Exercise Training and Energy Expenditure following Weight Loss

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ABSTRACT

HUNTER, G. R., G. FISHER, W. H. NEUMEIER, S. J. CARTER, and E. P. PLAISANCE. Exercise Training and Energy Expenditure following Weight Loss. *Med. Sci. Sports Exerc.*, Vol. 47, No. 9, pp. 1950–1957, 2015. **Purpose**: This study aims to determine the effects of aerobic or resistance training on activity-related energy expenditure (AEE; kcal·d^{-1}) and physical activity index (activity-related time equivalent (ARTE)) following weight loss. It was hypothesized that weight loss without exercise training would be accompanied by decreases in AEE, ARTE, and nontraining physical activity energy expenditure (nonexercise activity thermogenesis (NEAT)) and that exercise training would prevent decreases in free-living energy expenditure. **Methods**: One hundred forty premenopausal women had an average weight loss of 25 lb during a diet (800 kcal·d^{-1}) of furnished food. One group aerobically trained 3 times per week (40 min·d^{-1}), another group resistance-trained 3 times per week (10 exercises/2 sets × 10 repetitions), and the third group did not exercise. Dual-energy x-ray absorptiometry was used to measure body composition, indirect calorimetry was used to measure resting energy expenditure (REE) and walking energy expenditure, and doubly labeled water was used to measure total energy expenditure (TEE). AEE, ARTE, and nontraining physical activity energy expenditure (NEAT) were calculated. **Results**: TEE, REE, and NEAT all decreased following weight loss for the no-exercise group, but not for aerobic and resistance trainers. Only REE decreased in the two exercise groups. Resistance trainers increased ARTE. HR and oxygen uptake while walking on the flat and up a grade were consistently related to TEE, AEE, NEAT, and ARTE. **Conclusions**: Exercise training prevents a decrease in energy expenditure, including free-living energy expenditure separate from exercise training, following weight loss. Resistance training increases physical activity, whereas economy/ease of walking is associated with increased TEE, AEE, NEAT, and ARTE. **Key Words:** AEROBIC TRAINING, EXERCISE EASE, EXERCISE ECONOMY, NEAT, RESISTANCE TRAINING

Obesity continues to be a worldwide problem, and participation in physical activity may be one of the preeminent ways to slow or prevent weight gain (21,39). A number of studies have shown that physical activity is important for maintaining metabolic health independent of weight loss (20,32) and may be protective during weight regain (3,11,36). Despite these well-publicized benefits, more than 60% of individuals in the United States do not meet physical activity recommendations. Although it is well established that total energy expenditure (TEE) decreases as individuals reduce body size following weight loss, it is unclear whether or not weight loss alters free-living energy expenditure, with some studies showing little change (42) and others showing decreases (29,41). Resolving this question is important to fully understand the complex relationship between impact of exercise training during weight loss and free-living energy expenditure following weight loss.

Energy expenditure during locomotion varies by 10%–15% between individuals of similar body mass (17); thus, activity-related energy expenditure (AEE) and volume of physical activity are different, although highly related, entities. We have previously described an objective index derived from kilocalories of AEE per day divided by average kilocalories of net energy expenditure per minute during five different locomotion tasks (activity-related time equivalent (ARTE) index; min·d^{-1}) (40). The ARTE index may be particularly important for comparing differences in physical activity between individuals or groups that vary in locomotion economy. For example, we have previously shown that aerobic fitness and ease during submaximal locomotion tasks are more strongly related to the ARTE index than to AEE in a group of African-American and European-American women. (17). Given that African-American and European-American women tend to vary in both locomotion economy/ease and AEE, standardization of economy enabled the relationship between economy/ease and physical activity to be observed without the confounding effects of economy on AEE.

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Aerobic capacity is related to AEE and ARTE, as described previously (17). This study also demonstrated that HR and perceived exertion during locomotion were inversely associated with AEE and ARTE. AEE includes both energy expended during planned exercise (e.g., aerobic, resistance, yoga, and sports) and nonexercise activity thermogenesis (NEAT). It has been shown that NEAT makes up a large proportion of AEE in sedentary individuals (26), can be quite variable (25,26), and may increase in some individuals in response to overfeeding (25). Thus, it is possible that increasing NEAT is a primary factor that enables an individual to resist weight gain. In contrast, the decrease in AEE (NEAT in nonexercise training individuals) following weight loss (1,27) may increase the occurrence of weight regain.

Understanding factors that influence participation in physical activity is important. Ease of physical activity is related to increased NEAT (17), whereas muscle metabolic economy is related to subsequent reductions in weight gain (23). Thus, improved muscle metabolic economy should make physical tasks less demanding and may be an important factor that influences participation in physical activity. Aerobic training (14) and resistance training are known to improve locomotion economy (4,7,28,34,35), ease (4,7,28,34,35), and endurance (9). Taken together, these data suggest that ease of locomotion may be a critical component that enables individuals to be more physically active. Consistent with this, resistance training (10,18) and combined aerobic and resistance training (10) are two modes of training that increase TEE and free-living energy expenditure.

The purpose of this study was to determine the effects of aerobic or resistance training during a low-calorie weight loss program on AEE, ARTE, and NEAT following weight loss. It was hypothesized that weight loss without exercise training will be accompanied by decreases in AEE, ARTE, and NEAT but that exercise training will prevent decreases in free-living energy expenditure. Additionally, we hypothesized that economy/ease of walking would be related to AEE, ARTE, and NEAT.

METHODS

Subjects were sedentary (no exercise training during the prior year) overweight (body mass index (BMI) >27 and <30 kg·m^{-2}) women (n = 140) age between 20 and 44 yr. All were tested at baseline after a 4-wk weight stabilization period during which subjects were weighed 3 times per week, with food provided during the last 2 wk. After evaluation, they were randomly assigned to one of three groups: 1) weight loss with aerobic exercise training 3 times per week; 2) weight loss with resistance exercise training 3 times per week; and 3) weight loss without exercise training. During weight loss, subjects were provided an 800-kcal diet until they had reached a BMI of <25 kg·m^{-2}. After weight loss, subjects were weight stable for 4 wk while continuing to have food furnished. Food was provided (20%–22% fat, 20%–22% protein, and 56%–58% carbohydrate) by the General Clinical Research Center (GCRC) kitchen. Women were admitted to the GCRC 2 d before testing to ensure that physical activity and diet were standardized. Testing was performed in the fasted state in the morning after subjects spent the night in the GCRC. The study was approved by the University of Alabama at Birmingham Institutional Review Board, and informed consent was obtained from all subjects.

Exercise training. Exercise training occurred in a 1600-ft^2 exercise training facility devoted to research. Training was supervised by an exercise physiologist and was scheduled to occur 3 times per week. Both aerobic and resistance trainers warmed up with 5 min of walking and 3–5 min of stretching.

Aerobic training. Continuous treadmill walking/jogging was used as the mode of aerobic training. Subjects performed 20 min of continuous exercise at 67% maximum HR during the first week of training. Duration and intensity increased each week such that, by the beginning of the eighth week, subjects exercised continuously at 80% of maximum HR for 40 min. Subjects were encouraged to increase intensity (either speed or grade) when average exercise HR was consistently below 80% of maximum HR. After the exercise session, subjects cooled down for 3–5 min with gradually decreasing exercise intensity.

Resistance training. The resistance training program included squats, leg extension, leg curl, elbow flexion, triceps extension, lateral pull-down, bench press, military press, lower-back extension, and bent-leg sit-ups. After 1 wk of familiarization (training with light weight), one repetition maximum (1RM) was measured. On the first week following 1RM tests, one set of 10 repetitions was performed at 65% 1RM, with the percentage of 1RM increasing on subsequent weeks until week 4 intensity was at 80% 1RM. Starting on week 5, two sets of 10 repetitions were attempted at 80% 1RM for each exercise with 2-min rest between sets. Strength was evaluated every 5 wk, and adjustments in training resistance were made based on the most current 1RM in both the weight loss phase and the 1-yr weight maintenance phase.

Resting oxygen uptake/resting energy expenditure. Resting oxygen uptake and resting energy expenditure (REE) were determined in the fasted state on three consecutive mornings (between 0600 and 0650 h) following an overnight stay in the GCRC. Subjects remained awake in a quiet, softly lit, well-ventilated room in which temperature was maintained between 22°C and 24°C. Subjects laid supine on a comfortable bed, and oxygen uptake was measured using a ventilated hood system. After a 15-min rest, oxygen uptake was measured for 30 min with a computerized open-circuit indirect calorimetry system (Delta Trac II; Sensor Medics, Yorba, CA, USA). The last 20 min was used for analysis. Oxygen uptake values used to determinate exercise net $\dot{V}O_2$ (i.e., exercise $\dot{V}O_2$ − resting $\dot{V}O_2$) were the means of the three morning values. The coefficient of variation for repeated measures of $\dot{V}O_2$ is <4% in our laboratory.

$\dot{V}O_{2max}$. A maximal modified Bruce protocol was used to determine $\dot{V}O_{2max}$ (8). HR was measured using a POLAR

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Vantage XL HR monitor (Polar Electro Inc., Gays Mills, WI, USA). Oxygen uptake and carbon dioxide production were measured continuously using a MAX-II metabolic cart (Physiodyne Instrument Corporation, Quogue, NY, USA). Gas analyzers were calibrated with certified gases of known concentrations. Standard criteria for HR (HR within 10 bpm of estimated maximum), RER (RER >1.2), and plateauing were used to ensure achievement of $\dot{V}O_{2max}$. The coefficient of variation for repeated measures of $\dot{V}O_{2max}$ is <3% in our laboratory.

Economy/ease of physical activity. HR, RER, and oxygen uptake ($\dot{V}O_2$) were obtained during treadmill walk on the flat (4.8 $km \cdot h^{-1}$) and treadmill walk up a 2.5% grade (4.8 $km \cdot h^{-1}$). The duration of each of the tasks was between 4 and 5 min, and steady state was obtained. Oxygen uptake and carbon dioxide production were also measured using a MAX-II metabolic cart (Physiodyne Instrument Corporation). Net oxygen uptake (work steady-state $\dot{V}O_2$ − resting $\dot{V}O_2$; mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) is considered exercise economy for walking and stair climbing. HR increases as the intensity of exercise increases. Therefore, HR is considered an index of exercise difficulty.

Strength measure. Using methods previously described (16), we measured knee extension and elbow flexion strength isometrically. Force was measured using a universal shear beam load cell (LCC 500; Omega Engineering, Stanford, CT, USA). Knee extension maximal force was measured on the right leg at a knee position of 110° at the level of the lateral malleolus. Subjects were restrained across the upper legs and hips with padded straps. Elbow flexion strength was measured in standing position with the elbow at 110°. Upper arm position was fixed parallel with the torso with a shoulder harness. After three warm-up trials, three maximal isometric contractions were recorded with 60-s rest intervals between trials for both knee extension and elbow flexion tests. The coefficient of variation for these tests in our laboratory is <3%.

Estimated energy cost of exercise training. Net oxygen uptake (exercise oxygen uptake − resting oxygen uptake) was measured (Max-1 Cart; Physio-Dyne Instrument Corporation, Quogue, NY) while subjects were walking at a grade within 5 bpm of their HR in training during the 2-wk time period that TEE was measured at posttraining evaluation (no exercise training took place during pretraining evaluation). Oxygen uptake was measured during the first 5 min of exercise, between the 20th and 25th minutes of exercise, and between the 35th and 40th minutes of exercise, and averaged. Oxygen uptake was converted into kilocalories per session (5 kcal × L $O_2 \cdot min^{-1}$ × 40 min).

We measured the energy cost of resistance training and 15 min of recovery in a subset of 25 subjects (COSMED K4 b^2 portable metabolic system; COSMED S. r. l., Rome, Italy). According to these measured values, we developed a regression equation for estimating energy expenditure for the rest of the subjects based on the amount of weight lifted in each of the exercises used in resistance training. We then validated the equation using a different set of older women (n = 14) and found that the R^2 between predicted and actual energy expenditure was 0.95 (standard error of estimate, 11 kcal), using methods we have previously described (22). Actual measured resistance training energy expenditures were used for the 25 subjects who had measured resistance training energy expenditures, whereas estimated energy expenditures were generated from the regression equation for thee remaining subjects.

Dual-energy x-ray absorptiometry. Dual-energy x-ray absorptiometry (Lunar DPX-L densitometer; LUNAR Radiation, Madison, WI, USA) was used to determine total fat and lean mass according to the manufacturer's instructions. Adult Software version 1.33 was used to analyze the scans.

TEE. TEE was measured before and during the last 2 wk of resistance training using doubly labeled water, as previously described (40). Four timed urine samples were collected after oral dosing of doubly labeled water: two urine samples were taken in the morning after dosing and two more urine samples were taken 14 d later with a loading dose of 1 g of premixture (10% $H_2{}^{18}O$ and 8% ^2H_2O) per kilogram of body weight. Isotopic dilution spaces were calculated from $H_2{}^{18}O$ and ^2H_2O enrichments in the body by extrapolation of the log enrichments back to zero time using the following equation: dilution space (L) = $d/20.02 \times 18.02 \times 1/RE$, where d is grams of $H_2{}^{18}O$ and ^2H_2O given, R is the standard ratio for $^{18}O{:}^{16}O$ (0.002005) and $^2H{:}^1H$ (0.00015576), E is enrichment of $H_2{}^{18}O$ and ^2H_2O at extrapolated zero time (percentage above background). Rate of carbon dioxide production (rCO_2) was calculated from the equation by Schoeller et al. (30): $rCO_2 = 0.4554N(1.01K_0 - 1.04K_h)$, where rCO_2 is the amount of carbon dioxide produced ($mol \cdot d^{-1}$), 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 (d^{-1}), respectively. TEE was then calculated from carbon dioxide production using the equation by de Weir (2): TEE ($kcal \cdot d^{-1}$) = $3.9(rCO_2/FQ) + 1.1\ rCO_2$, where TEE is total energy expenditure ($kcal \cdot d^{-1}$), rCO_2 is rate of carbon dioxide production ($L \cdot d^{-1}$; 1 mol of CO_2 is equivalent to 22.4 L), and FQ is food quotient. Samples for $H_2{}^{18}O$ and ^2H_2O were analyzed in triplicate by isotope ratio mass spectrometry at the University of Alabama at Birmingham, as previously described (5). Samples for $H_2{}^{18}O$ and ^2H_2O were reanalyzed in seven subjects, and TEE values between days were in close agreement (coefficient of variation, 4.3%), thus demonstrating a high level of reproducibility.

AEE, NEAT, and physical activity level. AEE was estimated by subtracting REE from TEE after reducing TEE by 10% to account for thermic response to meals. NEAT was calculated as NEAT = AEE − energy cost of exercise training (25). Physical activity level (PAL) was calculated by dividing TEE by REE.

ARTE. Free-living physical activity was determined from AEE using the ARTE index (42). The ARTE index ($min \cdot d^{-1}$) = AEE/AEC, where AEC is a measure of the steady-state net energy cost (energy economy) of performing five standardized tasks in the laboratory: walking at 3 mph on the flat, walking at 3 mph while walking up a 2.5% grade, stair climbing (7-inch

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step) at a rate of 60 steps per minute, carrying a weighted box (30% of maximal isometric elbow strength) while walking at 3 mph on the flat, and riding a stationary cycle at 50 W. AEC, after adjustment for body weight, is a measure of the economy of performing the five exercise tasks. The exercise tasks were selected to reflect typical activities of women in a free-living environment. ARTE ($\text{min}\cdot\text{d}^{-1}$) is thus an index of the part of the day that the subjects participate in physical activity equivalent to the five standardized tasks. The index is particularly useful in comparing AEE values in which energy economy of locomotion may be different, such as following weight loss.

Statistics. Two (time)-by-two (group) ANOVA was run on all variables, with repeated measures on time. Bonferroni-corrected *post hoc t*-tests were run on contrasts of interest. Simple Pearson product correlations were run between AEE and physical activity variables and between walking HR and oxygen uptake variables. SPSS was used for the analyses, and α was set to 0.05.

RESULTS

Descriptive variables are presented in Table 1. All subjects had decreased weight, BMI, percent fat, fat mass, fat-free mass (FFM), and elbow flexion strength with weight loss. No significant change in $\dot{V}O_{2max}$ (when reported in $\text{L}\cdot\text{min}^{-1}$) was observed ($P$ = 0.07). In addition, no significant improvement in knee extension strength was found, but there was a significant increase in $\dot{V}O_{2max}$ (when reported in $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). Time–group interactions were observed for percent fat (P < 0.04), FFM (P < 0.01), $\dot{V}O_{2max}$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), $\dot{V}O_{2max}$ ($\text{L}\cdot\text{min}^{-1}$), and elbow flexion strength (P < 0.01), but not for knee extension strength (P = 0.09). *Post hoc* analysis revealed that the resistance training group decreased percent fat more than the other two groups and that there was a nonsignificant increase in elbow flexion strength and knee extension strength compared to the other two groups with decreased strength.

Submaximal walk HR and oxygen uptake results are shown in Table 2. HR significantly decreased during the 3-mph walk on the flat, the 3-mph walk up a 2.5% grade, and the average HR for the two tasks. Net $\dot{V}O_2$ decreased significantly for the 3-mph walk on the flat. No time–group interactions were observed for any variable. However, *post hoc* tests showed that the resistance training group significantly reduced net $\dot{V}O_2$ for the walk on the flat and average net $\dot{V}O_2$ for the level and grade walks.

Energy expenditure and physical activity variables are shown in Table 3. A significant time effect was observed for TEE and REE, whereas a significant time–group effect was observed for AEE, ARTE, and PAL. *Post hoc* analyses showed that the no-exercise group significantly decreased AEE, NEAT, and ARTE following weight loss. *Post hoc* analysis also revealed that the resistance training group significantly increased ARTE and PAL, whereas all groups significantly decreased REE.

Table 4 (overweight) and Table 5 (postoverweight) contain correlations of NEAT and ARTE with HR (measure of locomotion ease) and submaximal $\dot{V}O_2$ (measure of locomotion economy). In the overweight state, HR while walking at 3 mph was significantly related to NEAT (because

TABLE 1. Descriptive and fitness variables.

Variable	Group	Overweight	Postoverweight	Δ (Postoverweight)	*P* Time	*P* Group	*P* Time–Group Interaction
Age (yr)	Aerobic	35.2 ± 7.0			0.39		
	Resistance	33.9 ± 6.1					
	No exercise	35.6 ± 5.5					
Weight (kg)	Aerobic	76.9 ± 6.7	64.4 ± 6.1	−12.5 ± 2.3	<0.01	0.61	0.19
	Resistance	77.5 ± 7.6	65.9 ± 6.5	−11.6 ± 2.3			
	No exercise	78.1 ± 6.9	65.9 ± 6.3	−12.2 ± 3.1			
BMI ($\text{kg}\cdot\text{m}^{-2}$)	Aerobic	28.5 ± 1.5	23.8 ± 1.1	−4.7 ± 0.9	<0.01	0.69	<0.06
	Resistance	28.1 ± 1.2	23.9 ± 1.1	−4.2 ± 0.8			
	No exercise	28.2 ± 1.4	23.9 ± 1.1	−4.3 ± 1.1			
% Fat	Aerobic	44.0 ± 3.7	33.9 ± 4.6	−10.1 ± 2.2	<0.01	0.25	<0.04
	Resistance	43.0 ± 3.6	32.4 ± 4.5	−10.6 ± 2.7			
	No exercise	42.7 ± 3.4	33.5 ± 4.7	−9.2 ± 2.0			
Fat mass (kg)	Aerobic	33.9 ± 5.0	22.0 ± 4.6	−11.9 ± 1.5	<0.01	0.97	0.28
	Resistance	33.7 ± 5.2	21.7 ± 4.3	−12.0 ± 2.4			
	No exercise	33.4 ± 4.8	22.2 ± 4.5	−11.2 ± 2.1			
FFM (kg)	Aerobic	43.0 ± 3.7	42.5 ± 3.5	−0.5 ± 1.5	<0.01	0.08	<0.01
	Resistance	44.2 ± 4.1	44.5 ± 3.7	+0.3 ± 1.4			
	No exercise	44.7 ± 3.7	43.7 ± 4.0	−1.0 ± 1.7			
Knee extension strength (N)	Aerobic	493 ± 124	470 ± 124	−23 ± 12	0.70	<0.01	0.09
	Resistance	568 ± 179	599 ± 136	+31 ± 12			
	No exercise	551 ± 167	529 ± 176	−22 ± 16			
Elbow flexion strength (N)	Aerobic	191 ± 35	172 ± 36	−19 ± 2	<0.03	<0.01	<0.01
	Resistance	196 ± 32	202 ± 37	+6 ± 3			
	No exercise	202 ± 30	195 ± 32	−7 ± 3			
$\dot{V}O_{2max}$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	Aerobic	27.9 ± 4.1	34.8 ± 5.6	+6.9 ± 3.0	<0.01	0.24	<0.01
	Resistance	29.1 ± 3.6	33.4 ± 4.6	+4.3 ± 3.2			
	No exercise	27.7 ± 3.8	31.7 ± 4.7	+4.0 ± 2.4			
$\dot{V}O_{2max}$ ($\text{L}\cdot\text{min}^{-1}$)	Aerobic	2.02 ± 0.30	2.13 ± 0.31	+0.11 ± 0.02	0.07	0.16	0.03
	Resistance	2.24 ± 0.36	2.19 ± 0.37	−0.05 ± 0.02			
	No exercise	2.12 ± 0.32	2.06 ± 0.33	−0.06 ± 0.02			

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TABLE 2. Submaximal 3-mph flat walking and 2.5% grade walking economies and HRs.

Variable	Group	Overweight	Postoverweight	Δ (Postoverweight)	*P* Time	*P* Group	*P* Time–Group Interaction
3-mph submaximal walk HR (bpm)	Aerobic	121 ± 14	110 ± 17**	−11 ± 13	<0.01	0.73	0.80
	Resistance	120 ± 13	109 ± 15**	−11 ± 11			
	No exercise	118 ± 15	109 ± 15**	−9 ± 11			
3-mph submaximal walk $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	Aerobic	12.1 ± 1.4	11.9 ± 1.4	−0.2 ± 1.5	0.62	0.84	0.32
	Resistance	12.0 ± 1.3	11.7 ± 1.5	−0.3 ± 1.8			
	No exercise	11.9 ± 1.5	12.2 ± 1.7	+0.3 ± 1.8			
3-mph submaximal walk net $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	Aerobic	9.4 ± 1.1	9.0 ± 1.5	−0.4 ± 1.6	<0.04	0.74	0.11
	Resistance	9.4 ± 1.2	8.8 ± 1.4*	−0.6 ± 1.6			
	No exercise	9.2 ± 1.5	9.4 ± 1.6	+0.2 ± 1.5			
3-mph submaximal grade walk HR (bpm)	Aerobic	137 ± 15	124 ± 17**	−13 ± 12	<0.01	0.78	0.82
	Resistance	135 ± 14	122 ± 16**	−13 ± 11			
	No exercise	134 ± 17	123 ± 16**	−11 ± 12			
3-mph submaximal grade walk $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	Aerobic	14.7 ± 1.4	14.8 ± 1.6	+0.1 ± 1.5	0.19	0.71	0.42
	Resistance	14.6 ± 1.6	14.6 ± 1.5	0.0 ± 1.9			
	No exercise	14.5 ± 1.7	15.0 ± 1.8	+0.5 ± 1.9			
3-mph submaximal grade walk net $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	Aerobic	12.3 ± 1.3	12.0 ± 1.3	−0.3 ± 1.4	0.37	0.68	0.12
	Resistance	12.2 ± 1.3	11.6 ± 1.4	−0.6 ± 1.8			
	No exercise	11.9 ± 1.6	12.2 ± 1.6	+0.3 ± 1.7			
Average HR for the two tasks (bpm)	Aerobic	129 ± 14	117 ± 17	−12 ± 12	<0.01	0.71	0.78
	Resistance	127 ± 13	116 ± 15	−11 ± 10			
	No exercise	126 ± 16	115 ± 15	−11 ± 11			
Average $\dot{V}O_2$ for the two tasks (mL·kg^{-1}·min^{-1})	Aerobic	13.4 ± 1.2	13.4 ± 1.4	0.0 ± 1.4	0.63	0.80	0.80
	Resistance	13.3 ± 1.4	13.1 ± 1.5	−0.2 ± 1.8			
	No exercise	13.2 ± 1.5	13.6 ± 1.7	+0.4 ± 1.7			
Average net $\dot{V}O_2$ for the two tasks (mL·kg^{-1}·min^{-1})	Aerobic	10.9 ± 1.2	10.6 ± 1.3	−0.3 ± 1.4	0.13	0.70	0.21
	Resistance	10.8 ± 1.4	10.2 ± 1.4*	−0.6 ± 1.7			
	No exercise	10.6 ± 1.5	10.8 ± 1.8	+0.2 ± 1.7			

*Significant *post hoc* difference from overweight state, $P < 0.05$.
**Significant *post hoc* difference from overweight state, $P < 0.01$.

exercise training was not occurring in the overweight state, AEE and NEAT were identical) and ARTE. HR for the average of the two walking tasks was negatively related to NEAT in the overweight state, whereas HR during the grade walk and the average HR for the two tasks were negatively related to ARTE. AEE, ARTE, and NEAT were negatively related to all of the submaximal walking HR and $\dot{V}O_2$ (3 mph on flat, 3 mph up the grade, and average of the two walking tasks).

DISCUSSION

Relatively high levels of AEE are important for preventing weight regain following weight loss (31,40). Unfortunately, participation in physical activity often decreases following weight loss (24). Consistent with our hypothesis TEE, AEE, and NEAT decreased following weight loss in subjects who did not exercise train during energy restriction. On the other hand, exercise training enhanced post–weight-loss energy expenditure such that AEE was not reduced following weight loss. In fact, both aerobic and resistance training groups experienced nonsignificant increases in TEE and AEE. In addition, the resistance training group increased ARTE, a measure of free-living physical activity corrected for differences in locomotion economy. High walking exercise economy/ease (low HR) was significantly related to both NEAT and ARTE. In addition, economy/ease of walking increased in the

TABLE 3. Energy expenditure and physical activity variables.

Variable	Group	Overweight	Postoverweight	Δ (Postoverweight)	*P* Time	*P* Group	*P* Time–Group Interaction
TEE (kcal·d^{-1})	Aerobic	2095 ± 392	2032 ± 329	−63 ± 404	<0.03	<0.05	<0.10
	Resistance	1905 ± 346	1968 ± 290	+63 ± 411			
	No exercise	2194 ± 271*	1935 ± 388*	−259 ± 355			
REE (kcal·d^{-1})	Aerobic	1320 ± 127*	1246 ± 127*	−74 ± 107	<0.01	0.13	0.73
	Resistance	1358 ± 122*	1296 ± 128*	−62 ± 74			
	No exercise	1386 ± 127*	1303 ± 117*	−83 ± 116			
AEE (kcal·d^{-1})	Aerobic	559 ± 301	572 ± 291	+13 ± 354	0.84	<0.02	<0.02
	Resistance	362 ± 303	471 ± 212	+109 ± 370			
	No exercise	585 ± 223*	443 ± 313*	−142 ± 326			
NEAT (kcal·d^{-1})	Aerobic	559 ± 301	472 ± 289	−87 ± 354	0.07	0.06	0.09
	Resistance	362 ± 296	423 ± 218	+61 ± 372			
	No exercise	585 ± 222*	442 ± 313*	−143 ± 326			
ARTE index (min·d^{-1})	Aerobic	136 ± 71	162 ± 85	+26 ± 90	0.09	0.05	<0.05
	Resistance	91 ± 72*	135 ± 63*	+44 ± 92			
	No exercise	147 ± 67	126 ± 93	−21 ± 97			
PAL (TEE/REE)	Aerobic	1.54 ± 0.30	1.63 ± 0.30	+0.09 ± 0.30	0.27	0.04	<0.01
	Resistance	1.39 ± 0.29*	1.52 ± 0.18*	+0.13 ± 0.31			
	No exercise	1.57 ± 0.21	1.46 ± 0.30	−0.06 ± 0.29			

*Significant *post hoc* difference, $P < 0.05$.

TABLE 4. Correlation table for overweight time point.

	AEE/NEAT	ARTE
Walk HR	−0.163*	−0.176*
Walk $\dot{V}O_2$	0.001	−0.065
Grade walk HR	−0.132	−0.141*
Grade walk $\dot{V}O_2$	−0.012	−0.078
Average HR for the two tasks	−0.150*	−0.160*
Average $\dot{V}O_2$ for the two tasks	−0.007	−0.160*

*Significant *post hoc* difference from overweight state, $P < 0.05$.
**Significant *post hoc* difference from overweight state, $P < 0.01$.

resistance training group following weight loss. These results support the concept that energy expenditure can be maintained and physical activity can be increased following weight loss if exercise training and especially resistance training occur during energy restriction.

Previous work has shown that aerobic and resistance training results in increased REE (18,37) and TEE (10,18), supporting the hypothesis that exercise training, especially resistance training, increases TEE by increasing REE, probably through either increased FFM (15) or postexercise elevation of metabolism that lasts more than 24 h (12,38). In addition, exercise training increases locomotion economy/ease (4,7,16,19,28,34,35), AEE (10), and NEAT (10), whereas others show reductions (6,10). For example, Goran and Poehlman (6) found a decrease in AEE following an aerobic training program of 8 wk. It is possible that the exercise stimulus may have exceeded the recovery capacity of older adults and, as such, resulted in a classic "overtraining response" in this relatively high-intensity (75% of $\dot{V}O_{2max}$) and short-adaptation-period (8 wk) training program. Consistent with the concept that more is not always better, we found a 200-kcal·d^{-1} increase in NEAT following 16 wk of 2 d·wk^{-1} combined aerobic and resistance training but a 150-kcal·d^{-1} decrease in NEAT in a group that performed combined aerobic and resistance training 3 d·wk^{-1} for 16 wk. Because caloric restriction may offer dieters added stress, it is not clear what effects the added stress of an exercise training program may have on NEAT. In addition, it is not clear what effect weight loss has on energy expenditure when measured in energy balance. Recently, St-Onge et al. (33) reported no decrease in any energy expenditure compartment, including AEE. However, the subjects lost a relatively small amount of weight (<6 kg and <7% loss for all groups). On the other hand, Leibel et al. (24) reported quite large losses in TEE, REE, and non-REE following a larger loss of weight (7–9 kg and 10% loss). In this study, which included even a larger decrease in body weight (12 kg and >15% loss for all groups), a large decrease in TEE, REE, AEE, and ARTE occurred in the no-exercise group. However, no decrease in TEE, AEE, or ARTE occurred in the two exercise groups, and the resistance training group actually increased NEAT. Because maintaining high AEE seems to be important for preventing weight regain following dieting (31,40), these data strongly support the inclusion of exercise training during weight loss interventions.

The decrease in NEAT in the no-exercise group was more than 150 kcal·d^{-1} (~27%). Several possibilities may exist for the decrease in NEAT. First, less energy was required for locomotion following body weight reduction in the exercise groups. Estimate of minutes of physical activity per day did not significantly decrease in the no-exercise group (14% nonsignificantly lower ARTE postexercise), whereas AEE decreased significantly by more than 24%. Thus, it is probable that changes in energy costs of walking contributed, at least in part, to the decreased NEAT found with the no-exercise group. On the other hand, aerobic trainers showed a strong trend for increasing ARTE (19%), and resistance trainers significantly increased ARTE (27%). Contrary to the strong trend for decreased walking economy (increased net $\dot{V}O_2$) in the no-exercise group, walking economy in the aerobic group demonstrated a nonsignificant increase, whereas the resistance group demonstrated a significant increase in walking economy. Coupled with the significant relationships between walking economy/ease measures and NEAT, especially ARTE, it is probable that exercise training, especially resistance training, improved exercise economy, thus enhancing ARTE and NEAT in those subjects that exercise trained.

REE following a resistance training program increases primarily by increasing FFM (10,15). Following a 15% weight loss, resistance training has been shown to slow the decrease in REE (13), whereas following a less extreme weight loss of 7%, resistance training appears to have little effect on REE (33). The decrease in REE was not different between groups in this study, although the resistance training group showed a slightly nonsignificant trend for a smaller decrease in REE than the other two groups. The resistance training group did not decrease FFM (+0.3 kg), and the other groups decreased FFM (aerobic group, −0.5 kg; no-exercise group, −1.0 kg). It appears that resistance training may have little effect on REE following weight loss, especially when weight loss is modest. On the other hand, continuation of resistance training after weight loss would be expected.

It might be argued that exercise training had little effect on NEAT and AEE because the final values for the three groups were quite similar. Subjects were randomly assigned to groups, so it is surprising that there are group differences in the energy expenditure measures TEE, AEE, ARTE, and PAL at baseline. The group differences seem to be primarily attributable to the relatively large baseline values for the no-exercise group, contrasting with the relatively low values for the resistance training group. The nonsignificant slightly larger body weight and FFM values for the no-exercise group at baseline explain a small amount of the baseline differences, but not all of the differences. Multiple variables influence participation in free-living physical activity, including

TABLE 5. Correlation table for post–weight-loss time point.

	AEE	ARTE	NEAT
Walk HR	−0.217*	−0.266**	−0.204*
Walk $\dot{V}O_2$	−0.178*	−0.255**	−0.180*
Grade walk HR	−0.203*	−0.262**	−0.178*
Grade walk $\dot{V}O_2$	−0.226*	−0.307**	−0.229*
Average HR for the two tasks	−0.201*	−0.258**	−0.182*
Average $\dot{V}O_2$ for the two tasks	−0.227*	−0.323**	−0.226*

*Significant *post hoc* difference from overweight state, $P < 0.05$.
**Significant *post hoc* difference from overweight state, $P < 0.01$.

occupation, family considerations, and leisure time activities. These values were not assessed or manipulated in this study, so we cannot speculate as to why these initial differences occurred. We, however, think that the resistance training group increased NEAT, whereas the no-exercise group decreased NEAT, following weight loss. For some reason, resistance trainers increased physical activity during their nonexercise training time, presumably due in part to resistance training improving locomotion economy. As with our previous work, locomotion economy/ease is related to increased participation in NEAT, supporting this premise. With this said, it is should be remembered that the resistance training group only showed a small nonsignificant difference in energy expenditure compared to the no-exercise group in the final evaluation.

In conclusion, exercise training, particularly resistance training, is important for maintaining NEAT following weight loss. This is especially apparent in the maintenance of AEE, NEAT, and ARTE—factors that are known to be important for slowing and even preventing weight regain.

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