Effects of Endurance and Resistance Training on Total Daily Energy Expenditure in Young Women: A Controlled Randomized Trial

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There exists considerable controversy regarding the impact of different modes of exercise training on total daily energy expenditure (TEE). To examine this question, young, nonobese women were randomly assigned to a supervised 6-month program of endurance training, resistance training, or control condition. TEE was measured before and 10 d after a 6-month exercise program was completed with doubly labeled water. Body composition was determined from dual energy x-ray absorptiometry, maximum aerobic capacity from a treadmill test to exhaustion, and muscular strength from one-repetition maximum tests. Results showed that body composition did not change in endurance-trained women, but maximum aerobic capacity increased by 18%. Resistance-trained women increased muscular strength and fat-free mass (1.3 kg). TEE did not significantly change when measured subsequent to the endurance or resistance training programs. Absolute resting metabolic rate increased in resistance-trained women but not when adjusted for fat-free mass. No change in physical activity energy expenditure was found in any of the groups. These results suggest that endurance and resistance training does not chronically alter TEE in free-living young women. Thus, the energy-enhancing benefits of exercise training are primarily derived from the direct energy cost of exercise and not from a chronic elevation in daily energy expenditure in young, nonobese women. (J Clin Endocrinol Metab 87: 1004–1009, 2002)

REGULAR PHYSICAL ACTIVITY is viewed as an adjunct total body weight control by facilitating the matching between daily energy expenditure (TEE) and daily energy intake that favors a state of energy balance (1, 2). It is clear that energy expenditure is transiently increased due to the direct and short-term carryover effects of physical exercise (3). However, a body of literature has accumulated that suggests that exercise training (endurance and/or resistance training) may chronically increase energy expenditure independently of the direct energy cost of the training program (4, 5). The additional increase in energy expenditure may be mediated by several mechanisms, including an increase in resting metabolic rate (RMR) (6–24), an increase in physical activity energy expenditure (PAEE) (24–26), and/or an increase in sympathetic nervous system activity (10, 11). This notion remains controversial, however, because other investigators have found no effect of endurance or resistance training on resting energy expenditure and/or PAEE after exercise training (27–36). Some investigators have even suggested that regular exercise training may decrease PAEE (37, 38).

Discrepant results among investigators regarding the effects of exercise training on daily energy expenditure may be partially due to differences in methodological and experimental design factors. First, physical exercise has been traditionally studied in isolation, without regard to its potential influence on TEE. This methodological limitation has recently been overcome with the application of doubly labeled water, which quantifies TEE in free-living individuals. Second, investigators have tended to rely on cross-sectional designs (i.e. trained vs. untrained individuals) to examine the impact of the trained state on daily energy expenditure. Cross-sectional experimental approaches, although experimentally convenient, are fraught with potential confounders, such as subject self-selection and genetic biases. Third, the methodological assessment of PAEE has been problematic in free-living individuals. Investigators have tended to rely on physical activity questionnaires, accelerometers, pedometers, etc., that provide questionable estimates of daily energy expenditure (39). Fourth, there has been some confusion between the chronic and acute effects of exercise on energy metabolism. That is, most studies have examined energy expenditure during or immediately after the end of the exercise program (within 24 h), thereby obscuring the potential chronic effect of exercise on energy metabolism. Relative to this point, it is important to consider that suspension of exercise training for 72 h is associated with a decrease in resting energy expenditure (40).

Thus, in an attempt to partially resolve some of these controversies in the literature, we examined the effects of both endurance and resistance training on TEE and its components in young, nonobese, sedentary women. We performed our measurements of daily energy expenditure before and approximately 10 d after the exercise programs were completed. Furthermore, we used a randomized controlled clinical trial to help control for known and unknown sources of experimental bias.
Subjects and Methods

Subjects

Criteria for subject inclusion were: premenopausal, age between 18–35 yr, and a body mass index less than 26 kg/m². In addition, subjects had to be weight-stable (±2 kg) and not participating in a regular exercise program for 6 months before the study. Exclusion criteria included a history or evidence on physical examination or testing of the following: 1) diabetes; 2) orthopedic limitations or history of pathologic fracture; 3) hypertension (>160/90 mm Hg); 4) use of prescription or over-the-counter medications that could affect energy expenditure; 5) smoking; and 6) alcohol consumption greater than 15 g alcohol/d (one alcoholic beverage). An oral glucose tolerance test was performed in all volunteers to determine glucose tolerance according to the criteria of the National Diabetes Group (41) to exclude diabetics. This study was approved by the Committee for Human Research at the University of Vermont, and each participant gave her written, informed consent before the beginning of the study.

Overview of experimental protocol

Subjects were recruited from local newspaper advertisements in Burlington, VT, and the University of Vermont community. After determination of eligibility by telephone, volunteers were scheduled for the first screening visit. On the screening visit, an oral glucose tolerance test, medical history, physical examination, maximum oxygen consumption test, and complete blood chemistry and profile were performed. Two weeks later, participants were scheduled for an overnight visit to the General Clinical Research Center (GCRC) at the University of Vermont. For 3 d before the overnight visit, participants were provided with standardized diets prepared by the metabolic kitchen at the GCRC containing 55% carbohydrate, 25% fat, and 20% protein. During the afternoon of admission, we conducted body composition measurements using dual energy x-ray absorptiometry. Also, participants were administered the dose of doubly labeled water as described below, and baseline urine was collected for analysis. The next morning, we measured RMR using indirect calorimetry, and subjects were submitted to the treadmill stress test. After 10 d of normal daily activity, participants returned to the GCRC for posttest urine collection. Upon successful completion of this testing sequence, volunteers were randomly assigned to endurance exercise, resistance exercise, or control conditions. An identical sequence of posttesting measures was performed after the 6-month intervention period. Because the goal of the study was to examine the effects of endurance and resistance training after the programs were completed, posttraining measures were conducted approximately 72 h after the last exercise bout. TEE was then measured over the following 10 d. We have previously reported changes in insulin sensitivity from this group (42).

Recruiting and screening

On the basis of our advertisements, 321 women were interviewed by telephone. Of these 321 women, 105 women consented to participate in screening procedures. Of these 105 women, 89 were deemed eligible and consented to participate in pretraining testing procedures. Of these 89 women, 85 were Caucasian, 2 were of Asian descent, and 2 were of Hispanic origin. They were randomized to either aerobic training, resistance training, or control condition. A total of 31 women dropped out of the study for various reasons (detailed in the exercise training programs section), and 10 women were not dosed with doubly labeled water because of a worldwide shortage. Thus, the final number of women who completed the study was as follows: aerobic training, n = 13; resistance training, n = 16; and control condition, n = 19.

Exercise training programs

All endurance exercise sessions were preceded by a 10-min warm-up that consisted of stretching of the major muscle groups and slow walking around the track. All women were taught to monitor their heart rates (HRs). HRs were verified with a Polar Heart Rate monitor (Polar Electro, Port Washington, NY).

The endurance training program consisted of two parts: 1) wk 1–16 were an endurance base-training phase; and 2) wk 17–24 were an intermittent-training phase (both described below). Women trained on 3 nonconsecutive days per week for 6 months (24 wk) under the supervision of a personal trainer.

Endurance base-training phase (wk 1–16). The first 4 wk consisted of an exercise prescription of 25 min of slow jogging and/or brisk walking at 60% of HR. Thereafter, every 4-wk period would be performed as follows: at the beginning of the next period, time would increase by 5 min, and intensity would increase by approximately 10% of HR every week (from 60% of HR at wk 1 to 90% at wk 4). At the beginning of the next 4-wk period, time would increase by another 5 min, and intensity would be scaled back to 60% of HR. On wk 16, women were walking or jogging for 40 min at 90% of maximal HR.

Interval training (wk 17–24). Women followed a detailed program of specific workouts aimed at increasing exercise duration and intensity. The interval sessions consisted of 45 min of 80–90% HR maximum training on Monday, four 5-min periods at 95% HR maximum with 3-min rests on Wednesday, and 45 min at 80–90% of HR max on Friday.

Resistance training. Women randomized to resistance training exercised on 3 nonconsecutive days during the week (e.g., Monday, Wednesday, and Friday) under the supervision of a personal trainer. Because of the need for test specificity, one-repetition maximum (1-RM) evaluations of certain exercises used in the training program provided the most direct evaluation of the training gains made over the 6-month period. The 1-RM is defined as the maximum amount of resistance that can be moved through the full range of motion of an exercise for no more than one repetition. To determine the 1-RM, each subject initially performed three to five repetitions with the lightest weight possible to be sure proper technique is used. The trainer then selected a weight and asked the subject to perform the lift. After 3–4 min of rest, the next heaviest weight was selected, and the attempt was repeated until the subject could not complete the full lift. The same number of trials, time between trials, and order of exercises were used before and after training for the 1-RM test. Tests were administered before the start of the training program, midway through the program, and after the exercise phase. The following exercises were evaluated for 1-RMs: leg press, bench press, shoulder press, and seated rows. Training was approximately 60–80% of 1-RM at the beginning with the goal of having all subjects train at 80% 1-RM by the second week of the program. Each training session included a warm-up of low intensity cycling for 5 min, followed by 10 min of static stretching of all the major muscle groups used in training. The resistance program consisted of the following exercises: 1) leg press, 2) bench press, 3) leg extensions, 4) shoulder press, 5) sit-ups, 6) seated rows, 7) tricep extensions, 8) arm curls, and 9) leg curls. The exercises provided a total body resistance training program for all of the major muscle groups of the body. The volunteer was given a target load range and attempted to keep each set within the target range by adjusting the load to allow the prescribed number (n = 10) of repetitions. Rest periods were 1.5 min between sets.

During the conduct of the training programs, 31 women dropped out of the study, yielding a dropout rate of 32%. The reasons for dropouts included: 1) noncompliance with training (n = 16); 2) relocation (n = 3); 3) injury related to endurance training (n = 5); 4) refused posttesting (n = 2); 5) health problems not related to training (n = 3); and 6) pregnancy (n = 2). Thus, 58 women (20 resistance, 20 endurance, and 18 control) satisfactorily completed all pretesting and posttesting procedures and the 6-month training program. Because of a shortage of doubly labeled water, we were able to dose only 48 subjects. Herein, we report the results of 48 subjects who completed all tests. The exercising women successfully completed 90% of all exercise training sessions. Oral contraceptive use was 70% in resistance-trained women (14 of 20), 35% in endurance-trained women (7 of 20), and 50% in controls (9 of 18) (x²; P = 0.89).

Measures of energy expenditure

TEE. TEE was determined from doubly labeled water over a 10-d period before and after the training programs. After the exercise program was completed, TEE was measured during a 10-d period, starting 72 h after the last exercise session. During this 10-d period, subjects were asked to abstain from any structured exercise program and to maintain their normal daily physical activity routines. Specific details about the doubly
labeled water technique and the analyses have been described previously (43, 44).

RMR. RMR was measured for 60 min by indirect calorimetry using the ventilated hood technique (9, 10) after an overnight, 12-h fast in the GCRC. RMR was specifically measured on the first day of urine collections for the doubly labeled water. Respiratory gas analysis was performed using a Deltatrac metabolic cart (Sensormedics, Yorba Linda, CA). RMR (kilocalories per day) was calculated from the equation of Weir (45). The test-retest correlation coefficient within 1 wk has been shown to be 0.90 for RMR in our laboratory. The respiratory quotient (RQ) was calculated from indirect calorimetry. Test-retest correlation coefficients for RQ are 0.91 in our laboratory.

PAEE. Doubly labeled water in conjunction with indirect calorimetry was used to measure PAEE. PAEE was calculated using the following equation: PAEE = TEE – (RMR + thermic effect of a meal), as previously reported from our laboratory (26, 37). Thermic effect of a meal was estimated as 10% of TEE (23).

Body composition. Fat mass and fat-free mass were measured by dual energy x-ray absorptiometry using a Lunar DPX-L densitometer (Lunar Corp., Madison, WI) as previously described (37, 42). All scans were analyzed using the Lunar Version 1.3 DPX-L extended-analysis program for body composition. Test-retest coefficient of variation for this measurement was 1.2% for fat mass and 2% for fat-free mass, respectively.

Cardiorespiratory fitness. Maximum aerobic capacity (VO2 max) was determined from an incremental exercise test on a treadmill to volitional exhaustion, as previously described (42). After an initial 3-min warm-up, the speed was held constant, and the grade was increased by 2.5% every 2 min. The criteria for achieving a VO2 max were: 1) a respiratory exchange ratio greater than 1.1; 2) a HR at or above the age-predicted maximum; and 3) no further increase in oxygen consumption with an increasing workload. At least two of these criteria were met by all volunteers. Test-retest conditions for nine individuals (on two occasions tested 1 wk apart) yielded an intraclass correlation of 0.94 and a coefficient of variation of 3.8% in our laboratory.

Statistical analysis. Differences in physical characteristics among groups at baseline were examined using a one-way ANOVA. A 2 × 3 repeated measures ANOVA was used to detect changes with time within the treatment condition (pre/post) and among groups (endurance vs. resistance vs. control). The repeated measures factor was the repeated tests during the exercise programs. Significance was accepted at P < 0.05.

Results

Table 1 shows physical characteristics for endurance-trained, resistance-trained, and control subjects before and after training. There were no differences among the three groups in baseline physical characteristics, suggesting a successful randomization. Body weight and body mass index did not change in endurance-trained, resistance-trained, or control groups. Fat mass showed no change in endurance-trained, resistance-trained, or control women. Fat-free mass showed no change in endurance-trained or control women, but increased in resistance-trained women (P < 0.05) compared with controls. Endurance-trained individuals increased their VO2 max by 18%, whereas no changes were noted in resistance-trained or control subjects for this variable. Resistance-trained women increased their 1-RM for leg press (29%), bench press (39%), shoulder press (29%), and seated rows (27%; data not shown).

Table 2 shows data for TEE and its components (RMR and PAEE) in endurance-trained, resistance-trained, and control subjects before and after training. There were no differences at baseline among groups in any component of daily energy expenditure. After the training intervention, there were no significant or chronic changes in any group in TEE. Absolute RMR increased in resistance-trained women (P < 0.05) but did not significantly change when adjusted for fat-free mass. There was no change in absolute or relative RMR in either the endurance-trained or control groups. PAEE, as measured by doubly labeled water, showed no changes in any group after the training period. Similarly, fasting RQ was not different among groups at baseline and showed no changes in response to endurance or resistance training.

Discussion

We examined the effects of both endurance and resistance training on TEE and its components in young, nonobese, sedentary women using a randomized clinical trial. We found that despite significant increases in VO2 max and muscular strength in endurance- and resistance-trained groups, respectively, TEE was unchanged. These findings argue against a chronic enhancing effect of endurance or resistance exercise on TEE in free-living young women.

Our experimental design and methods lend credibility to our findings. First, the use of a randomized, controlled, clinical trial helps control for experimental sources of known and unknown biases, including subject self-selection, seasonality, etc. To our knowledge, no previous study has used this experimental approach, and the majority of exercise studies lack a control group. Second, most studies have focused on the exclusive measurement of RMR (6, 7, 9–12, 14–23, 27, 32, 33, 35), whereas TEE is of greater clinical relevance with respect to body weight regulation. Some studies have measured daily energy expenditure during the exercise training program (13, 24, 25, 36–38). This approach provides useful information on the acute energetic adaptations to exercise.

### Table 1. Physical characteristics before and after 6-month training intervention in 48 young, nonobese, sedentary women

<table>
<thead>
<tr>
<th>Physical characteristics</th>
<th>Aerobic training n = 13</th>
<th>Resistance training n = 16</th>
<th>Control condition n = 19</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>28 ± 4</td>
<td>28 ± 3</td>
<td>164 ± 7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>163 ± 5</td>
<td>163 ± 5</td>
<td>58 ± 6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>58 ± 5</td>
<td>60 ± 5</td>
<td>22.0 ± 2.0</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>14.5 ± 4.4</td>
<td>14.7 ± 3.6</td>
<td>40.2 ± 4.1</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>2.2 ± 0.5</td>
<td>2.6 ± 0.6^b</td>
<td>2.1 ± 0.3</td>
</tr>
</tbody>
</table>

Values are means ± SD.

^a The difference between total body weight and the sum of fat mass and fat-free mass is bone mass.

^b P < 0.05.
TABLE 2. Energy expenditure data before and after 6-month training intervention in young, non-obese, sedentary women

<table>
<thead>
<tr>
<th>Energy expenditure component</th>
<th>Endurance training (n = 13)</th>
<th>Resistance training (n = 16)</th>
<th>Control (n = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>TEE (kcal/d)</td>
<td>2581 ± 530</td>
<td>2599 ± 440</td>
<td>2473 ± 429</td>
</tr>
<tr>
<td>RMR (kcal/d)</td>
<td>1388 ± 78</td>
<td>1362 ± 137</td>
<td>1351 ± 127</td>
</tr>
<tr>
<td>PAEE (kcal/d)</td>
<td>943 ± 428</td>
<td>976 ± 406</td>
<td>845 ± 425</td>
</tr>
<tr>
<td>RQ</td>
<td>0.83 ± 0.03</td>
<td>0.87 ± 0.08</td>
<td>0.85 ± 0.02</td>
</tr>
</tbody>
</table>

Values are the means ± SD.
\(^a\) P < 0.05.

training, but not on chronic adaptations. Finally, several investigators have determined the effects of chronic training on daily energy expenditure in a room calorimeter, which unfortunately underestimates PAEE (8, 29, 34). This study extends these previous studies by examining TEE in endurance- and resistance-trained young women.

The effects of endurance training on TEE are controversial (1–5). Although it is intuitively appealing from a public health perspective to hypothesize that endurance training may chronically increase energy expenditure beyond the energy cost of the training program itself (4, 5), these assumptions remain unsubstantiated. This is partially due to the timing of the metabolic measurements relative to the exercise program. Several studies have measured daily energy expenditure during exercise training. For example, we and others (37) reported no change in daily energy expenditure in response to endurance training in older men and women. This was due, partially, to a compensatory decline in nonexercising physical activity that offset the direct energetic cost of the endurance exercise program. Still other investigators have reported an increase in daily energy expenditure with endurance training (25, 35, 46), but this was due to the direct energetic cost of the endurance exercise and not to a change in RMR or PAEE during nonexercising time. It has even been suggested that energetic adaptations to exercise training are gender-specific, in which exercise may stimulate habitual physical activity in males, but less so in females (25). Despite significant increases in VO₂ max in the present study, TEE after training was similar to pretraining values in young women. Thus, we interpret these findings to suggest that there is no chronic or carryover effect of endurance training on daily energy expenditure subsequent to the exercise programs. Had we encouraged participants to be more physically active, they may have been more capable of doing so in their trained state; however, an increase in physical activity did not occur spontaneously.

Our results illustrate the differences that may be obtained from cross-sectional vs. longitudinal investigations. That is, previous cross-sectional studies have suggested that a higher VO₂ max is associated with higher RMR per kilogram of fat-free weight and PAEE (6, 9–12, 16–21, 26, 46), although these results are discrepant (32–34). Given the present findings, we would suggest that cross-sectional physiological relationships do not always reflect physiological changes observed in exercise intervention studies. Our study, however, cannot address the question of whether years of participation in endurance exercise training influences daily energy expenditure in young women.

The effect of resistance training on daily energy expenditure, using doubly labeled water, has been studied less extensively than endurance training. We are aware of only two studies that examined the effects of resistance training on TEE (24, 36). Van Etten et al. (36) measured daily energy expenditure in young men with doubly labeled water before and during an 18-wk resistance training program. They found a mean increase in daily energy expenditure 18 wk into a resistance training program that approached 260 kcal/d, of which the majority was due to the direct caloric cost of the resistance training program (47). These findings are surprising based on the fact that resistance training has a very low energetic cost compared with aerobic training. Sleeping metabolic rate and free-living physical activity were unaltered in response to resistance training, despite an increase in fat-free mass (2.1 kg). Thus, the increase in daily energy expenditure was due primarily to the resistance training program and not to an enhancing effect on RMR and/or PAEE. On the other hand, Hunter et al. (24) found that 6 months of resistance training significantly increased daily energy expenditure in addition to the direct energy cost of the resistance training program. This increase was due to an increase in both RMR and PAEE in older individuals when they were not exercising. The results are not directly comparable to the present investigation because our measures were conducted after the endurance and resistance training programs were completed. Although we cannot rule out that energetic adaptations may occur acutely during endurance and resistance training programs that may serve to acutely enhance the total energy cost of the exercise programs, we would suggest that these adaptations are probably short-lived.

One may suggest that we were overly optimistic to hypothesize that favorable changes in physiology (i.e. increase in VO₂ max and muscular strength) may result in a spontaneous increase in TEE in inactive young women. It is possible that additional behavioral interventions and counseling are required to alter the physical activity behavior patterns of young women once a structured and heavily supervised exercise program is terminated. Another potential reason for the absence of changes in daily energy expenditure in our population is a ceiling effect. That is, although our subjects were not regularly participating in a regular physical activity program, our subjects were not impaired in their ability to participate in an exercise training program. Thus, it may be difficult to augment PAEE in individuals whose physical capacity is not limited by a poor fitness level. It is interesting to note that approximately one third of the volunteers enrolled in our study dropped out for various reasons. The primary reason for the dropouts was noncompliance, in
which women failed to maintain or lost interest in participating in a regular exercise training program. The physiological characteristics of these women (i.e., baseline body weight, fitness, etc.) were similar to those who completed our study. Thus, we were unable to identify physiological characteristics that may have predicted noncompliance in our study.

One limitation of the study pertains to doubly labeled water measurement that needs to occur over a 10-d period. It has been shown that after 3 d, a detraining effect on RMR can be observed (40), and it is possible that the lack of a stimulation effect of exercise on TEE may reflect a partially detraining effect over the 10-d period. However, resting energy expenditure was measured within 72 h of the last exercise session; thus, we would suggest that the acute effects of exercise had probably dissipated but that a detraining effect had not completely occurred yet.

In conclusion, our results demonstrate that chronic training does not alter daily energy expenditure or its components after the end of the exercise program. The energy enhancing benefits derived from endurance or resistance training are probably short-lived and derived primarily from the direct energy cost of the physical activity and not from a chronic elevation in daily energy expenditure in young women.

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