) and fat-free mass (2 kg) significantly increased, but body weight did not change. REE increased 6.8%, whereas resting RER decreased from 0.86 to 0.83. TEE (12%) and ARTE (38%) increased significantly, and AEE (30%) approached significance ($P = 0.06$). The TEE increase remained significant even after adjustment for the energy expenditure of the resistance training. In response to resistance training, TEE increased and RER decreased. The increase in TEE occurred as a result of increases in both REE and physical activity. These results suggest that resistance training may have value in increasing energy expenditure and lipid oxidation rates in older adults, thereby improving their metabolic profiles.

RESTING ENERGY EXPENDITURE (REE) has been shown to be reduced in older adults, at least in part as a result of age-related reductions in fat-free mass (FFM) (12, 13, 24, 25, 29, 38, 44). Resistance training has previously been shown to increase both FFM and REE in older adults (5, 32, 42). Additionally, fat oxidation rates may be increased after resistance training. Respiratory exchange ratio (RER) has been found to be reduced in young men 15 h after a resistance training bout, suggesting an increase in lipid oxidation (14, 28). Furthermore, we have previously observed, in a group of older women (60–77 yr), an almost twofold increase in lipid oxidation after a 16-wk resistance training program (42). Posttraining metabolic measures were evaluated from 22 to 44 h (measured in a room calorimeter) after the last exercise bout. Therefore, it is likely that the lowered RER is not due to the acute effects of the last exercise session. Because both energy and macronutrient balance are important factors for body weight and body composition control, further study of the effects resistance training has on metabolism in older adults is warranted.

Controversy exists concerning the effects that training has on total energy expenditure (TEE) of older adults. Withers et al. (47) recently compared REE, TEE, and activity-related energy expenditure (AEE) of chronically active and chronically inactive women, 49–70 yr old. They reported that the chronically active older women had increased REE, TEE, and AEE. Furthermore, they found an almost identical AEE adjusted for the estimated energy expenditure of the planned training sessions. However, Goran and Poehlman (17) have previously reported increased REE, but not increased TEE, after an 8-wk high-intensity aerobic training program in 58- to 78-yr-old men and women. This suggests that a compensatory decrease in AEE may exist consequent to high-intensity aerobic training in older adults. To our knowledge, no one has examined the effects that resistance training has on TEE and AEE in older adults. Therefore, the purpose of this study was to examine the effects of 26 wk of resistance training on REE, TEE, AEE, and RER in a group of older adults.

METHODS

Subjects

Eight women and seven men, 61–77 yr old, participated in a 26-wk resistance training program. All subjects were healthy, Caucasian, and of normal body weight (mean body mass index of 24.8 ± 3.9 kg/m^2) and were free of any metabolic disorders or medications that might affect energy expenditure. All subjects were nonsmokers and were weight stable (defined as within 1% body weight during the previous 4 wk). None of the subjects had ever participated in resistance training before, and all subjects except one were sedentary (defined as exercising less than once per week for the past year). One male subject was a runner and ran between

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6 and 7 miles per week in 3–4 exercise sessions. He continued running at the same level throughout the course of the study. All the women were postmenopausal. Institutional review board-approved informed consent was obtained before participation in the study, in compliance with the Department of Health and Human Services regulations for the protection of human research subjects. Subjects were evaluated before and after 26 wk of resistance training.

Strength Testing

One-repetition maximum. For the first three exercise sessions, the subjects trained with a resistance that allowed them to become familiar with both the equipment and the exercises. In the third session, the subjects performed a one-repetition maximum (1 RM) test on the leg press, leg extension, leg curl, chest press, elbow flexion, and seated press using methods previously described (19, 22, 41). 1-RM testing was repeated during the last scheduled exercise session. The 1-RM results of the three upper- and three lower-body exercises were summed. Depending on the type of 1-RM test, the test-retest reliability in our laboratory for 1-RM testing varies from 0.95 to 0.99 for intraclass correlation coefficients with standard error of measurements varying from 1.5 to 4.0 kg for samples that have standard deviations that vary from 9 to 22 kg (19, 22, 41).

Isometric strength tests. Measurement of maximal elbow flexion strength, using methods previously described, was used to determine how much weight each subject would carry during the weight-loaded walking test (20). Briefly, the subject stood with arms fixed to the side wearing a harness designed to limit shoulder movement during the task. Force was measured on the right forearm at the level of the styloid process. Subjects were asked to attempt to flex the elbow as hard as possible with the elbow fixed at a position of 110° elbow flexion. Isometric knee extension strength was obtained at 110° extension while subjects were seated, and the legs and upper torso were strapped to the chair to prevent hip movement. Subjects were instructed to attempt to straighten the leg as hard as possible. Force was measured with a universal shear beam load cell (LCC 500, Omega Engineering, Stamford, CT). A digital transducer (DP2000, Omega Engineering) gave instantaneous force measurement feedback to the subjects. After three practice trials, three maximal isometric contractions were recorded. Sixty seconds rest was allowed between trials. The average of the two highest maximal forces generated was used for statistical purposes. The test-retest reliability in our laboratory for isometric tests is 0.95–0.96 for intraclass correlation coefficients with a standard error of measurement of 10.4–32.9 N for samples with standard deviations of 33 and 118 N (41).

Resistance training. Resistance training took place at a local fitness center, where the subjects exercised for 26 wk, 3 times per week for ~45 min per session. Each session was supervised by exercise physiologists, and average adherence rate of the subjects was >90%. Each exercise session began with a 5-min warm-up on either a bicycle ergometer or a treadmill at a low intensity followed by 10 static stretches. The resistance exercises were elbow flexion, elbow extension, lateral pulldown, seated row, chest press, leg extension, leg curl, seated press, back extensions, and bent-leg sit-ups (15–25 repetitions). In addition, four of the women and four of the men performed squats, and four of the women and three of the men performed leg presses. Subjects were instructed to complete two sets of 10 repetitions in all exercises with a 2-min rest between each set. The three initial training sessions were to allow subjects to become familiar with the equipment and exercises; afterward subjects trained at an intensity within 65–80% of 1 RM. Progression was incorporated into the program with daily training log evaluations and 1-RM testing every 3 wk.

Estimated energy cost of resistance training. We did not measure the energy cost of the resistance training with this group of subjects. However, we have previously measured energy expenditure for resistance training for a number of different exercises, exercise intensities, and age groups (19, 22, 41). These include unpublished measurements of energy expenditure of three older adults after a resistance exercise program identical to the one used in this study. On the basis of these measurements, the relative intensities used, and the amount of work completed, estimates of energy expended and work performed during training were made for each subject. Briefly, the methods for determining the energy cost in these studies were as follows: O_2 uptake ($\dot{V}O_2$) was determined continuously during the resistance-training session and during recovery until the 1-min value for $\dot{V}O_2$ returned to resting $\dot{V}O_2$. Expired O_2 and CO_2 percentages were determined by use of Vista/Turbofit (Vacumetrics, Ventura, CA) medical gas analyzers, and volume was determined on a Vista/Turbofit turbine. The analyzers were calibrated before and after each measurement with Micro-Scholander analyzed gases, and the Vista/Turbofit turbine was calibrated with a 3-liter calibration syringe. Net $\dot{V}O_2$ was determined by subtracting resting $\dot{V}O_2$ from the total $\dot{V}O_2$ consumed during work and recovery. The energy equivalent of 1 liter of O_2 was assumed to be 20.9 kJ, so net kilojoules expended was calculated by multiplying 20.9 times net $\dot{V}O_2$ (19). Total work completed was calculated using previously described procedures (19). The model included a summation of the product of vertical distance moved times the mass of each component moved in an exercise (i.e., weight stack, upper arm, lower arm, trunk, upper leg, or lower leg). Resistance-training energy cost-to-work ratio was calculated by dividing net kilojoules expended by total joules vertical work completed (19). The intraclass correlation was >0.998, and standard error of measurement for estimating energy expended on the basis of vertical work and exercise intensity average was <3 kJ/min (14%) for sample standard deviations averaging 21 kJ. These estimates were used to adjust posttraining energy expenditure and physical activity index measures for the energy expenditure of the resistance training sessions.

Body Composition Measures

Four-compartment model. Body composition was evaluated by use of the four-compartment model, as described by Baumgartner et al. (2). This model assumes densities of 0.9 g/ml for fat, 0.99 g/ml for water, 3.042 g/ml for bone mineral, and 1.34 g/ml for the unmeasured fraction of the body composed of protein and glycogen. The model calculates percent body fat from the independent measures of total body density (by BOD POD, as described below), the fraction of body weight that is water (by isotope dilution, as described below), and the fraction of body weight that is bone mineral [by dual-energy X-ray absorptiometry (DXA), as described below]. Although it is acknowledged that there is a potential for the propagation of measurement error when using the four-compartment model, we feel that this potential error is more than compensated for, because the assumption that bone mineral content and total body water are similar in all older adults and the same as that in younger adults does not have to be made. On the basis of standard error of prediction for measurement of body density, total body water, and bone density in our laboratory (reported at the end of respective methods sections), potential propagation error would be 2.3% fat. This assumes that each component (body density, total body water, and bone mineral content) is measured with an error equal to one standard error of measurement and in the direction favoring maximum error.

Body density. Body density was evaluated with the BOD POD version 1.69 (Body Composition System; Life Measurement Instruments, Concord, CA), as we have previously described (10). Calibration of chamber pressure amplitudes occurred before all tests with use of a 50-liter calibration cylinder. While the subject wore a tight-fitting swimsuit, raw body volume was determined in the chamber. Thoracic gas volume was measured in a separate step. Thoracic gas volume measurement required the subject to sit quietly in the BOD POD and breathe through a disposable tube and filter connected to the reference chamber in the rear of the BOD POD. After four or five normal breaths, the airway was occluded during midexhalation, and the subject was instructed to make two quick light pants. Body density (Db) from the BOD POD was calculated as follows

$$\mathrm{Db} = \mathrm{M}/(\text{raw body volume} + 0.40\ \mathrm{Vtg} - \mathrm{SAA})$$

where SAA (surface area artifact) and 0.40 Vtg (thoracic gas volume) are used to correct for the isothermic conditions within the chamber and M is the mass of the subject.

The repeat measures between consecutive days for body density derived from the BOD POD in eight healthy women has an intraclass correlation of $r = 0.98$ and a standard error of measurement 0.0036 g/cm^3 in our laboratory. In addition, we have previously demonstrated good agreement between BOD POD and hydrostatic weight-determined density ($r = 0.97$ and standard error of measurement = 0.005 g/cm^3) (10).

Total body water. Total body water was determined by isotope dilution techniques using both deuterium- and oxygen-18-labeled water, as previously described (15). Briefly, a mixed dose of doubly labeled water was administered orally after collection of a baseline urine sample (10 ml). The isotope loading dose was ~0.1 and 0.08 g of oxygen-18 and deuterium, respectively, per kg body mass. Two samples were collected the morning after dosing, and an additional two samples were collected in the morning 14 days later. All samples were analyzed in triplicate for deuterium and oxygen-18 using the off-line zinc reduction method (23) and equilibration technique (7), respectively, as previously described (18). Zero-time enrichments of deuterium and oxygen-18 were calculated from the intercepts of the semilogarithmic plot of isotope enrichment in urine vs. time after dosing. Isotope dilution spaces were calculated using the equation of Coward et al. (8). Total body water was taken as the average of the oxygen-18 dilution space divided by 1.01 and the deuterium dilution space divided by 1.04. Test-retest analysis of samples from eight older adults has an intraclass correlation of 0.97 and a standard error of prediction of 1.38 liters.

DXA. Bone mineral content was determined by DXA (DPX-L, Lunar Radiation, Madison, WI). The scans were analyzed using the Adult Software (Version 1.33). The bone mineral content was used in the calculation of percent body fat using the four-compartment model (2).

TEE. TEE was measured before and during the last 2 wk of resistance training by use of the doubly labeled water technique as previously described (15). Four timed urine samples were collected after oral dosing of the doubly labeled water: two urine samples were taken in the morning after dosing and two more urine samples were taken 14 days later with a loading dose of 1 g of premixture (10% $H_2{}^{18}O$ and 8% ^2H_2O) per kilogram of body weight. The isotopic dilution spaces (in liters) were calculated from the $H_2{}^{18}O$ and ^2H_2O enrichments in the body by the extrapolation of the log enrichments back to zero time (8) by use of the following equation (36)

$$\text{Dilution space} = \mathrm{d}/20.02 \cdot 18.02 \cdot 1/\mathrm{R} \cdot \mathrm{E}$$

where d is grams of $H_2{}^{18}O$ and ^2H_2O given, R is the standard ratio for ^{18}O to ^{16}O (0.002005) and ^2H to ^1H (0.00015576), and E is the enrichment of the $H_2{}^{18}O$ and ^2H_2O at the extrapolated zero time (the % above background). The rate of carbon dioxide production ($r\mathrm{CO}_2$) was calculated from the equation by Schoeller et al. (35)

$$r\mathrm{CO}_2 = 0.4554 \cdot \mathrm{N}(1.01k_0 - 1.04k_\mathrm{h})$$

where $r\mathrm{CO}_2$ is the amount of CO_2 produced (mol/day) corrected for fractionation, N is total body water (mol), and k_0 and k_h are the turnover rates of $H_2{}^{18}O$ and ^2H_2O (days $^{-1}$), respectively. TEE was then calculated from CO_2 production using the equation from de Weir (9)

$$\mathrm{TEE} = 3.9(r\mathrm{CO}_2/\mathrm{FQ}) + 1.1r\mathrm{CO}_2$$

where TEE is total energy expenditure (kcal/day), $r\mathrm{CO}_2$ is the rate of carbon dioxide production (l/day where 1 mol of CO_2 is equivalent to 22.4 liters), and FQ is the food quotient. Samples were analyzed in triplicate for $H_2{}^{18}O$ and ^2H_2O by isotope ratio mass spectrometry at the University of Alabama at Birmingham as previously described (16). When samples for $H_2{}^{18}O$ and ^2H_2O were reanalyzed in seven subjects, the values of TEE between days were in close agreement (coefficient of variation = 4.3%), thus demonstrating a high level of reproducibility.

REE. REE was measured between 5:00 and 8:00 AM after a 12-h fast. Subjects were not allowed to sleep, and measurements were made in a quiet, softly lit, well-ventilated room. Temperature was maintained between 22 and 24°C. Measurements were made with the subject supine on a comfortable bed, head enclosed in a Plexiglas canopy. Posttraining REE was measured an average of 96 h after the last resistance exercise session. After 15 min of rest, REE was measured for 30 min with a computerized, open-circuit, indirect calorimetry system with a ventilated canopy (Delta Trac II, Sensor Medics, Yorba Linda, CA). The last 20 min of measurement were used for analysis. $\dot{V}\mathrm{O}_2$ and CO_2 production ($\dot{V}\mathrm{CO}_2$) were measured continuously, and values were averaged at 1-min intervals. Energy expenditure and RER were calculated from the $\dot{V}\mathrm{O}_2$ and $\dot{V}\mathrm{CO}_2$ data.

Measurement of submaximal $\dot{V}\mathrm{O}_2$ during three standardized tasks. Submaximal $\dot{V}\mathrm{O}_2$ was obtained in the steady state, during the third and fourth minutes of three standardized exercise tasks (variation between the third and fourth minutes was no greater than 0.4 ml $O_2 \cdot \mathrm{kg}^{-1} \cdot \mathrm{min}^{-1}$ for any subject, and the mean $\dot{V}\mathrm{O}_2$ between the third and fourth minutes varied less than 1%). $\dot{V}\mathrm{O}_2$ and $\dot{V}\mathrm{CO}_2$ were measured continuously via open-circuit spirometry and were analyzed with the use of a metabolic cart (Model 2900, Sensormedics, Yorba Linda, CA). Before each test, the gas analyzers were calibrated with certified gases of known standard concentrations. The three tasks selected to reflect typical activities of older adults in free-living conditions were level walking (0% grade, 3 mph, 4 min), stair climbing (7-in. step, 60 steps/min, 4 min), and level walking carrying a loaded box (0% grade, 2 mph, 4 min). The weight of the box was equivalent to 30% of the subjects' pretraining maximal isometric elbow flexion strength and was intended to simulate carrying a small load. A shoulder harness was worn to standardize shoulder position, and the elbow was maintained at 110° flexion throughout the test. Average energy cost (AEC) of the three tasks was determined by converting $\dot{V}O_2$ for the tasks to kilojoules per minute by assuming 20.9 kJ/l of O_2 consumed per minute, as previously described (19). Average $\dot{V}O_2$ for the three tasks adjusted for body mass was considered exercise economy. We have previously reported a standard deviation of 0.05 liters for differences between repeat measurements of submaximal exercise $\dot{V}O_2$ measured ~4 days apart (11).

AEE and free-living physical activity. AEE was estimated by subtracting REE from TEE after reducing TEE by 10% to account for the thermic response to meals.

Free-living physical activity (min/day) was derived from AEE (kJ/day) by using the activity-related time equivalent (ARTE) index (45). The index is determined by dividing AEE by the subject's AEC. For this study, the AEE was adjusted for the AEC of performing three standardized tasks: stair climbing, walking while carrying a small load, and walking without a grade. Therefore, ARTE index (min/day) = [AEE (kJ/day)/AEC (kJ/min)], where AEC is the AEC of three exercise tasks above REE. The ARTE index reflects the amount of time the subject spent in free-living physical activities similar to the tasks performed in the laboratory.

Statistics

The purpose of this investigation was to evaluate the effects of resistance training on energy metabolism in older adults. Two-way repeated measures ANOVA (training × gender), with repeated measures for the training factor, showed no significant interaction for any of the body composition (P range = 0.20–0.77) or energy expenditure (P range = 0.43–0.60) variables. Therefore, we report paired t-test analyses on only the training factor in this paper. Paired t-tests were used to evaluate pre- to posttraining differences with α set at 0.05.

RESULTS

Subjects did not significantly change body weight during the 26 wk of training. However, percent body fat significantly decreased 3.4%, fat mass significantly decreased 3.1 kg, and FFM significantly increased 2 kg. Strength also significantly increased an average of 14.9 kg in three upper-body exercises and 49.0 kg in three lower-body exercises. (See Table 1.) Individual data for doubly labeled water data and the components of energy expenditure are provided in Table 2.

Energy expenditure results are presented in Table 3. REE and TEE significantly increased after 26 wk of resistance training. Furthermore, resting RER significantly decreased (Table 3). The ratio of REE to FFM also was significantly increased after training (Table 3), indicating that REE increased relatively more than FFM.

Table 1. *Body composition and strength changes in 15 older adults after 26 wk of resistance training*

Variable	Pretraining	Posttraining	P
Age, yr	66.8 ± 3.7		
Body weight, kg	70.4 ± 8.7	69.8 ± 8.3	0.12
Percent fat	28.8 ± 12.1	25.4 ± 12.1	<0.01
Fat free mass, kg	50.0 ± 10.1	52.0 ± 10.7	<0.01
Fat mass, kg	20.4 ± 9.8	17.7 ± 9.3	<0.01
Upper-body strength, kg	59.0 ± 20.3	73.9 ± 24.2	<0.01
Lower-body strength, kg	117.6 ± 36.5	166.6 ± 47.5	<0.01

Values are means ± SD.

Although the mean difference in AEE was >500 kJ, the change only approached significance ($P = 0.06$). No significant differences in either average body weight, adjusted $\dot{V}O_2$, or AEC were found. However, ARTE was significantly increased by 37 min/day after the 26 wk of resistance training. Estimated energy expenditure for resistance training averaged 615 ± 157 kJ/exercise session during the last 2 wk of training. Because the subjects trained five times during the 14 days that TEE was evaluated at the end of the training program (one training day was omitted during the final 2 wk to allow 96 h of washout for any acute residual effects on metabolic factors), average daily energy expenditure for the resistance training was 215 ± 55 kJ/day. TEE, with the average daily energy cost of the resistance training subtracted, remained significantly increased after training (+747 kJ/day). Although not significantly different from the pretraining values, posttraining adjusted AEE (+503 kJ/day) and ARTE (+23 min/day) tended to be higher than the pretraining values.

DISCUSSION

To our knowledge, this is the first study to show that resistance training in older adults is associated with increased TEE. This increase was large (963 kJ/day) and still remained after TEE was adjusted for the estimated energy cost of the resistance training. The TEE increase was associated with increases in both REE and physical activity (Fig. 1). This TEE increase is potentially relevant for addressing the problem of reduced energy expenditure in older adults.

A number of studies have reported increases in TEE in younger adults after aerobic training (3, 26, 43, 46). However, Goran and Poehlman (17) have previously reported no significant increase in TEE in older adults after an 8-wk high-intensity aerobic training program, despite increases in REE and planned exercise energy expenditure. They observed a compensatory decrease of >544 kJ/day in free-living physical activity. The aerobic training intensity of 85% of maximal $\dot{V}O_2$ was very high during the period of time in which the posttraining TEE was measured in the Goran and Poehlman study (17). This intensity may have been too vigorous for this group of individuals, thereby fatiguing the subjects during the remainder of the day. It is impossible to determine whether a less intense aerobic training protocol or one that would allow a longer adaptation period may have been associated with increased TEE. The resistance training program in the present study was also of high intensity (65–80% of 1 RM). Meijer et al. (27) have recently reported that a moderate-intensity combined resistance and aerobic program in older adults did not influence free-living physical activity as measured by an accelerometer. The intensity of training in the Meijer et al. study (27) was described as moderate, although the intensity of neither the aerobic nor the resistance training was reported. The duration of this study was only 12 wk, and

Table 2. *Individual data for doubly labeled water variables and energy expenditure*

Subject	Turnover Rate, $days^{-1}$		Dilution Space, mol		Dilution Space Ratio	rH_2O, l/day	rCO_2, l/day	Total Energy Expenditure, kcal/day	Total Body Water, g
	^2H_2O	$H_2{}^{18}O$	D_H	D_O					
001									
Pre	−0.0739	−0.1008	1413.64	1388.02	1.0185	105.73	14.842	1839	24,715
Post	−0.0684	−0.0944	1528.42	1464.62	1.0436	104.48	15.411	1910	26,397
002									
Pre	−0.1003	−0.1184	2259.95	2046.64	1.1042	220.32	13.233	1640	37,959
Post	−0.0842	−0.1025	2210.01	2081.21	1.0619	184.40	14.099	1747	37,839
003									
Pre	−0.0808	−0.1056	2242.88	2133.56	1.0512	180.41	20.852	2584	38,594
Post	−0.0799	−0.1041	2382.94	2148.69	1.1090	184.73	20.970	2598	39,940
005									
Pre	−0.1187	−0.1384	1575.16	1543.89	1.0203	189.08	10.180	1261	27,514
Post	−0.1200	−0.1407	1628.85	1622.02	1.0042	199.21	11.302	1401	28,682
006									
Pre	−0.0784	−0.1067	1775.48	1738.66	1.0212	140.61	19.542	2422	30,999
Post	−0.0936	−0.1206	1967.35	1919.12	1.0251	185.72	19.913	2467	34,282
007									
Pre	−0.0867	−0.1087	1600.42	1602.27	0.9988	141.73	13.076	1620	28,258
Post	−0.0868	−0.1101	1786.43	1756.03	1.0173	156.92	15.485	1919	31,250
008									
Pre	−0.0696	−0.0949	1604.14	1569.53	1.0220	112.76	15.805	1958	27,996
Post	−0.0660	−0.0894	1745.82	1694.27	1.0304	115.82	15.823	1961	30,343
009									
Pre	−0.0978	−0.1113	1845.11	1725.10	1.0696	178.19	7.420	919	31,479
Post	−0.0673	−0.0875	1968.26	1892.84	1.0398	132.69	14.912	1848	34,053
011									
Pre	−0.1402	−0.1671	1541.37	1474.09	1.0456	215.74	14.092	1746	26,594
Post	−0.1223	−0.1539	1557.31	1549.30	1.0052	194.06	18.256	2262	27,409
012									
Pre	−0.0765	−0.0973	2367.06	2217.98	1.0672	179.11	17.847	2212	40,427
Post	−0.0901	−0.1124	2612.24	2483.83	1.0517	234.43	20.891	2589	44,940
013									
Pre	−0.1109	−0.1260	2305.53	2317.68	0.9948	261.83	10.660	1321	40,794
Post	−0.0867	−0.1056	2383.86	2358.13	1.0109	210.01	16.077	1992	41,835
016									
Pre	−0.0750	−0.0960	2509.21	2496.78	1.0050	191.82	19.783	2451	44,167
Post	−0.0629	−0.0818	2656.68	2555.10	1.0398	167.45	18.746	2323	45,966
019									
Pre	−0.0742	−0.0982	2461.82	2403.25	1.0244	184.30	22.593	2800	42,915
Post	−0.0743	−0.0979	2551.98	2432.32	1.0492	188.91	22.721	2815	43,956
025									
Pre	−0.1155	−0.1389	1627.39	1574.66	1.0335	188.77	13.182	1633	28,243
Post	−0.1279	−0.1561	1530.78	1464.54	1.0452	195.55	15.191	1882	26,416
032									
Pre	−0.0890	−0.1096	1817.98	1755.37	1.0357	162.31	13.387	1659	31,517
Post	−0.0792	−0.1001	1889.59	1823.32	1.0364	150.06	14.529	1800	32,748

D_H and D_O, *time 0* dilution spaces of deuterium and oxygen-18 respectively; rH_2O, total body H_2O turnover; rCO_2, CO_2 production rate.

the resistance training occurred only once each week. Because we evaluated energy expenditure after 26 wk, but not after 8 or 12 wk, comparison of our resistance training TEE data with the aerobic training study of Goran and Poelman (17) or the combined training program of Meijer et al. (27) has its limitations. However, it is noteworthy that, unlike high-intensity aerobic training, the resistance training in the present study was not associated with a drop in AEE, even after subtracting the exercise energy expenditure. In fact, both AEE and adjusted AEE showed strong trends toward being elevated (503 kJ/day, $P = 0.06$; 288 kJ/day, $P = 0.18$). ARTE increased 38% after training (98–135 min/day), although a portion of the increase (14 of 37 min/day) can be attributed to the five resistance training sessions during the 14-day evaluation period. The resistance training did not attenuate free-living physical activity and may have had an invigorating effect in these older adults.

Consistent with other studies, REE increased after the resistance training program (28, 32, 42). The majority of the increase found in this study probably resulted from the increase in FFM. Consistent with this hypothesis, Taaffe et al. (39) have reported no increase in basal metabolic rate after 15 wk of resistance training in a group of women aged 65–79 yr who did not increase FFM. However, the REE differences in our study persisted even after adjustment for changes in FFM, suggesting that other factors may also be contributing to the increase in REE. Although not measured in this study, protein turnover (37) and sympathetic nervous system activity have both been shown

Table 3. *Energy expenditure changes in older adults after 26 wk of resistance training*

Variable	Pretraining	Posttraining	*P*
REE, kJ/day	5388 ± 520	5753 ± 560	<0.01
REE/FFM, $kJ \cdot day^{-1} \cdot kg^{-1}$	28.2 ± 5.3	29.2 ± 5.6	0.04
RER, kJ/day	0.86 ± 0.04	0.83 ± 0.03	0.03
TEE, kJ/day	7831 ± 2223	8796 ± 1629	<0.01
Adjusted TEE, kJ/day	7834 ± 2223	8581 ± 1612	<0.02
AEE, kJ/day	1660 ± 1784	2163 ± 1193	0.06
Adjusted AEE, kJ/day	1660 ± 1784	1948 ± 1185	0.18
Exercise $\dot{V}O_2$ ml $O_2 \cdot kg^{-1} \cdot min^{-1}$	13.3 ± 1.3	13.6 ± 1.3	0.42
AEC, kJ/min	19.7 ± 3.2	19.9 ± 3.3	0.64
ARTE, min/day	98 ± 107	135 ± 72	0.04
Adjusted ARTE, min/day	98 ± 107	121 ± 72	0.14

Values are means ± SD. REE, resting energy expenditure; FFM, Fat-Free mass; RER, respiratory exchange ratio; TEE, total energy expenditure over 14 days; AEE, activity-related energy expenditure; exercise $\dot{V}O_2$, average O_2 uptake during the 3 standardized exercise tasks; AEC, average energy expenditure above resting for the 3 standardized exercise tasks; ARTE, activity-related time equivalent. Adjusted values for TEE, AEE, and ARTE were derived by reducing the appropriate energy expenditure measure by the average daily energy expenditure of the resistance exercise.

to be related to changes in REE (31, 32, 40). Resistance training has been shown to acutely increase muscle sympathetic nerve activity (6) and to elevate rates of muscle protein synthesis and breakdown up to 48 h postexercise (30). Whether these effects persist at 96 h is unknown.

Consistent with the RER changes found with training in this study, we have previously found decreased RER and increased fat oxidation rates after a 16-wk resistance training program in older women. Melby et al. (28) reported a decrease in resting RER 15 h after a single session of resistance training in young men. RER was measured 96 h after the last resistance training exercise session in the present study and ~44 h after the last exercise session in our previous study with older women. Therefore, it is unlikely that the decrease in RER found in our studies is due to any acute effects of exercise. Broeder et al. (4) and Pratley et al. (32) did not find any change in RER after resistance training. However, the Broeder study used young men and also did not find any significant increase in REE. Pratley and co-workers' subjects were older men, and an increase in REE was observed. A few cross-sectional studies (21, 34, 40) have reported higher lipid oxidation rates in endurance-trained subjects.

Some research has suggested that at least part of the training-induced change in lipid oxidation rates may be caused by changes in energy intake and macronutrient intake (1). The subjects in this study were weight stable and reported very similar macronutrient and energy intakes before training and during the last week of training. It is possible that the subjects were in slight energy imbalance because a shift of 2 kg from fat to lean stores, as observed in this study, would be associated with an estimated loss of 12,896 kJ (based on estimates of 32,240 kJ/kg for fat mass and 25,792 kJ/kg for lean mass). Because this estimated loss would presumably have occurred across the entire 26 wk of training, the estimated daily energy deficit would be very small (<71 kJ/day). This change is presumably too small to cause measurable differences in RER. Another possible explanation for the decrease in RER may include changes in sympathetic nervous system activity, which would affect lipid mobilization in adipose tissue. Plasma norepinephrine has been shown to increase after resistance training in men (32). In addition, attenuation of β-adrenergic activity through the oral administration of propranolol is associated with an attenuation of elevated lipid oxidation rates found in exercise-trained men (40). Sympathetic nervous system activity was not measured in this study; however, it is certainly possible that an exercise-induced increase in sympathetic nervous system tone may be at least partly related to decreased RER found in this and other studies.

Absence of a control group is a potential limitation for this study. For example, seasonal variations in energy expenditure may occur. Individuals may tend to be more active during the summer months, at least in the northern parts of the United States. The pretraining data were collected in Birmingham, Alabama, during June, July, and August, whereas the posttraining data were collected during December, January, and February. Using data previously reported (45), we separated subjects based on the month that the evaluation occurred. A total of 26 measurements were made during June, July, and August, and 34 observations were made during December, January, and February. No differences were seen for body weight or any of the energy expenditure variables, including AEE (2,350 kJ/day in the summer and 2,310 kJ/day in the winter) and ARTE (124 min/day in the summer and 123 min/day in the winter). This does not ensure that a seasonal

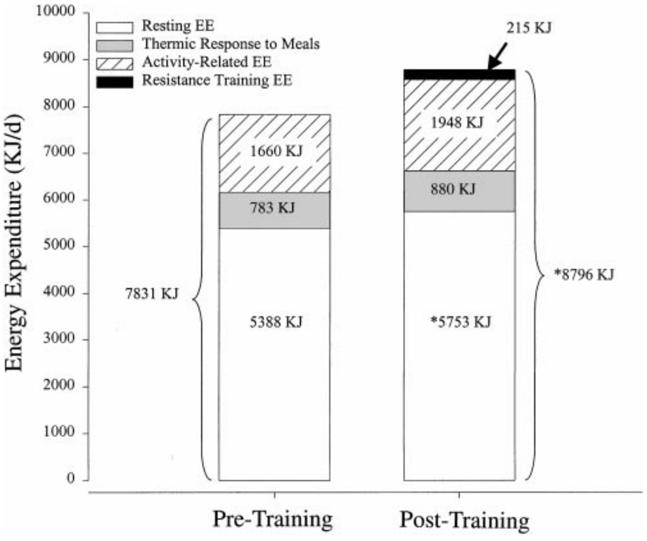

Fig. 1. Summary of components of free-living total energy expenditure before and during the last 2 wk of a 26-wk resistance training program. Subjects were 61- to 77-yr-old men and women. EE, energy expenditure. *Posttraining significantly different from pretraining, $P < 0.05$.

variation or some other time-related measurement confounder may not have affected our measurement of energy expenditure. However, it does suggest that seasonal variations in energy expenditure do not occur in the moderate environment of middle Alabama and are not responsible for the significant increases in TEE and ARTE found in this study.

Although we did not find any difference between men and women for any of the training-related changes in energy expenditure and physical activity, our sample size was too small to adequately address the null hypothesis that older men and women increase energy expenditure identically after resistance training. It was not the intent of this study to compare strength training-induced changes in energy expenditure between older men and women. The study's purpose was to determine what effects resistance training has on the various categories of energy expenditure in older adults, and, because we found statistically significant changes in energy expenditure, the sample size was adequate for this purpose.

In conclusion, this study shows that in older adults TEE is increased and RER is decreased in response to resistance training. The increase in TEE occurs as a result of increases in both REE and physical activity. We feel that any healthy older adult can tolerate and in most cases enjoy the exercise training. This is the second resistance training program we have completed using adults aged 60–77 yr, and only 2 of the 45 subjects in the two studies have had adherence rates of less than 90%. No training-induced injuries occurred. In addition, all subjects said that they planned to continue training after the conclusion of the study. These results suggest that resistance training may have value in increasing energy expenditure and lipid oxidation rates in older adults, thereby improving their metabolic profiles.

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