

Energy expenditure and free-living physical activity in black and white women: comparison before and after weight loss¹⁻³

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ABSTRACT

Background: The prevalence of obesity is higher in black than in white women. Differences in energy economy and physical activity may contribute to this difference.

Objective: The objective of this study was to compare free-living energy expenditure and physical activity in black and white women before and after weight loss.

Design: Participants were 18 white and 14 black women with body mass indexes (in kg/m²) between 27 and 30. Diet, without exercise, was used to achieve a weight loss of ≥ 10 kg and a body mass index < 25 . After 4 wk of energy balance in overweight and normal-weight states, body composition was assessed by using a 4-compartment model, sleeping and resting energy expenditures were assessed by using a chamber calorimeter, physiologic stress of exercise and exercise economy were measured by using standardized exercise tasks, and daily energy expenditure was assessed by using doubly labeled water.

Results: Weight loss averaged 12.8 kg. Sleeping and resting energy expenditures decreased in proportion to changes in body composition. Weight reduction significantly improved physiologic capacity for exercise in both groups of women, making it easier for them to be physically active. Black women had lower body composition-adjusted energy requirements than did white women—both before and after weight loss—during sleep (9% lower, 519 kJ/d; $P < 0.001$), at rest (14% lower, 879 kJ/d; $P < 0.001$), during exercise (6% lower; $P < 0.05$), and as a daily total (9% lower, 862 kJ/d; $P < 0.06$). By contrast, free-living physical activity was similar between the groups.

Conclusions: Weight-reduced women had metabolic rates appropriate for their body sizes. Black women had lower resting and nonresting energy requirements in both overweight and normal-weight states than did white women and did not compensate with greater physical activity, potentially predisposing them to greater weight regain. *Am J Clin Nutr* 2000;71:1138–46.

KEY WORDS Overweight, obesity, weight loss, body composition, energy expenditure, aerobic capacity, energy economy, physical activity, exercise, African American women, white women

INTRODUCTION

Obesity has reached epidemic proportions in the United States; 55% of adults are now classified as being overweight or obese

[body mass index (BMI; in kg/m²) > 25] (1). The prevalence of overweight or obesity in black women (66%) is 1.4 times that in white women (47%). The cause of the rising prevalence of obesity, particularly in the black population, is unclear, although there is increasing evidence to suggest that physical inactivity may play a major role (2). The results of several investigations suggest that physical inactivity may have a stronger influence on variations in adiposity than do dietary intake patterns (3–5).

Despite the suspected importance of sedentary behaviors as a contributing factor to long-term weight gain, it has not been established whether physical inactivity causes obesity or obesity causes physical inactivity. Cross-sectional analyses indicate that obesity is more prevalent in sedentary persons; however, the variation in adiposity that can be attributed to physical activity is small (1–16%) (5–9). In a cohort of > 9000 men and women who were followed up for 10 y in the National Health and Nutrition Examination Survey Epidemiologic Follow-up Survey, no relation was found between reported physical activity at baseline and subsequent weight gain (10). By contrast, the same investigators found that if reported physical activity increased, weight gain decreased. These inconsistent findings led the researchers to suggest that low physical activity may be a cause as well as a consequence of weight gain. Part of the problem in understanding these relations is that physical activity is difficult to assess under free-living conditions (11). In addition, relatively little research has been done in select racial groups at greatest risk of obesity and its comorbidities (12).

The purpose of this study was to determine the effect of diet-induced weight loss, without an exercise intervention, on daily

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energy expenditure (EE), exercise economy, and spontaneous free-living physical activity in overweight black and white women. We speculated that weight loss would result in improved aerobic capacity and reduced physiologic stress of exercise and, in turn, a spontaneous increase in free-living physical activity. Further, we speculated that black women would have greater energy economy (ie, lower EE relative to body composition), at rest and during exercise, in both the overweight and normal-weight states, which would account for their greater tendency to gain weight.

SUBJECTS AND METHODS

Subjects

The study subjects were black and white premenopausal women aged 20–46 y. Women with BMIs between 27 and 30 were selected to participate to increase the likelihood that their body weights could be reduced to normal within a reasonable time frame. To be included in the study, subjects had to have a family history of obesity (BMI > 27) in at least one first-degree relative, increasing the likelihood that all subjects had a familial as well as a personal predisposition to obesity. Classification of subjects as black or white was based on subjects' indication that both parents and all grandparents were of the same race. Normal glucose tolerance was documented by fasting and 2-h postprandial blood glucose concentrations after an oral glucose load. The subjects were nonsmokers and were not taking medications known to affect EE, fuel utilization, insulin concentration, heart rate, or thyroid status. The study was approved by the Institutional Review Board of the University of Alabama at Birmingham and all subjects provided informed consent.

Of 45 overweight women entering the study (23 white and 22 black), 37 (19 black and 18 white; 82%) successfully reached the goals of losing ≥ 10 kg and achieving a BMI < 25. Of these 37 subjects, 32 (18 white and 14 black) had full data sets for the major study variables in both the overweight and normal-weight states, which are included in this report. Data on underwater weighing were missing for 2 black women, which precluded use of the 4-compartment body-composition model. Hence, these 2 subjects were not included in the data analyses that were dependent on this missing measurement.

Study design and intervention

All subjects were evaluated in the overweight state and again in the normal-weight state. Study variables were assessed under weight-stable, diet-controlled conditions through the General Clinical Research Center (GCRC) at the University of Alabama at Birmingham. Initially, overweight subjects underwent a 4-wk period of outpatient weight stabilization, during which body weights were measured at the GCRC 3 times weekly during the first 2 wk and 5 times weekly during the final 2 wk. A macronutrient-controlled diet was provided during the final 2 wk; energy content was adjusted as necessary to ensure a stable body weight, defined as being within 1% of the subject's first weight at the beginning of the 4 wk. Subjects were then admitted to the GCRC for 4 d. Timing was such that all GCRC admissions were during the follicular phase of the menstrual cycle. On discharge, subjects were followed up as outpatients of the GCRC. All meals were provided by the research kitchen. The subjects were seen twice weekly by the GCRC research dietitian (BED) to measure

body weight, monitor dietary adherence, and provide meals to be eaten until the next visit. The energy content of the meals was 3350 kJ/d (800 kcal/d) in all cases.

The study diet provided a fixed proportion of carbohydrate, fat, and protein ($\approx 55\%$, 22% , and 23% , respectively) during the weight-maintenance and energy-restricted phases. No alcohol intake was permitted. The meals included Stouffer's Lean Cuisine entrées (Nestlé Food Co, Solon, OH) at lunch and dinner. The 3350-kJ (800 kcal) diet used in this study was designed to meet all nutrient requirements except energy requirements. For women who are overweight but not obese, we found previously that the 3350-kJ diet is generally well tolerated and results in a safe rate of weight loss (13, 14).

Subjects were maintained on the energy-restricted diet until they lost ≥ 10 kg and reached a normal body weight, defined as a BMI < 25. Because one of the main outcome measures of the study was spontaneous changes in free-living physical activity with weight loss, no attempt was made to alter the subjects' self-selected patterns of physical activity. On reaching a normal body weight, the subjects repeated the 4-wk protocol of weight maintenance as described above, with the exception that all foods were provided during the entire 4-wk period. Subjects were then readmitted for a second 4-d period of evaluation.

Study variables

Body composition

Body composition was determined by the 4-compartment model, as described by Baumgartner et al (15). This model assumes densities of 900 g/L for fat, 990 g/L for water, 3042 g/L for bone mineral, and 1340 g/L for the unmeasured fraction of the body composed of protein and glycogen. The model calculates percentage body fat from the independent measures of total body density (by underwater weight), the fraction of body weight that is water (by isotope dilution), and the fraction of body weight that is mineral (by dual-energy X-ray absorptiometry). Total body water was determined by isotope dilution techniques using ^2H - and ^{18}O -labeled water, as described previously (16). Briefly, during the 4-wk period of energy balance, on the morning of the 14th day before GCRC admission, a baseline urine sample (10 mL) was collected and a mixed dose of doubly labeled water was orally administered. The isotope loading dose was ≈ 0.10 g ^{18}O and 0.08 g ^2H , respectively, per kilogram of body mass. Two urine samples were obtained from the morning after dosing and the results were averaged. An additional 2 samples were obtained and the results were averaged from the morning 14 d later to increase accuracy of determining the beginning and ending enrichments. All samples were analyzed in triplicate for ^2H and ^{18}O by using the off-line zinc-reduction method (17) and the equilibration technique (18), respectively, as described previously (19). Zero-time enrichments of ^2H and ^{18}O were calculated from the intercepts of the semilogarithmic plot of isotope enrichment in urine versus time after dosing. Isotope dilution spaces were calculated by using the equation of Coward (20). Total body water was taken as the average of the ^{18}O dilution space divided by 1.01 and the ^2H dilution space divided by 1.04.

Bone mineral content and fat-free mass (FFM) were determined by dual-energy X-ray absorptiometry (DPX-L; Lunar Corp, Madison, WI). The scans were analyzed by using the DPX-L adult software, version 1.33 (Lunar Corp). The bone

mineral content was used in the calculation of percentage fat by using the 4-compartment model (15). Densitometry was determined by underwater weighing; residual volume was measured simultaneously by a closed-circuit oxygen dilution technique (21). An electronic scale was used to determine body weight immediately after the subjects had voided in the morning after an overnight fast. The CV for body density of repeat tests on separate days in our laboratory is 0.3%.

Submaximal and maximal oxygen uptake

Maximal oxygen uptake ($\dot{V}O_{2\max}$) was determined during a maximal modified Bruce graded treadmill protocol (22). Heart rate was measured with a Polar Vantage XL heart rate monitor (Polar Electro Inc, Gays Mills, WI). Oxygen consumption and carbon dioxide production were measured continuously by open-circuit spirometry and were analyzed by using a Sensormedics metabolic cart (model 2900; Yorba Linda, CA). Before each test, gas analyzers were calibrated with certified gases of known standard concentrations. Standard criteria for heart rate, respiratory quotient (RQ), and plateauing were used to ensure achievement of $\dot{V}O_{2\max}$ (23).

Submaximal $\dot{V}O_2$ was obtained in the steady state during the third and fourth minutes of 5 standardized exercise tasks. The 5 tasks, selected to reflect typical activities of adult women under free-living conditions, were level walking (0% grade, 4.8 km/h, 4 min), grade walking (2.5% grade, 4.8 km/h, 4 min), cycling (bicycle ergometer, 60 rpm, 50-W workload, 4 min), stair climbing (17.8-cm step, 60 steps/min, 4 min), and level walking carrying a loaded box (0% grade, 3.2 km/h, 4 min). The weight of the box was equivalent to 30% of the subject's 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. Exercise economy was taken as the average steady state $\dot{V}O_2$ of the 5 tasks, above sleeping $\dot{V}O_2$, and adjusted for body mass. Average $\dot{V}O_2$ for the tasks was converted to kJ/min by assuming 21 kJ (5 kcal)/L oxygen consumed per minute, as described previously (24). Exercise difficulty was evaluated as the average heart rate, ventilatory rate, and RQ responses to the 5 exercise tasks, taken during the third and fourth minutes, in the steady state. We used these methods previously to determine the relative physiologic stress during physical activities (25).

Muscle aerobic capacity (muscle oxidative phosphorylation)

^1H -magnetic resonance images (MRIs) and ^{31}P -magnetic resonance spectroscopy (MRS) data were collected on a 4.1-T whole-body imaging and spectroscopy system. The subjects were studied on 2 separate days. A series of resting calf-muscle MRIs were collected on the first day to measure maximum cross-sectional area of the gastrocnemius and soleus muscle groups. The images were collected by using a torroid coil with the following protocol: a repetition time of 1000 ms, an echo time of 14.5 ms, a 256-mm field of view, and a 5-mm slice thickness with a slice separation of 10 mm. The cross-sectional area of the gastrocnemius and soleus muscle groups was determined by manually drawing the area around both muscles from the MRIs of each slice. The maximum cross-sectional area was used in both the overweight and normal-weight states to calculate a theoretical maximum voluntary contraction (26). The cross-sectional area was subsequently used to calculate muscle aerobic

capacity. On the second day, the women performed 90-s unilateral, isometric plantar flexion exercises at 70% of theoretical maximum voluntary contraction. A 7-cm $^1\text{H}/^{31}\text{P}$ surface coil, fastened to the underbelly of the calf muscle, was used to collect 2-s time-resolved ^{31}P -MRS data during 60 s of rest, 90 s of exercise, and 7.5 min of recovery. ^{31}P -MRS data were collected by using a repetition time of 2000 ms, 4 dummy pulses, 1 average, and a half-passage adiabatic excitation pulse. The adiabatic pulse increases the ratio of signal to noise and ensures uniform excitation of the muscle volume seen by the coil. Peak areas and positions of the phosphate metabolites were found by time domain fitting by using Fitmasters (Phillips Medical Systems, Inc, Shelton, CT), as described previously (26, 27). The exercise bench and force collection devices were similar to those described previously (26, 27).

Muscle oxidative (aerobic) capacity (MAC) was estimated from the recovery rate of ADP, ie, 1/time constant of ADP recovery (28), after the 90-s exercise. The CV of this measurement is <6% (29). The concentration of ADP was calculated from the equilibrium equation of the creatine kinase reaction, assuming an unchanged total creatine pool (phosphocreatine and creatine), an equilibrium constant $K_{\text{eq}} = 1.66 \times 10^9$ (30), and a 15% unphosphorylated creatine pool at rest (26). MAC was defined by the following equation:

$$\text{MAC (mL} \cdot \text{kg}^{-1} \cdot \text{s}^{-1}) = \frac{\text{postexercise ADP recovery rate} \times (\text{muscle slice volume})}{(\text{body wt})} \quad (1)$$

where the muscle slice volume is measured at the maximum cross-sectional area. Higher values indicate greater oxidative capacity.

Sleeping and resting EE

Subjects spent 23 h in a whole-room respiration calorimeter. The design characteristics and calibration of the calorimeter were described previously (31). Oxygen consumption and carbon dioxide production were measured continuously with a magnetopneumatic differential oxygen analyzer (Magnos 4G; Hartmann & Braun, Frankfurt, Germany) and the NDIR industrial photometer differential carbon dioxide analyzer (Uras 3G; Hartmann & Braun). The calorimeter was calibrated before each subject entered the chamber. The zero calibration was carried out simultaneously for both analyzers. The full scale was set for 0–1% for the carbon dioxide analyzer and for 0–2% for the oxygen analyzer. Each subject entered the calorimeter at 0800. Although metabolic data were collected throughout the 23-h stay, only sleeping and resting metabolic data are reported here. The onset of sleep was determined to be when the lights were turned off (between 2130 and 2300 in all cases). Sleep may have included some resting awake time while the subject was falling asleep. Radar motion sensors used to detect spontaneous physical activity indicated that the subjects were inactive during the sleep period. The subjects were awakened at 0630 the next morning and resting EE was measured for 30 min. EE was calculated by using the de Weir equation (32). Sleeping and resting EE were extrapolated over 24 h and expressed as kJ/d.

Total daily energy expenditure

Free-living total daily EE was measured by the doubly labeled water technique during the 14-d period immediately preceding admission to the GCRC, during which time diet and energy balance were tightly controlled. The previously described protocol



(16) has a theoretical error of <5%. 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 described previously (33). When all samples for 2H and ^{18}O measurement were reanalyzed in 7 subjects, values of total EE were in close agreement (CV = 4.3%) (33). Carbon dioxide production rates were determined by using a fixed assumption for the dilution space ratio (1.0427) and equation R2 of Speakman et al (34). EE was calculated with equation 12 of de Weir (32) by using the food quotient value derived from the diet provided from the GCRC during the energy-balance period.

Activity-related energy expenditure and free-living physical activity

Activity-related EE (AEE) was assessed as total daily EE above basal EE, less the thermic effect of food. The thermic effect of food was estimated as 10% of total daily EE, where total EE can be assumed to equal energy intake because the subjects were in energy balance. The assumption that the thermic effect of food is constant is based, in part, on our previous findings that this effect did not change appreciably in overweight women after reduction to a normal weight (13). In addition to examining AEE as above-resting EE, we also examined AEE as above-sleeping EE, because sleeping EE encompassed a much longer period of assessment and had a 45% lower SD than did resting EE. Hence:

$$\text{AEE above rest (kJ/d)} = 0.9 \times \text{total EE} - \text{resting EE} \quad (2)$$

$$\text{AEE above sleep (kJ/d)} = 0.9 \times \text{total EE} - \text{sleeping EE} \quad (3)$$

Free-living physical activity (min/d) was derived from AEE (kJ/d) by using the Activity-Related Time Equivalent (ARTE) index, which we developed previously (35, 36).

$$\text{ARTE index (min/d)} = [\text{AEE (kJ/d)/AEC (kJ/min)}] \quad (4)$$

where AEC is the average, above-basal energy cost of performing the 5 standardized exercise tasks in the laboratory, ie, AEC (kJ/min) = [exercise EE (during 5 tasks, kJ/min) – resting or sleeping EE (kJ/min)]. Hence, the ARTE index is an index of the portion of the day the subject spends in free-living physical activities comparable with the 5 tasks performed in the laboratory. The ARTE index provides a practical measure of physical activity because it adjusts AEE for each subject's exercise economy by using AEC. This is important because we found previously that exercise economy varies as much as 42% in women (35) and because exercise economy differed significantly in the present study between black and white women. Because of the racial difference in exercise economy, the ARTE index was found to be more appropriate than the physical activity level (PAL) index (total EE/resting EE). That is, in assessing change in physical activity with weight loss, the above-sleep ARTE index showed no race effect ($P = 0.85$) whereas the PAL index showed a highly significant race effect ($P < 0.002$).

To ensure that use of the ARTE index complies with statistical principles, we examined the relation between AEE and AEC and found no significant correlation. Whereas the use of the ratio may thus seem counterintuitive, the ARTE index provides practical units for describing free-living physical activity (ie, min/d) without violating statistical principles.

Statistical analysis

Descriptive statistics, such as means \pm SDs, were calculated for all outcome variables by racial group. Scatter plots were

used to examine the changes due to weight loss by group in regard to the outcome means. Because of the possibility that the racial groups may have responded differently to weight loss, repeated-measures analysis of variance (ANOVA) was used to test the effects of weight loss and race on the outcome variables. To determine whether there were racial differences in EE measurements after adjustment for FFM and fat mass, ordinary least-squares regression models were fitted separately to overweight and normal-weight observations. The residuals of these outcome measures were then included in the repeated-measures ANOVA model to determine whether there were racial differences after adjustment for body composition. Statistical differences are reported on the basis of the ANOVAs unless otherwise stated.

RESULTS

Subject characteristics

Age and body-composition characteristics of the 32 subjects in the overweight and normal-weight states are shown in **Table 1**. The length of time required to reach the normal-weight state averaged 24 wk, at an average weight loss of 0.6 kg/wk; rates between racial groups were not significantly different. Body weight, BMI, FFM, fat mass, and percentage body fat were significantly reduced after weight loss in both racial groups (all values $P < 0.001$). Weight loss averaged 16% of baseline, or 12.8 kg (13.3 kg in white women and 12.0 kg in black women). Body fat represented 83% of weight lost (85% in white women and 79% in black women). FFM and fat mass were not significantly different between the racial groups before or after weight loss, although percentage body fat was lower in the black women in the overweight state ($P = 0.04$, t test). The difference was not significant after weight loss. There were no significant race by weight loss interactions.

Exercise performance

The results of exercise testing in the overweight and normal-weight states are shown in **Table 2**. Reduced body weight was associated with significantly improved MAC (postexercise muscle ADP recovery rate; $P < 0.01$) and whole-body aerobic capacity ($\dot{V}O_2\text{max}$; $P < 0.001$), expressed relative to body weight. $\dot{V}O_2\text{max}$ was also examined relative to FFM as a measure of aerobic fitness adjusted for metabolically active tissue. Examined this way, aerobic fitness was unchanged after weight loss. Weight loss was associated with significant reductions in exercise difficulty, measured as heart rate and ventilatory rate responses to steady state exercise (both $P < 0.001$). The absolute energy cost of steady-state exercise (as kJ/min) also fell significantly ($P < 0.001$), largely because of reduced body mass. However, weight loss did not change the subjects' exercise economy (oxygen cost of exercise relative to body mass).

Energy expenditure and free-living physical activity

Sleeping and resting EE measurements were highly correlated in the overweight state ($r = 0.87$, $P < 0.001$) and in the normal-weight state ($r = 0.73$, $P < 0.001$). Absolute values of both measures fell significantly after weight reduction ($P < 0.001$), as shown in **Table 3**. However, when adjusted for declines in FFM and fat mass, the effects of weight loss on sleeping and resting EE were not significant ($P = 0.98$ and 0.81 , respectively). Total

TABLE 1Age and body-composition characteristics of women in overweight and normal-weight energy-balanced states¹

Characteristic	Overweight state			Normal-weight state		
	All women	White women	Black women	All women	White women	Black women
Age (y)	38.0 ± 6.9	38.1 ± 6.9	37.9 ± 7.2	—	—	—
Body weight (kg)	78.8 ± 6.5	79.5 ± 4.9	78.0 ± 8.1	65.9 ± 5.6 ²	66.0 ± 4.8	65.7 ± 6.7
BMI (kg/m ²)	29.0 ± 1.9	29.1 ± 1.7	28.9 ± 2.1	24.0 ± 1.0 ²	24.0 ± 1.2	24.1 ± 0.9
Percentage body fat (%)	38.8 ± 4.2	40.1 ± 3.8	37.0 ± 4.1 ³	31.1 ± 4.5 ²	31.8 ± 4.7	30.0 ± 4.1 ³
Fat mass (kg)	30.7 ± 4.8	32.2 ± 3.9	28.5 ± 5.3	20.5 ± 4.0 ²	21.3 ± 3.8	19.5 ± 4.0
Fat-free mass (kg)	48.1 ± 3.9	48.0 ± 3.5	48.2 ± 4.7	45.3 ± 3.6 ²	45.3 ± 3.6	45.1 ± 3.9
Limb lean mass (kg)	19.1 ± 2.0	18.6 ± 1.8	20.0 ± 2.1 ³	18.4 ± 1.9 ²	17.8 ± 1.7	19.3 ± 1.8 ³
Trunk lean mass (kg)	19.8 ± 2.0	20.4 ± 1.6	19.0 ± 2.3 ³	18.9 ± 4.0 ²	20.3 ± 1.8	16.9 ± 5.4 ³

¹ $\bar{x} \pm SD$; $n = 18$ white women, 14 black women.²Significantly different from overweight state, independent of any race effect, $P < 0.05$ (no significant interaction).³Significantly different from white women, independent of any weight-loss effect, $P < 0.05$ (no significant interaction).

daily EE was not significantly different after weight loss, even after adjustment for body-composition changes ($P = 0.97$). Although the doubly labeled water method had a CV of $<5\%$ in our laboratory, it is possible that small, consistent changes in total daily EE were missed with even this small degree of methodologic error.

Free-living AEE did not change significantly after weight loss, whether expressed as above-sleep EE or above-rest EE. On the other hand, free-living physical activity increased an average of 30% (from 125 to 162 min/d; $P < 0.03$, paired t test), expressed in terms of the above-sleep ARTE index. Physical activity increased an average of 16% (from 122 to 136 min/d; NS), expressed as above-rest ARTE index. The differences were not explained by seasonal variation. Changes in the ARTE index were not influenced by racial differences in the energy cost of exercise ($P = 0.85$ for above sleep and $P = 0.65$ for above rest, ANOVA). Because the ARTE index is based on the energy cost

of performing a set of exercise tasks in the laboratory, its reliability depends in part on the self-selected, free-living physical activities being similar before and after weight loss. An examination of physical-activity questionnaires showed that two-thirds of the women chose the same types of activities in the overweight and normal-weight states and that there were no systematic changes in the nature of physical activities selected after weight loss.

Racial differences in energy expenditure and fuel utilization

For all variables examined, there were no significant differences between racial groups in responses to weight loss. In addition, there were no racial differences in fuel-utilization patterns—measured as sleeping, resting, or 24-h RQ—in the overweight or normal-weight states (Table 3). However, compared with the white women, the black women had lower body composition—adjusted EE during sleep, at rest, during steady

TABLE 2Exercise testing data measured in overweight and normal-weight, energy-balanced states¹

	Overweight state			Normal-weight state		
	All women	White women	Black women	All women	White women	Black women
Muscle aerobic capacity, ADP recovery rate (mL·kg wt ⁻¹ ·s ⁻¹ × 1000) ²	24.4 ± 10.2	24.4 ± 10.7	24.6 ± 10.0	29.5 ± 11.1 ³	30.0 ± 11.2	28.4 ± 12.2
Whole-body aerobic capacity ($\dot{V}O_2$ max, mL O ₂ ·kg body wt ⁻¹ ·min ⁻¹) ⁴	26.8 ± 2.8	27.0 ± 3.1	26.6 ± 2.4	30.4 ± 4.6 ³	31.6 ± 4.7	28.9 ± 4.0
Whole-body aerobic capacity ($\dot{V}O_2$ max, mL O ₂ ·kg FFM ⁻¹ ·min ⁻¹) ⁴	44.7 ± 4.6	45.4 ± 4.9	43.6 ± 4.1	45.1 ± 5.6	46.6 ± 5.5	43.0 ± 5.3
Exercise difficulty, mean heart rate response for 5 tasks (beats/min)	126 ± 10	125 ± 10	127 ± 11	115 ± 11 ³	115 ± 9	116 ± 14
Exercise difficulty, mean ventilatory response for 5 tasks (L/min)	28.8 ± 4.3	29.9 ± 4.2	27.2 ± 4.1 ⁵	24.5 ± 3.3 ³	25.7 ± 3.6	22.8 ± 2.0 ⁵
Exercise cost, mean for 5 exercise tasks (kJ/min)	17.2 ± 2.1	17.6 ± 2.1	16.7 ± 2.1 ⁵	14.2 ± 1.7 ³	14.6 ± 2.1	13.4 ± 0.8 ⁵
Exercise economy, submaximal $\dot{V}O_2$ for 5 exercise tasks (mL O ₂ ·kg ⁻¹ ·min ⁻¹)	10.4 ± 0.9	10.6 ± 0.9	10.2 ± 1.0 ⁵	10.3 ± 1.1	10.6 ± 1.3	9.8 ± 0.7 ⁵

¹ $\bar{x} \pm SD$; $n = 18$ white women, 14 black women.²Obtained from magnetic resonance spectroscopy in a subset of 16 women (11 white and 5 black women). A higher value indicates greater aerobic capacity (see Methods section).³Significantly different from overweight state, independent of any race effect, $P < 0.05$.⁴Expressed relative to body weight, whole-body aerobic capacity increased after weight loss, reflecting the subjects' improved physiologic capacity for day-to-day physical activities. Expressed relative to fat-free mass (FFM), aerobic capacity did not improve after weight loss, suggesting no change in aerobic capacity per unit muscle mass.⁵Significantly different from white women, independent of any weight-loss effect, $P < 0.05$.

TABLE 3Energy expenditure (EE), free-living physical activity, and respiratory quotient (RQ) measured in overweight and normal-weight energy-balanced states¹

	Overweight state			Normal-weight state		
	All women	White women	Black women	All women	White women	Black women
Sleeping EE (kJ/d)	6043 ± 611	6286 ± 427	5733 ± 682 ²	5449 ± 515 ³	5637 ± 444	5210 ± 515 ²
Resting EE (kJ/d)	6098 ± 745	6374 ± 619	5738 ± 762 ²	5809 ± 820 ³	6198 ± 757	5302 ± 607 ²
Activity-related EE, above sleep (kJ/d)	2122 ± 1343	2105 ± 1364	2186 ± 1364	2285 ± 1251	2465 ± 1013	2055 ± 1515
Activity-related EE, above rest (kJ/d)	2067 ± 1364	2021 ± 1352	2134 ± 1427	1929 ± 1289	1900 ± 1038	1963 ± 1594
Total EE, free-living (kJ/d)	9073 ± 1615	9324 ± 1649	8747 ± 1574 ⁴	8596 ± 1473	9002 ± 1101	8073 ± 1749 ⁴
Physical activity, free-living, above sleep, ARTE index (min/d) ⁵	125 ± 80	121 ± 80	130 ± 83	162 ± 91 ⁶	170 ± 73	151 ± 112
Physical activity, free-living, above rest, ARTE index (min/d) ⁵	122 ± 82	117 ± 81	129 ± 85	136 ± 99	129 ± 81	144 ± 121
Sleeping RQ	0.84 ± 0.03	0.85 ± 0.03	0.84 ± 0.03	0.85 ± 0.03	0.85 ± 0.03	0.84 ± 0.03
Resting RQ	0.87 ± 0.05	0.88 ± 0.06	0.86 ± 0.04	0.86 ± 0.04	0.86 ± 0.04	0.86 ± 0.03
24-h RQ	0.88 ± 0.03	0.88 ± 0.02	0.88 ± 0.04	0.88 ± 0.03	0.88 ± 0.03	0.87 ± 0.03

¹ $\bar{x} \pm$ SD; *n* = 18 white women, 14 black women.²Significantly different from white women, independent of fat-free mass and fat mass, *P* < 0.001.³Absolute values were significantly different from overweight state, independent of any race effects, *P* < 0.05. However, after adjustment for differences in fat-free mass and fat mass, values were not significantly different.⁴Significantly different from white women, independent of fat-free mass and fat mass, *P* < 0.06.⁵Activity-related time equivalent (ARTE) index = portion of day spent in physical activities equivalent to 5 exercise tasks performed in the laboratory.⁶Significantly different from overweight state, independent of any race effects, *P* < 0.03.

state exercise, and as a daily total. Overall, sleeping EE (adjusted for FFM and fat mass) was lower by 9%, or 519 kJ/d (124 kcal/d), in black women (*P* < 0.001): 8.5% lower in the overweight state and 9.0% lower in the normal-weight state. Resting EE (adjusted for FFM and fat mass) was lower by 14%, or 879 kJ/d (210 kcal/d), in black women (*P* < 0.001): 10.3% lower in the overweight state and 17.8% lower in the normal-weight state. Exercise energy cost (oxygen cost of steady-state exercise adjusted for body weight) was lower by 6% in black women (*P* < 0.05): 3.7% lower in the overweight state and 7.6% lower in the normal-weight state. Total daily EE (adjusted for FFM and fat mass) was lower by 9%, or 862 kJ/d (206 kcal/d), in black women (*P* < 0.06): 8.6% lower in the overweight state and 10.3% lower in the normal-weight state.

Despite similar amounts of FFM in the white and black women, the black women had significantly higher limb lean mass (ie, muscle) and significantly lower trunk lean mass (ie, muscle plus organ) (*P* < 0.05) (Table 1). This suggests that the black women may have a higher proportion of muscle and a lower proportion of more metabolically active organ tissue, which might have contributed to their lower rates of EE.

DISCUSSION

Changes in functional fitness and physical activity

This study showed that diet-induced weight reduction without an exercise intervention was associated with several changes in functional fitness that favored an increase in free-living physical activity. Relative to the new body mass in the weight-reduced state, MRS-derived muscle and whole-body aerobic capacity improved significantly. These findings agree with those of studies indicating that lean women have significantly greater aerobic capacity, adjusted for body mass (37). However, the apparent improvement in aerobic fitness associated with weight loss in our study was due to the reduction in fat mass, because $\dot{V}O_{2\max}$

did not improve relative to changes in FFM. In addition to the relatively greater aerobic capacity of the subjects, the physiologic stress of exercise fell significantly after weight loss, making it easier for the subjects to be more physically active. The study was designed to induce weight loss through an energy-restricted diet and no recommendations were made to change physical activity patterns. Whether as a result of reduced physiologic stress or as a result of personal desires to facilitate weight loss, the weight-reduced women tended to be more physically active than they had been previously.

Changes in physical activity were measured by using the ARTE index, which permitted quantitative assessment of the portion of the day subjects spent in free-living activities equivalent to 5 standardized tasks. The 5 tasks were selected to reflect the typical activities of women in free-living conditions, ie, walking level and up a grade, walking with a small load, bicycling, and climbing stairs. The ARTE index is based on a commonly used measure, AEE (38), except that adjustment is made for individual variability in the energy cost of performing typical daily tasks (35, 36). This adjustment takes into account individual differences in body mass as well as differences in energy cost of movement. The potential importance of differences in exercise economy (ie, oxygen cost of exercise relative to body mass) comes from our preliminary findings that exercise economy varies only 16% within individuals but as much as 42% between individuals (35) and that the energy cost of exercise was significantly lower in black than in white women in this study. By adjusting for differences in exercise economy, the ARTE index enabled comparisons of physical activity within a mixed racial group.

In contrast with the racial differences in exercise economy, which persisted before and after weight loss, reductions in body weight did not change exercise economy in either racial group. The results of other studies agree with this finding in that neither weight loss (39) nor weight gain (40) was reported to significantly alter an individual's exercise economy. The implication of these findings is that the energy economy of performing



physical activities is an inherent characteristic, unaffected by changes in body weight, yet variations in energy economy between individuals, especially between racial groups, may potentially affect estimates of free-living physical activity made from EE measures.

Changes in energy expenditure

We anticipated that total daily EE would fall after weight loss because of reduced body mass. In part, this expectation was based on findings of Weigle and Brunzell (41), which showed that the energy intake required for weight stability in 10 obese subjects fell after weight loss. Although these authors did not measure AEE, their data suggest that the decrease in total daily energy requirements was largely due to the reduced energy cost of moving the reduced body weight. Contrary to our expectations, the women in our study spontaneously increased their physical activity sufficiently to maintain their baseline AEEs. The net effect was that total daily EE did not fall, despite significant declines in sleeping and resting EE. The findings suggest that weight reduction does not necessarily result in reduced total EE and that if the spontaneous increase in physical activity is sustained, the women may not need to significantly reduce their energy intakes to maintain the reduced body weights.

Although absolute sleeping and resting EE fell significantly after weight loss, the new values were appropriate for the new body compositions. Data of Leibel et al (42), based on weight-stabilizing energy intake, suggest that resting EE falls in a manner disproportionate to reductions in body mass, resulting in a hypometabolic state and a predisposition to weight regain. By contrast, studies in which EE was measured directly showed that resting EE falls in proportion to changes in body mass (14, 43, 44). The results of the current study confirm and extend the results of the latter investigations by including sleeping EE and by providing further evidence that weight-reduced persons have resting energy requirements that are appropriate for their body size.

Racial differences


We found no significant differences between racial groups in responses to weight loss. In addition, we found no racial differences in fuel utilization patterns—measured as sleeping, resting, or 24-h RQ—in the overweight or normal-weight states. Weyer et al (45) also reported that black and white women had similar resting and 24-h RQs (45). In contrast with the similar fuel-utilization patterns of the 2 groups, the black women had significantly lower sleeping EEs and resting EEs than did the white women, differences that were present whether the women were in the overweight or normal-weight state. The lower EEs persisted after adjustment for any small differences in body composition, based on the 4-compartment model. The 4-compartment model, which includes bone mineral content, total body water, and body density in the analysis, is important in making racial comparisons because black women have denser bones and more bone mineral content than do white women (46). Failure to take these differences into account may result in overestimates of FFM and falsely low estimates of FFM-adjusted resting EE values. However, we did find significant racial differences in the distribution of lean tissue. Despite having amounts of total FFM similar to those of white women, the black women had a lower amount of trunk lean mass, which contains organ tissue. As we reported previously in a group of normal-weight women (47), this finding suggests that black women have a lower proportion

of metabolically active organ tissue, which may contribute to their lower sleeping and resting EEs.

With some exceptions (38, 48), other investigators also found that, relative to their white counterparts, black girls (49, 50) and black women (45, 51–55) had lower resting EEs. Our findings are supportive in that the black women in our study had overall body composition-adjusted energy requirements (ie, averages before and after weight loss) that were lower during sleep by 9% and lower at rest by 14%. Foster et al (56) reported that resting EE fell to a greater extent in black than in white women after weight-loss treatment. The results of the current study differ in that the EEs of the black women remained proportionally lower than those in the white women in the overweight state and after reduction to a normal-weight state. The reason for the difference in findings is not evident although, as the authors pointed out, they did not use the 4-compartment model of body-composition assessment and energy balance after weight loss was not documented.

The black women in our study were not only more energetically economical in the sleeping and resting states, but they also had a 6% lower average energy cost of exercise. Despite greater resting and exercise energy economy, the black women did not appear to compensate by being more physically active than were the white women. Black women have generally been found to be less physically active than white women, measured by self-report (57–59). Lower AEE was found in black than in white obese women when doubly labeled water was used (38), although potential differences in exercise economy were not considered. The apparent net effect of the greater resting and exercise energy economy of the black women in our study was that the black women had an average total daily EE that was 9% lower than that of the white women ($P < 0.06$). Weyer et al (45) recently reported that black women had lower daily EEs than did white women within the confines of a respiration chamber. Collectively, the findings suggest that black women may be inherently predisposed to more positive energy balance than are white women because of lower energy requirements uncompensated by higher amounts of physical activity.

Summary and implications

Several notable findings resulted from this study. First, decreases in sleeping and resting EE in weight-reduced (but weight-stable) black and white women were proportional to changes in body composition. This is an important finding because it suggests that weight regain is not likely to be due to disproportionately low sleeping or resting energy requirements in previously overweight persons. Second, both black and white women benefited similarly from weight loss. Weight reduction made it easier for the women to be physically active by significantly reducing the physiologic stress of exercise. Finally, compared with the white women, the black women had substantially lower energy requirements during sleep, at rest, during exercise, and throughout the day. The greater energy economy of the black women appeared to be an inherent characteristic because it persisted in both the overweight and normal-weight states. This racial difference in energy requirements may have been due, in part, to a reduced amount of metabolically active organ mass relative to muscle mass in the black women. Despite their lower energy requirements, the black women were not more physically active than were the white women. Failure to compensate with greater physical activity, lower energy intake, or both may predispose black women to greater weight regain. 

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