Effect of strength training on resting metabolic rate and physical activity: age and gender comparisons

JEFFREY T. LEMMER, FREDERICK M. IVEY, ALICE S. RYAN, GREG F. MARTEL, DIANE E. HURLBUT, JEFFREY E. METTER, JAMES L. FOZARD, JEROME L. FLEG, and BEN F. HURLEY

Department of Kinesiology, College of Health and Human Performance, University of Maryland, College Park, MD 20742; National Institute on Aging, Gerontology Research Center, Baltimore, MD 21224; Department of Physical Therapy, University of Maryland Eastern Shore, Princess Anne, MD 21853; Department of Medicine, Division of Gerontology, University of Maryland at Baltimore, Baltimore, MD 21201; and Florida Geriatric Research Program, Morton Plant Mease Health Care, Clearwater, FL 33756

ABSTRACT

LEMMER, J. T., F. M. IVEY, A. S. RYAN, G. F. MARTEL, D. E. HURLBUT, J. E. METTER, J. L. FOZARD, J. L. FLEG, and B. F. HURLEY. Effect of strength training on resting metabolic rate and physical activity: age and gender comparisons. *Med. Sci. Sports Exerc.*, Vol. 33, No. 4, 2001, pp. 532–541. **Purpose:** The purpose of this study was to compare age and gender effects of strength training (ST) on resting metabolic rate (RMR), energy expenditure of physical activity (EEPA), and body composition. **Methods:** RMR and EEPA were measured before and after 24 wk of ST in 10 young men (20-30 yr), 9 young women (20-30 yr), 11 older men (65-75 yr), and 10 older women (65-75 yr). **Results:** When all subjects were pooled together, absolute RMR significantly increased by 7% (5928 ± 1225 vs 6328 ± 1336 $kJ \cdot d^{-1}$, $P < 0.001$). Furthermore, ST increased absolute RMR by 7% in both young (6302 ± 1458 vs 6719 ± 1617 $kJ \cdot d^{-1}$, $P < 0.01$) and older (5614 ± 916 vs 5999 ± 973 $kJ \cdot d^{-1}$, $P < 0.05$) subjects, with no significant interaction between the two age groups. In contrast, there was a significant gender × time interaction ($P < 0.05$) for absolute RMR with men increasing RMR by 9% (6645 ± 1073 vs 7237 ± 1150 $kJ \cdot d^{-1}$, $P < 0.001$), whereas women showed no significant increase (5170 ± 884 vs 5366 ± 692 $kJ \cdot d^{-1}$, $P = 0.108$). When RMR was adjusted for fat-free mass (FFM) using ANCOVA, with all subjects pooled together, there was still a significant increase in RMR with ST. Additionally, there was still a gender effect ($P < 0.05$) and no significant age effect (P = NS), with only the men still showing a significant elevation in RMR. Moreover, EEPA and TEE estimated with a Tritrac accelerometer and TEE estimated by the Stanford Seven-Day Physical Activity Recall Questionnaire did not change in response to ST for any group. **Conclusions:** In conclusion, changes in absolute and relative RMR in response to ST are influenced by gender but not age. In contrast to what has been suggested previously, changes in body composition in response to ST are not due to changes in physical activity outside of training. **Key Words:** RESISTANCE TRAINING, WEIGHT TRAINING, METABOLIC EFFECTS

There is a decline in total energy expenditure (TEE) with advancing age, resulting from declines in resting metabolic rate (RMR; 17,34), energy expenditure of physical activity (EEPA; 1,16), and the thermic effect of feeding (28). These age-related changes in TEE can predispose the elderly to increased adiposity (5). Because RMR and EEPA account for ~90% of TEE, any intervention that can increase these two components of energy expenditure could be useful in restoring energy balance and preventing the increase in adiposity in the elderly. Because strength training (ST) has already been reported to be important for the prevention of sarcopenia (12,13) and falls (27) in the elderly and because of its potential to increase fat free mass (FFM), which is associated with an increase in RMR among the elderly (18), it may be an ideal intervention for increasing RMR and EEPA.

Investigators who have examined the effect of ST on RMR have shown mixed results, whether men (4,19,35,36) and women (8,25,30,32) were studied separately or combined (3,6,20). Furthermore, none of these investigations compared the gender responses of RMR with ST. Most (3,6,19,25,32), but not all studies (20,30), have demonstrated an increase in RMR in older individuals in response to ST. In contrast, investigations in young individuals have found a consistent lack of change in RMR with ST (4,8,20,35,36). The only study we could find that compared age responses of RMR to ST showed no change in RMR for either young (age = 26 yr) or older (age = 70 yr) individuals (20). However, this could be related to the fact that the subjects did not increase FFM in response to ST. No gender comparisons were reported in that study (20).

Increases in EEPA (11, 15) and TEE (6) outside of training have been reported in response to ST. These responses may depend on age (11, 15, 36) and gender (30), but currently this issue has not been addressed in the same study.

Increases in RMR and EEPA with ST could explain the decreases in fat mass that have been reported in response to

0195-9131/01/3304-0532/$3.00/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

Received for publication December 1999.
Accepted for publication July 2000.

ST (22, 23, 31–33). However, the possibility that the differences in body composition responses to ST between genders or age groups can be explained by differential responses in RMR or EEPA has not been explored. Therefore, to better understand how ST affects factors that influence body composition, the purpose of this study was to determine the effect of 24 wk of whole body ST on RMR, EEPA, and body composition in groups of young and older men and women.

METHODS

Subjects. Forty-six subjects volunteered to participate in this study after being screened via a telephone interview, medical history, physical activity questionnaire, and a thorough physical examination to rule out any obvious signs of cardiovascular, musculoskeletal, and metabolic disorders. Subjects were divided into each of the following four groups: young men (20–30 yr), young women (20–30 yr), older men (65–75 yr), and older women (65–75 yr). Subjects were nonsmokers, physically inactive for the last 6 months, and were not currently taking any cardiovascular, antihypertensive, or metabolic medications, with the exception of two older women on hormone replacement therapy and three young women on oral contraceptives.

One older man, one older woman, three young men, and one young woman dropped out of the study before completion of the study for reasons unrelated to the study. The net result was that 10 young men, 9 young women, 11 older men, and 10 older women completed the 24 wk of ST. Additionally, one older male was not included in the analysis of RMR because he was diagnosed as diabetic during the study, as well as 1 older man, 1 young man, and 2 young women were not included in this analysis due to missing RMR or body composition data. Thus, 9 young and older men, 7 young women, and 10 older women were included in the final analysis for changes in RMR in response to ST. Lastly, due to missing data at one or more time points, 3 young men, 2 young women, 1 older man, and 2 older women were not included in analysis of physical activity monitoring (PAM) and Physical Activity Recall Questionnaire (PAQ) response to training. This left 7 young men and women, 10 older men, and 8 older women.

Before their participation in this study, subjects had all the procedures and risks explained to them and signed a written informed consent. All procedures in the study were approved by the Institutional Review Boards at the University of Maryland, College Park, University of Maryland Medical School, Baltimore, and the Johns Hopkins Bayview Medical Center.

Graded exercise test (GXT) and aerobic capacity ($\dot{V}O_{2max}$). To screen for signs of coronary heart disease, to better characterize the subjects, and to confirm that they were physically inactive, a GXT and $\dot{V}O_{2max}$ test were performed using a constant speed and incremental grade treadmill exercise protocol. The GXT was performed using a standard 12-lead ECG and allowed for the assessment of any covert signs and symptoms of cardiovascular disease. The test was terminated when the subjects could no longer continue or when cardiac abnormalities were demonstrated on the ECG tracing. Concurrently with the GXT, $\dot{V}O_{2max}$ was determined from the measurement of the fractional concentrations of O_2 and CO_2. To achieve a true $\dot{V}O_{2max}$, subjects had to meet two of the following criteria: 1) plateau in $\dot{V}O_2$, 2) respiratory quotient (RER) $>$ 1.1, or 3) heart rate within 10 beats of their age predicted maximum.

Body composition. FFM and fat mass were measured using a Lunar DPXL dual energy x-ray absorptiometer (DEXA), as previously described (33). These measures were used to determine whether any training effects on the main variables were due to changes in body composition. Subjects were instructed to refrain from eating or drinking after midnight the night before the test. The DEXA was calibrated daily according to the Lunar User's Manual by using a known calibration standard. Scanning accuracy was assured by scanning a phantom of 41% oil and 59% water on a monthly basis.

Resting metabolic rate (RMR). RMR was measured as described previously (19). Concentrations of CO_2 and O_2 were measured using the ventilated hood technique with a SensorMedics V_{max} 229 metabolic system (SensorMedics Corp., Yorba Linda, CA). These gas concentrations were then used to determine 24 h RMR using the equation of Weir (9). Subjects were instructed to: 1) fast and drink only water for 12 h before testing, 2) wear comfortable clothing, and 3) report to the lab for testing at 7 a.m. Subjects were also instructed to keep physical activity to a minimum the morning of the test by dressing slowly and not taking a shower before testing. Once subjects reported for testing, the test was explained to them in detail. They were instructed to lie on the bed as still as possible for 60 min. The first 15 min were used as an acclimatization period to the testing environment. After the first 15 min, the ventilated hood was placed on the subject, and another 15-min acclimatization period allowed. During this second 15-min period, the flow rate in the ventilated hood was adjusted to maintain the fraction of expired CO_2 between 0.5 and 1.0%. The last 30 min of the test comprised the collection period. Twenty-four-hour RMR was calculated from the average of the O_2 and CO_2 concentrations collected during the last 30 min. RMR after training was conducted between 24 and 48 h after the last ST session with a mean time of ~35 h after the last training session. Both before and after training, the young women were tested during days 5–10 of the follicular phase of their menstrual cycle. If subjects had a RER greater than 0.90, they were asked to repeat the test. The temperature of the room was maintained at 26 ± 0.3°C.

Physical activity monitoring (PAM). Estimates of EEPA and TEE were obtained with a Tritrac R3D (Hemokinetics, Madison, WI) PAM. The subjects wore the PAM for 4 consecutive days, 2 weekdays, and 2 weekend days, over their nondominant hip as previously described (21,24). The nondominant hip was determined by kicking preference. To avoid any possible effects of a ST session on the PAM, subjects started wearing the PAM after their training session on Friday and did not train on the following

Monday. EEPA was calculated from the physical activity counts using proprietary formulas of Hemokinetics. TEE was calculated from the sum of the EEPA plus RMR derived from predication equations used by the Tritrac R3D. For the two time points where data were available, the estimates of physical activity and the measured RMR were combined to make a TEE score. TEE estimated by the Tritrac has been shown to have very high positive correlations with oxygen consumption during level, ambulatory walking (29), and with TEE measured in a whole room calorimeter (7). Subjects were also instructed to wear the PAM throughout the day, except when sleeping or when the instrument might get wet.

A second PAM was given to the subjects, who were instructed to place this PAM in their car during the testing period. This was done because the PAM cannot distinguish between the motion of a person or a car; thus, this second PAM allowed for the removal of any effects of vehicular travel on the subject's PAM. They were also given a diary that divided each day into 5-min segments. The subjects were instructed to record any time during the day that they did not wear the PAM, as well as any times they were in a car without the second PAM. Physical activity monitoring was conducted at the beginning, middle, and end of the whole body ST program.

Physical Activity Recall Questionnaire (PAQ). When the subjects returned the PAM after 4 d, they were administered the Stanford Seven-Day PAQ, as previously described (26). The 7-d period included the 4 days that subjects wore the PAM. The PAQ was also administered at the beginning, middle, and end of the ST program. This questionnaire provided another estimate of TEE in these subjects.

One-repetition maximum (10RM) strength test. To assess the effectiveness of the ST program, 1-RM testing was conducted before and after training. Before performing the 1-RM test, all subjects underwent six familiarization sessions on the Keiser K-300 air resistance equipment (Fresno, CA) using a light resistance. These sessions were conducted to orient the subjects to the machines and to learn proper lifting technique. Moreover, this procedure helps control for the large increases in strength that occur during the initial stages of training due to motor unit recruitment efficiency and skill acquisition, as well as to prevent injury and muscle soreness after the strength test.

The 1-RM test was performed on the following Keiser K-300 exercise equipment: leg press, leg extension, chest press, lat pull-down, shoulder press, triceps pushdown. Additionally, the biceps were tested with free weights by using a biceps curl. Leg strength on both leg machines was tested unilaterally, but the summed values were used in the analysis. In addition to the 1-RM test, a 5-RM test was performed on each of the above machines, along with the leg curl, upper back, and abdominal machines. Where appropriate, straps and/or belts were used to stabilize subjects to minimize recruitment of outside muscle groups. Strength tests were conducted by the same investigator before and after training.

Before testing, subjects performed a light 3-min warm-up on a cycle ergometer, along with supervised stretching of all the major muscle groups. The test started with a light 5-repetition warm-up, after which a resistance was chosen that was estimated to be just below the subject's 1-RM strength. The subject was instructed to lift the weight one time. If the subject was able to lift the resistance through the full range of motion, the resistance was increased and another attempt was made after a rest of ~60 s. This process was continued until the subject could no longer lift the prescribed resistance. The highest weight lifted was recorded as the 1-RM value. A similar process was conducted for the 5-RM test except that the subject was asked to lift the weight for five repetitions instead of one.

Whole body strength training (ST) program. Subjects underwent a whole body ST program for 3 $d \cdot wk^{-1}$ for an average of 24 wk. Training occurred on Keiser K-300 air-powered exercise equipment, which allows for easy modulation of the resistance within an exercise set. Training included exercises that trained all the major muscle groups of the body. Lower body exercises included unilateral leg press, leg curl, and leg extension, whereas the upper body muscle groups were trained using the chest press, lat pull-down, military press, upper back, and triceps machines. The biceps were trained unilaterally using free weight dumbbells with biceps curls, whereas the abdominal muscles were exercised with both the Keiser abdominal machine and abdominal crunches.

To minimize the risk of staleness and boredom during the study, a modified periodization program was employed during this study. The ST program was divided into two 12-wk periods. During the first 12 wk of training, subjects performed one set on all the upper body exercises and two sets of the lower body exercises. After a light warm-up at ~50% of their 1 RM, all exercises, except the biceps curls, started at a 5-RM resistance. After the fourth or fifth repetition, the resistance was reduced just enough to perform one or two additional repetitions. This process was repeated for all subsequent repetitions until 15 continuous repetitions were completed without altering the cadence of the repetitions. This procedure allowed subjects to exert near-maximal effort on all repetitions in an individualized fashion. The concentric phase of each repetition was performed in ~2 s and the eccentric in ~3 s.

During the second 12 wk of training, subjects gradually increased the resistance, after a warm-up at 50% of their 1 RM, until failure to complete a repetition occurred. This resulted in ~15 RM, including the warm-up repetitions. During the second half of training, not all exercises were performed during every training session. On Mondays, subjects performed one set of the chest press, lat pull-down, and shoulder press exercises and two sets of the three leg exercises. On Wednesdays, subjects performed one set of all upper and lower body exercises. On Fridays, the ST session consisted of one set of triceps, upper back, abdominal, and biceps curls and two sets of the leg exercises. Biceps curls and abdominal crunches were performed in the same manner as during the first 12 wk of training. Abdominal

TABLE 1. Physical characteristics in young and older men and women before and after 24 wk of strength training.

	Young Men ($N = 10$)		Young Women ($N = 9$)		Older Men ($N = 11$)		Older Women ($N = 10$)	
	Before Training	After Training	Before Training	After Training	Before Training	After Training	Before Training	After Training
Age	25 ± 2	—	26 ± 1	—	69 ± 3	—	68 ± 3	—
Height (cm)	177 ± 7	—	168 ± 4	—	173 ± 6	—	162 ± 7	—
$\dot{V}_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	43 ± 3	—	32 ± 8	—	24 ± 6	—	19 ± 3	—
Total body mass (kg)	84.4 ± 16.5	84.6 ± 15.6	64.7 ± 12.9	67.2 ± 13.7	80.8 ± 9.6	81.1 ± 9.3	69.9 ± 6.7	71.1 ± 7.2
Fat free mass (kg)	62.9 ± 7.1	64.9 ± 7.1*	42.9 ± 5.4	44.8 ± 6.2*	56.5 ± 3.4	57.5 ± 3.1*	41.1 ± 3.4	42.0 ± 3.1*
Fat mass (kg)	21.9 ± 12.0	19.7 ± 10.2	21.8 ± 7.7	22.4 ± 7.7	24.3 ± 6.9	23.6 ± 6.7	28.8 ± 4.5	29.1 ± 5.6
Percent body fat	24.2 ± 8.4	22.3 ± 7.3	32.0 ± 5.5	32.4 ± 5.4	29.5 ± 4.9	28.6 ± 5.1†	41.0 ± 3.7	40.6 ± 4.7

All values are mean ± SD.
Significantly different than before training, * $P < 0.05$, † $P = 0.051$ for older men.

crunches were performed on all training days. During both phases of training, the beginning and ending weights were recorded in order to assess the increases in muscular strength that were occurring. All subjects were given 2–3 min of rest between sets throughout the entire ST program.

All subjects were asked to maintain their current dietary habits and body weight throughout the training program. Compliance was checked with weekly measurement of body weight. All ST sessions were monitored by at least two exercise physiologists.

Statistical analysis. Age and gender responses to ST for EEPA were assessed using a 2 × 2 × 3 (age × gender × time) repeated measures ANOVA, because this variable was assessed at the beginning, middle, and end of the ST program. Age and gender responses to ST for body composition, RMR, and 1-RM strength were analyzed using a 2 × 2 × 2 (age × gender × time) repeated-measures ANOVA, because these variables were only assessed before and after training. To control for the effects of body composition, RMR was normalized for FFM using the traditional ratio method ($RMR \cdot kg\ FFM^{-1} \cdot d^{-1}$) as well as with ANCOVA. Planned comparisons were performed among individual groups using Tukey's HSD or paired *t*-tests. Correlations for the changes in RMR, EEPA, and body composition were conducted using Pearson product correlations. Unless otherwise reported, values are means ± standard deviations, and significance was set at the $P < 0.05$ level.

A *post hoc* sample size calculation was performed using an $\alpha = 0.05$ and $\beta = 0.80$ to determine the number of subjects needed to detect an effect size of 600 $kJ \cdot d^{-1}$. The results showed that 13 people per age and gender group are needed to detect this change in RMR. This effect size was chosen because it is similar to the change in RMR observed in previous ST studies (6,19), and it represents a caloric equivalent associated with ~~7 kilograms of body weight per year and is the ~amount of change in RMR in the current investigation.

RESULTS

Physical characteristics. Table 1 shows the physical characteristics for all four groups. The young women were significantly shorter than the young men ($P < 0.05$), and the older women were significantly shorter than both groups of men ($P < 0.001$). $\dot{V}O_{2max}$ values for all four groups verified that subjects in all groups were aerobically untrained. Young subjects (men and women combined) had significantly higher $\dot{V}O_{2max}$ values than the older subjects ($P < 0.05$). In addition, $\dot{V}O_{2max}$ values were significantly greater in young men compared with the young women ($P < 0.001$).

No significant age by gender or age by gender by time interactions existed among groups for total body mass. However, each of the four groups did increase FFM significantly in response to ST ($P < 0.05$). Additionally, there was an age effect ($P < 0.05$), but no gender effect for changes in FFM with ST. Young subjects showed a significantly greater increase in FFM compared with older subjects (2.0 kg vs 1.0 kg, respectively, $P < 0.05$). In contrast, changes in fat mass were effect by gender ($P < 0.05$), but not by age, with men showing a significant reduction in fat mass ($P < 0.05$), whereas women showed no change ($P = 0.451$). Additionally, there was a reduction ($P = 0.051$) in percent body fat in the older men. There was no effect of either age or gender on changes in percent body fat with ST.

1-RM strength tests. All groups showed significant increases in 1-RM strength for all exercises (Table 2, all $P < 0.05$). Changes in 1-RM strength for the leg press and chest press were analyzed separately for any effects of age and/or gender. These exercises were chosen because they employ the largest muscle groups in the lower and upper body, respectively. Changes in leg press 1-RM strength showed significant increases for both age ($P < 0.001$) and gender ($P < 0.001$) groups. However, combined young subjects increased 1-RM strength greater than older subjects (31% vs 23%, $P < 0.001$). Similarly, the chest press showed significant increases with ST, but in contrast to the changes in leg press strength, these changes showed an effect of age ($P < 0.05$) and gender ($P < 0.05$). Young subjects increased chest press 1-RM strength significantly more (28%) than older subjects (16%; $P < 0.001$), and men increased significantly more than women, despite lower relative changes in men (21% vs 23%; $P < 0.01$). The changes in 1-RM strength being influenced by age was in accordance with the finding of a previous study from our lab using a unilateral knee extension ST program (14); however, the effect of gender in response to whole body ST in the present was a new finding.

RMR. Changes in absolute RMR in response to the ST program are presented in Table 3 and Figure 1. When all subjects were pooled together, there was a 7% increase in

TABLE 2. Changes in 1 RM strength in young and older men and women with 24 wk of ST.

	Young Men (N = 10)		**Young Women (N = 9)**		**Older Men (N = 11)**		**Older Women (N = 10)**	
	Before Training	**After Training**	**Before Training**	**After Training**	**Before Training**	**After Training**	**Before Training**	**After Training**
Chest press (kg)	72 ± 17	89 ± 23†	36 ± 4	47 ± 8†	46 ± 6	54 ± 7†	27 ± 5	31 ± 4†
Lat Pull-down (kg)	75 ± 18	92 ± 21†	36 ± 8	45 ± 8†	51 ± 4	63 ± 8†	29 ± 5	36 ± 5†
Shoulder press (kg)	57 ± 14	71 ± 20†	33 ± 4	37 ± 5†	38 ± 7	45 ± 7†	26 ± 3	28 ± 4*
Triceps push-down (kg)	81 ± 25	110 ± 33†	44 ± 8	58 ± 12†	52 ± 8	68 ± 10†	31 ± 6	39 ± 5†
Biceps curl (kg)	35 ± 10	47 ± 12†	14 ± 4	24 ± 4†	27 ± 5	35 ± 4†	15 ± 2	20 ± 3†
Leg extension (kg)	160 ± 53	200 ± 56†	146 ± 33	185 ± 48†	157 ± 24	203 ± 30†	92 ± 21	117 ± 25†
Leg press (kg)	697 ± 84	871 ± 112†	439 ± 100	600 ± 153	537 ± 77	635 ± 78†	350 ± 92	446 ± 83†

All values are mean ± SD
Significantly different than before training, * $P < 0.05$, † $P < 0.01$.

absolute RMR in response to ST (5928 ± 1226 vs 6328 ± 1337 kJ·d^{-1}, $P < 0.001$) with no interaction between the four individual groups. When changes in absolute RMR were examined for the effects of age and gender, there was a training by gender interaction ($P < 0.05$) but no training by age ($P = 0.966$) or training by age by gender effect ($P = 0.582$). Planned comparisons showed that when both young and older subjects were pooled across gender absolute RMR increased by 7% for each group (6302 ± 1458 vs 6719 ± 1617 kJ·d^{-1} for the young; 5614 ± 916 vs 5999 ± 973 kJ·d^{-1} for the older subjects, $P < 0.01$ for both groups). In contrast, there was an effect of gender on absolute RMR ($P < 0.05$), which was the result of a 9% increase in absolute RMR for the men (6645 ± 1073 vs 7237 ± 1150 kJ·d^{-1}, $P < 0.001$), compared with no significant increases in women (5170 ± 884 vs 5366 ± 692 kJ·d^{-1}, $P = 0.108$).

When groups were analyzed individually, significant increases in absolute RMR were also observed in the young men (7091 ± 1316 vs 7726 ± 1386 kJ·d^{-1}, $P < 0.01$), and older men (6198 ± 517 vs 6747 ± 593 kJ·d^{-1}, $P < 0.01$). These changes represent increases of 9% for each group. Neither young women (5287 ± 932 vs 5423 ± 703 kJ·d^{-1}, $P = 0.362$) nor older women (5088 ± 890 vs 5325 ± 719 kJ·d^{-1}, $P = 0.209$) showed significant increases in absolute or relative RMR in response to ST.

When RMR was corrected for FFM (adjusted RMR) in an ANCOVA model, there was still a significant increase in RMR in response to ST for all groups combined ($P < 0.05$), but there were no significant interactions among the groups. When the adjusted RMR was analyzed for effects of age and gender, there was still a significant gender × time interaction ($P < 0.05$). As with the absolute RMR, the adjusted RMR was significantly elevated in men in response to ST ($P < 0.05$), whereas women showed no significant increase. In addition, the individual groups of young and older women showed no significant increase in RMR. However, in contrast to the change in absolute RMR with ST, neither individual group of young or older men showed an increase in adjusted RMR.

When RMR was expressed in the traditional ratio method of kJ·kg^{-1} of FFM·d^{-1} (Table 3), there was a significant increase in RMR for all groups combined ($P < 0.05$), with no interaction among any of the four groups. Additionally, there was no interaction between age or gender with time for changes in RMR when expressed as a ratio of RMR to FFM (kJ·kg^{-1} of FFM·day^{-1}).

There was a trend for a differential change in RER between the genders ($P = 0.06$) but no effect of age. This trend was the result of a nonsignificant decline in RER in men (0.87 ± 0.04 vs 0.84 ± 0.06) and nonsignificant increase in RER in women (0.86 ± 0.06 vs 0.88 ± 0.06) as a result of ST.

A significant relationship was demonstrated between training-induced changes in absolute RMR and FFM for men (r = 0.511, $P < 0.05$) but not for women (r = 0.016, $P = 0.95$). This differential association between changes in FFM and RMR for men and women, along with our previous finding that absolute and relative RMR changed only for the men in response to ST, even though both men and women showed similar increases in FFM, indicates a clear

TABLE 3. Changes in resting metabolic rate (RMR) in young and older men and women with 24 wk of ST.

	Young Men (N = 9)		**Young Women (N = 7)**		**Older Men (N = 9)**		**Older Women (N = 10)**	
	Before Training	**After Training**	**Before Training**	**After Training**	**Before Training**	**After Training**	**Before Training**	**After Training**
RMR								
kJ · d^{-1}	7091 ± 1316	7726 ± 1386†	5287 ± 932	5423 ± 703	6198 ± 517	6747 ± 593*	5088 ± 890	5325 ± 719
kJ · kg FFM · d^{-1}	112 ± 9	118 ± 10*	124 ± 11	123 ± 11	110 ± 6	118 ± 7*	125 ± 24	127 ± 18
RER	0.87 ± 0.051	0.83 ± 0.082	0.87 ± 0.067	0.88 ± 0.065	0.88 ± 0.028	0.86 ± 0.028	0.86 ± 0.055	0.88 ± 0.065
	Young Men and Women (N = 16)		**Older Men and Women (N = 19)**		**Young and Older Men (N = 18)**		**Young and Older Women (N = 17)**	
RMR								
kJ · d^{-1}	6302 ± 1,458	6719 ± 1,617†	5614 ± 916	5999 ± 973†	6645 ± 1073	7237 ± 1150†‡	5170 ± 884	5366 ± 692
kJ · kg FFM · d^{-1}	118 ± 12	121 ± 11	118 ± 19	123 ± 15	111 ± 8	118 ± 8†	125 ± 20	125 ± 16
RER	0.87 ± 0.057	0.85 ± 0.079	0.87 ± 0.045	0.87 ± 0.050	0.88 ± 0.041	0.84 ± 0.062	0.86 ± 0.059	0.88 ± 0.063

All values are mean ± SD.
Significantly different from before training, * $P < 0.05$, † $P < 0.01$.
‡ After controlling for FFM, RMR was significantly greater than baseline at $P < 0.05$.

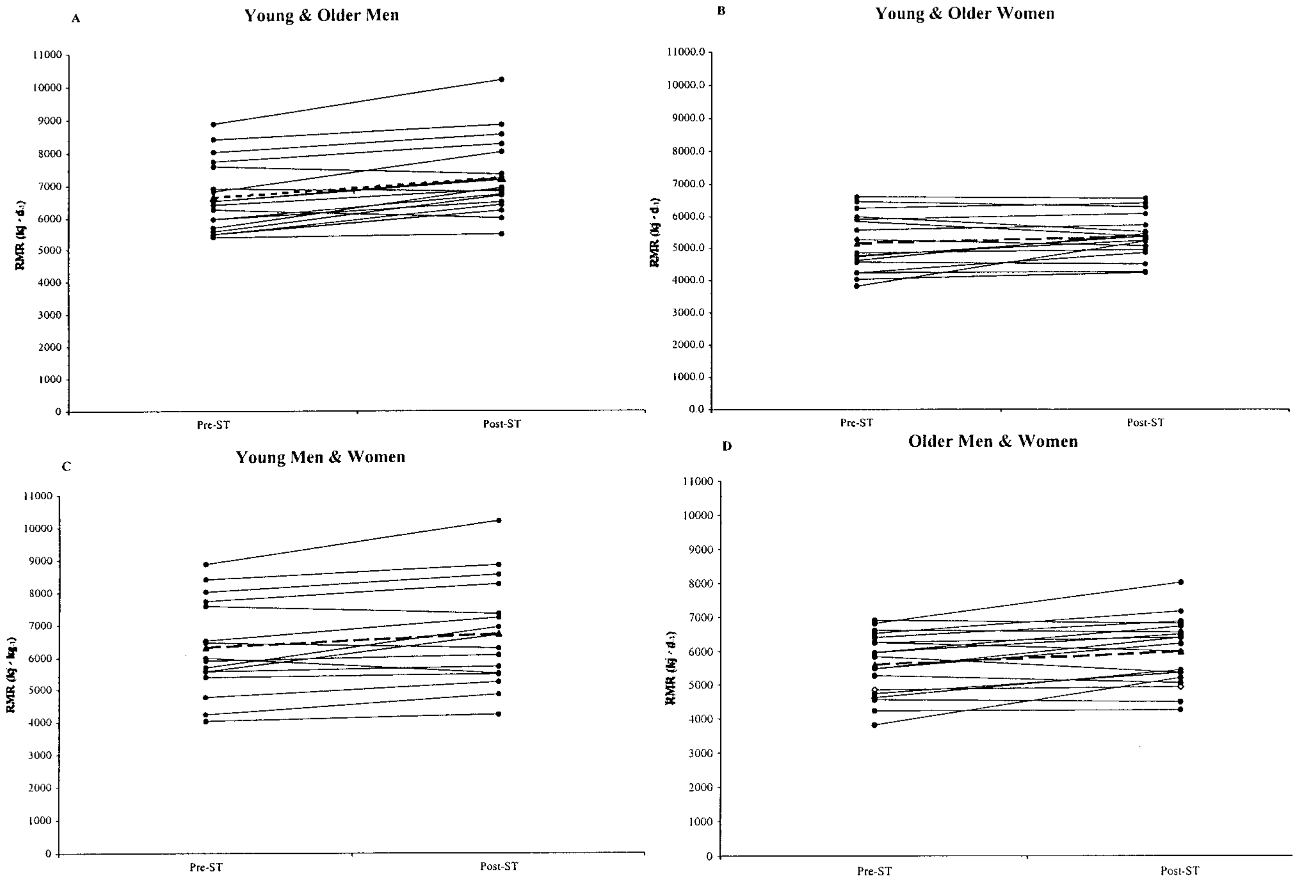

FIGURE 1—Change in RMR in response to 24 wk of whole-body ST with subjects grouped as men (A), women (B), young (C), and older (D). ***Solid lines*** **represent the change in RMR for each individual subject, whereas the** ***dashed line*** **represents the mean change in RMR for each group.**

difference in gender responses for RMR in response to ST. When all subjects were pooled together, changes in RER were positively correlated with changes in fat mass (r = 0.430, $P < 0.01$) and percent body fat (r = 0.457, $P < 0.01$). When these correlations were analyzed by age and gender, RER remained significantly correlated to changes in fat mass for young subjects (r = 0.530, $P < 0.05$) and for men (r = 0.492, $P < 0.05$). Additionally, changes in RER were significantly correlated to changes in percent body fat in young subjects (r = 0.623, $P < 0.01$) and in men (r = 0.617, $P < 0.05$).

PAM. Changes in the estimated measures of EEPA and TEE measured with the PAM are presented in Table 4. In response to the 24 wk of whole body ST, there was no change in EEPA outside of the ST sessions whether all subjects were pooled together or analyzed as separate age and gender groups. In addition, there was no interaction between age and gender for changes in EEPA and TEE in response to ST. Estimated TEE from the PAM also did not change significantly in response to ST program for all groups together or for any group individually. When estimates of physical activity from the PAM were combined with the measured RMR and an index of TEE created, there was still no significant change in TEE estimated from the PAM from before to after training (data not shown). In addition, there was no change in TEE as estimated from the PAM when subjects were pooled together by age and gender. Changes in physical activity and TEE were not significantly correlated to any of the changes in body composition.

PAQ. The Stanford Seven-Day PAQ also did not reveal any changes in TEE in response to ST when all subjects were pooled together, as well as when analyzed by individual groups or by age and gender (Table 4). Changes in TEE as assessed by the Stanford Seven-Day PAQ were not significantly correlated to any of the changes in body composition.

EEPA estimated from the PAM was significantly correlated to the TEE estimated from the PAQ at baseline (r = 0.542, $P < 0.001$) and after training (r = 0.416, $P < 0.05$). TEE estimated from the PAM was significantly correlated with TEE estimated by the PAQ at baseline (r = 0.710, $P < 0.001$), mid-training (r = 0.623, $P < 0.001$), and after training (r = 0.577, $P < 0.001$. These correlation suggest that the two methods of estimating energy expenditure are assessing similar outcomes.

DISCUSSION

The results of this study show for the first time that changes in RMR in response to ST is affected by gender and not by age. When young and older men were pooled as a group, there was a significant increase in RMR with training, whereas young and older women showed no change. In addition, there was an increase in RMR in response to ST

TABLE 4. Changes in physical activity in young and older men and women with ST.

	Accelerometer			Questionnaire
	Physical Activity (kJ · d^{-1})	Physical Activity (counts · d^{-1})	Total Energy Expenditure (kJ · d^{-1})	Total Energy Expenditure (kJ · d^{-1})
Young men (N = 7)				
Before training	2213 ± 733	177,747 ± 46,635	10,801 ± 1,640	13,123 ± 3,587
Mid training	1959 ± 997	154,708 ± 70,905	10,667 ± 1,658	12,861 ± 2,325
After training	2239 ± 1004	170,831 ± 46,793	10,947 ± 2,005	12,886 ± 2,761
Young women (N = 7)				
Before training	1577 ± 941	161,952 ± 75,021	8177 ± 1336	10,328 ± 2,445
Mid training	1413 ± 482	146,477 ± 50,553	8081 ± 815	10,183 ± 1,540
After training	1366 ± 472	140,031 ± 42,881	8060 ± 898	11,072 ± 2,882
Older men (N = 10)				
Before training	1657 ± 537	136,064 ± 49,983	8875 ± 671	12,686 ± 2,277
Mid training	1457 ± 564	117,641 ± 48,523	8764 ± 889	13,061 ± 2,437
After training	1544 ± 565	129,080 ± 49,968	8723 ± 972	12,357 ± 1,733
Older women (N = 8)				
Before training	1174 ± 249	113,620 ± 24,442	7085 ± 365	11,024 ± 2,240
Mid training	1157 ± 231	109,667 ± 24,113	7128 ± 363	11,164 ± 1,467
After training	1036 ± 311	99,319 ± 30,081	6977 ± 451	11,767 ± 2,563

All values are means ± SD.
None of these differences were significant.

when all groups were combined. Furthermore, when RMR was corrected for FFM there was still a significant gender effect, with men having a ST-induced significant increase in RMR, whereas women still showed no change. Our finding that older men and women, when pooled together, can increase RMR in response to ST is not new (3,6,19,25,32), but the finding that this change is not significantly different from young men and women, pooled together, has not been reported previously. In addition, contrary to what has been suggested previously (11,15), ST does not cause an increase in EEPA outside of the training sessions in healthy, sedentary young and older men and women.

The finding that an increase in RMR is still present in men after correcting for FFM is in agreement with previous reports by Pratley et al. (19) and Campbell et al. (6) but in opposition to the finding of Ryan et al. (25) in women. The elevation in RMR above that which can be explained by increased FFM in men suggests that there is an increase in the metabolic activity of FFM after ST in men. However, this finding is no longer present after correcting for FFM when young and older men are analyzed separately, perhaps due to the reduced statistical power from the smaller sample size in each group. One possible explanation for ST-induced elevations in RMR above that which can be accounted for by changes in FFM is an increase in sympathetic nervous system activity (19).

The result that young and older men significantly increased RMR by 9% (592 kJ·d^{-1}), whereas young and older women showed no significant increase in response to ST is a new finding. The lack of a change in RMR for the women is consistent with previous studies in both young (8) and older (30) women but is in contrast to other studies in women (25,32). Nevertheless, because both men and women had similar increases in FFM (~1.5 and 1.4 kg), it was expected that both men and women would have significant increases in RMR. However, this was not what we found. One possible explanation for RMR increasing in men, but not in women, are differences in sympathetic nervous system activity responses to ST. Pratley et al. (19) attributed their increase in RMR above that which could be accounted for by increased FFM to an increase in sympathetic nervous system activity (19), which conversely was not demonstrated by Ryan et al. (25). Unfortunately, sympathetic nervous system activity was not measured in the current study. This difference between men and women is consistent with previous studies that have shown RMR is lower in women compared with men, even after correcting for FFM, and may be related to differences in sympathetic nervous system activity (2,10,18).

Our finding that young men and women, when pooled together, can increase absolute RMR in response to ST is in opposition with previous findings in this age group (4,8,20,35,36). The discrepancy between the present study and previous studies could be related to differential changes in FFM between studies, because the increase in RMR in these young men and women disappeared after correcting for changes in FFM. The current study showed an increase in FFM of ~2 kg in these young men and women, which is similar to changes in some studies involving young men and women (4,8,36) but is greater than changes in others (20,35). This could indicate that the change in RMR in young men and women, when pooled together, isn't related to changes in FFM but to some underlying metabolic adaptation. However, even though the young men showed similar increases in FFM as the young women in the present study, the significant 7% increase (417 kJ·d^{-1}) in absolute RMR for young men and women combined resulted largely from the significant 9% increase (635 kJ·d^{-1}) in the young men. When examined separately, the change value for young women did not reach significance for absolute and relative RMR, whereas the young men showed a significant elevation in absolute, but not relative RMR, further indicating that the increase in the pooled young group was probably the result of the increased RMR in the young men. Additionally, the absence of a significant increase in relative RMR in the young men indicates that the increase in absolute RMR is only related to the increased FFM in the young men after training.

Although the lack of an increase in absolute RMR in the young women is consistent with a previous report (8), the increase in RMR for the young men conflicts with previous studies (4,35,36). However, this study was longer than any of these previous studies, thus, a training period of at least 24 wk might be needed to induce an elevation in RMR in young men. Why this longer period of training is needed to induce an increase in young men is not readily apparent. However, this study was designed such that during the initial 12 wk of training each repetition was close to a maximal effort (initial resistance 5 RM and then 1–2 repetitions to failure with decreasing weight until a total of 15 repetitions was performed, followed by 12 wk of increasing resistance at each repetition until a 15 RM is completed. The previous studies in young men used three sets varying from 6 to 12 RM (4), three sets of 15 RM (36), and resistance dependent on body weight (35). Thus, it is unclear whether the level of resistance training volume or other factors might explain the difference observed between the present study and others. It does appear, however, that the elevation in RMR in young men is the result of increased muscle mass, because the increased RMR was no longer present after controlling for FFM.

Factors were examined that might explain why some people increased RMR (responders) and others showed no change or a decrease in RMR (nonresponders). When men were pooled across both age groups, two of the three who showed a decrease in RMR also showed a decline in FFM. All three of these men showed a decrease in total body mass (TBM), which is known to suppress RMR. This is in contrast to the men who increased RMR, where only 1 of 15 showed a decrease in FFM, and 3 of 15 showed a reduction in TBM. In the women, there was a similar trend for changes in body composition in responders and nonresponders. For example, 4 of 6 women who experienced a decrease in RMR showed a decrease in either FFM or TBM, whereas only 3 of 11 women who increased RMR in response to ST also showed a decrease in either FFM or TBM. Furthermore, the overall correlation between absolute RMR and FFM for women did not reach statistical significance.

One of the aims of this study was to determine whether any of the changes in metabolic parameters related to RMR were associated with changes in body composition. The only variable that showed any significant relationship to changes in body composition with ST was the change in RER. Interestingly, the young and older men pooled together were the only group to show a significant decrease in fat mass, as well as a trend for a decline in RER. The positive correlations between reductions in RER and fat mass and percent body fat in conjunction with the significant reductions in fat mass and the trend for a reduction in RER in the young and older men suggests that ST may decrease fat mass through increased fat utilization. This finding in men extends the results of previous studies that show that ST can have a positive effect on body composition (31–33) and that ST-induced reductions in fat mass may be related to increases in fat oxidation (32).

The finding that ST does not enhance EEPA in the young men and women is consistent with previous findings in young men (36) and some previous studies in older men and women (6,30) but conflicts with others (11,15). Campbell et al. (6) showed an increase in TEE in response to ST, but this increase was the result of an increased RMR and the energy cost of the ST sessions, suggesting that EEPA outside of the ST sessions did not change with training. It is not clear why the present study did not show an increase in EEPA outside of the ST sessions, whereas two other studies did (11,15). However, the older subjects in the study by Nelson et al. (15) were of a slightly younger age than the men and women in the current study, and the training program was 52 wk in duration compared with the 24 wk in the current study. Therefore, it is possible that a training program longer than 24 wk is needed to elicit increases in EEPA outside of the ST sessions in healthy, elderly individuals. The difference between this study and that of Fiatarone et al. (11) probably results from the use of frail subjects in this previous study. Because their subjects were extremely frail, the increase in muscular strength with ST could have allowed the subjects to ambulate more freely, leading to an increase in EEPA outside of the training sessions. This was supported by their findings that several subjects went from wheelchairs to walkers, walkers to canes, and canes to no assistance. In the current study, the subjects were inactive, but free-living, so any increases in strength might not have translated into increased physical activity, because all subjects were very mobile at the start of the study.

The correlations between EEPA estimated by PAM and TEE estimated by PAQ showed moderate but significant relationships before and after training, and no relationship at mid training. The lack of a stronger correlation is probably due to the fact that this analysis was correlating slightly different measures of energy expenditure (physical activity vs TEE), whereas a much stronger significant relationship was observed at all time points for TEE estimated by PAQ vs PAM. However, the correlations between these two measures were probably slightly underestimated due to the TEE from the PAQ being based on 7 d of physical activity, whereas the TEE from the PAM was estimated from 4 d of physical activity. Nevertheless, the significant relationships between the two instruments further support our finding that physical activity didn’t change in response to ST, because both instruments showed no change with training.

In conclusion, this study showed for the first time that changes in RMR in response to ST are influenced by gender but not age. The similar RMR response between the young and older subjects was related to similar increases in FFM in response to training. Additionally, this study showed that young and older men and women do not show an increase in EEPA outside of the ST sessions. This suggests that changes in body composition reported in previous studies are most likely related to metabolic adaptations in response to the ST program itself. Furthermore, the significant correlation between changes in RER and changes in fat mass and percent body fat in men, in conjunction with a significant reduction in fat mass and a trend for a reduction in

RER, provides further support for the hypothesis that ST might induce changes in fat mass through increased fat oxidation.

We would like to thank Dr. Barbara Albert for performing the physical exams and GXT screening of our subjects, as well as Dorothy O'Donnell for her help in recruiting the subjects and her preparation of this manuscript. We would also like to thank the staff of the University of Maryland Wellness Research Center for the use of their facilities during the course of this project. Additional thanks to Brian Tracy, Ken Wilund, Autumn Powell, Bob Harper, Kevin Cross, Dan Barlow, Brennan Harmon, Tanya Limpakan, and Carl Litton for their help in training our subjects. Lastly, we want to thank all the subjects who participated in this project and without whose help we could have not completed this work.

This research project was supported by the National Institutes of Health contract #1AG42148 and Research Service Award 2T32AG00219.

Address for correspondence: Ben Hurley, Ph.D., Dept. of Kinesiology, University of Maryland, College Park, MD 20742; E-mail: bh24@umail.umd.edu.

REFERENCES

1. Anderssen, N., D. R. Jacobs, Jr., S. Sidney, et al. Change and secular trends in physical activity patterns in young adults: a seven-year longitudinal follow-up in the coronary artery risk development in young adults study (CARDIA). *Am. J. Epidemiol.* 143:351–362, 1996.
2. Arciero, P. J., M. I. Goran, and E. T. Poehlman. Resting metabolic rate is lower in women than in men. *J. Appl. Physiol.* 75:2514–2520, 1993.
3. Ballor, D. L., J. R. Harvey-Berino, P. A. Ades, J. Cryan, and J. Calles-Escandon. Contrasting effects of resistance and aerobic training on body composition and metabolism after diet-induced weight loss. *Metabolism* 45:179–183, 1996.
4. Broeder, C. E., K. A. Burrhus, L. S. Svanevik, and J. H. Wilmore. The effects of either high-intensity resistance or endurance training on RMR. *Am. J. Clin. Nutr.* 55:802–810, 1992.
5. Calles-Escandon, J., P. J. Arciero, A. W. Gardner, C. Bauman, and E. T. Poehlman. Basal fat oxidation decreases with aging in women. *J. Appl. Physiol.* 78:266–271, 1995.
6. Campbell, W. W., M. C. Crim, V. R. Young, and W. J. Evans. Increased energy requirements and changes in body composition with resistance training in older adults. *Am. J. Clin. Nutr.* 60:167–175, 1994.
7. Chen, K. Y., and M. Sun. Improving energy expenditure estimation by using a triaxial accelerometer. *J. Appl. Physiol.* 83:2112–2122, 1997.
8. Cullinen, K., and M. Caldwell. Weight training increases fat-free mass and strength in untrained young women. *J. Am. Diet. Assoc.* 98:414–418, 1998.
9. De V. Weir, J. B. New methods for calculating metabolic rate with special reference to protein metabolism. *J. Physiol. (Lond.)* 109: 1–9, 1949.
10. Ferraro, R., S. Lillioja, A.-M. Fontvieille, R. Rising, C. Bogardus, and E. Ravussin. Lower sedentary metabolic rate in women compared with men. *J. Clin. Invest.* 90:780–784, 1992.
11. Fiatarone, M., E. F. O'Neill, N. D. Ryan, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. *N. Engl. J. Med.* 330:1769–1775, 1994.
12. Frontera, W. R., C. N. Meredith, K. P. O'Reilly, H. G. Knuttgen, and W. J. Evans. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J. Appl. Physiol.* 64:1038–1044, 1988.
13. Hurley, B. F., R. A. Redmond, R. E. Pratley, M. S. Trueth, M. A. Rogers, and A. P. Goldberg. Effects of strength training on muscle hypertrophy and muscle cell disruption. *Int. J. Sports Med.* 16:378–384, 1995.
14. Lemmer, J. T., D. E. Hurlbut, G. F. Martel, et al. Age and gender responses to strength training and detraining. *Med. Sci. Sports Exerc.* 32:1505–1512, 2000.
15. Nelson, M. E., M. A. Fiatarone, C. M. Morganti, I. Trice, R. A. Greenberg, and W. J. Evans. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. *JAMA* 272:1909–1914, 1994.
16. Pannemans, D. L. E., and K. R. Westerterp. Energy expenditure, physical activity and basal metabolic rate of elderly subjects. *Br. J. Nutr.* 73:571–581, 1995.
17. Poehlman, E. T., M. I. Goran, A. W. Gardner, et al. Determinants of decline in resting metabolic rate in aging females. *Am. J. Physiol.* 264:E450–E455, 1993.
18. Poehlman, E. T., M. J. Toth, P. A. Ades, and J. Calles-Escandon. Gender differences in resting metabolic rate and noradrenaline kinetics in older individuals. *Eur. J. Clin. Invest.* 27:23–28, 1997.
19. Pratley, R., B. Nicklas, M. Rubin, et al. Strength training increases resting metabolic rate and norepinephrine levels in healthy 50- to 65-yr-old men. *J. Appl. Physiol.* 76:133–137, 1994.
20. Rall, L. C., S. N. Meydani, J. J. Kehayias, B. Dawson-Hughes, and R. Roubenoff. The effect progressive resistance training in rheumatoid arthritis: increased strength with changes in energy balance or body composition. *Arthritis Rheum.* 39:415–426, 1996.
21. Richardson, M. T., A. S. Leon, D. R. Jacobs, Jr., B. E. Ainsworth, and R. Serfass. Ability of the Caltrac accelerometer to assess daily physical activity levels. *J. Cardpulm. Rehabil.* 15:107–113, 1995.
22. Ross, R., H. Pedwell, and J. Rissanen. Effects of energy restriction and exercise on skeletal muscle and adipose tissue in women as measured by magnetic resonance imaging (MRI). *Am. J. Clin. Nutr.* 61:1179–1185, 1995.
23. Ross, R., and J. Rissanen. Mobilization of visceral and subcutaneous adipose tissue in response to energy restriction and exercise. *Am. J. Clin. Nutr.* 60:695–703, 1994.
24. Rutter, S. Comparison of energy expenditure in normal-weight and overweight women using the Caltrac personal activity computer. *Int. J. Eat. Disord.* 15:37–42, 1994.
25. Ryan, A. S., R. E. Pratley, D. Elahi, and A. P. Goldberg. Resistive training increases fat-free mass and maintains resting metabolic rate despite weight loss in postmenopausal women. *J. Appl. Physiol.* 79:818–823, 1995.
26. Sallis, J. F., W. L. Haskell, P. D. Wood, et al. Physical activity assessment methodology in the five-cities project. *Am. J. Epidemiol.* 121:91–106, 1985.
27. Sauvage, L. R., B. M. Myklebust, J. Crow-Pan, et al. A clinical trial of strengthening and aerobic exercise to improve gait and balance in elderly male nursing home residents. *Am. J. Phys. Med.* 71:333–342, 1992.
28. Schwartz, R. S., L. F. Jaeger, and R. C. Veith. The thermic effect of feeding in older men: the importance of the sympathetic nervous system. *Metabolism* 39:733–737, 1990.
29. Sherman, W. M., D. M. Morris, T. E. Kirby, et al. Evaluation of a commercial accelerometer (Tritrac-R3D) to measure energy expenditure during ambulation. *Int. J. Sports Med.* 19:43–47, 1997.
30. Taaffe, D. R., L. Pruitt, J. Reim, G. Butterfield, and R. Marcus. Effect of sustained resistance training on basal metabolic rate in older women. *J. Am. Geriatr. Soc.* 43:465–471, 1995.
31. Treuth, M. S., G. R. Hunter, T. Kekes-Szabo, R. L. Weinser, M. I. Goran, and L. Berland. Reduction in intra-abdominal adipose tissue after strength training in older women. *J. Appl. Physiol.* 78:1425–1431, 1995.
32. Treuth, M. S., G. R. Hunter, R. L. Weinser, and S. H. Kell. Energy expenditure and substrate utilization in older women after strength training: 24-h calorimeter results. *J. Appl. Physiol.* 78: 2140–2146, 1995.

33. Treuth, M. S., A. S. Ryan, R. E. Pratley, et al. Effects of strength on training on total and regional body composition in older men. *J. Appl. Physiol.* 77:614–620, 1994.
34. Tzankoff, S. P., and A. H. Norris. Longitudinal changes in basal metabolism in man. *J. Appl. Physiol.* 45:536–539, 1978.
35. van Etten, L. M., K. R. Westerterp, and F. T. Verstappen. Effect of weight-training on energy expenditure and substrate utilization during sleep. *Med. Sci. Sports Exerc.* 27:188–93, 1995.
36. van Etten, L. M. L. A., K. R. Westerterp, F. T. J. Verstappen, B. J. B. Boon, and W. H. M. Saris. Effect of an 18-wk weight training program on energy expenditure and physical activity. *J. Appl. Physiol.* 82:289–304, 1997.