

The Effects of a 20-Week Exercise Training Program on Resting Metabolic Rate in Previously Sedentary, Moderately Obese Women

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The present study was designed to investigate the effects of exercise training on resting metabolic rate (RMR) in moderately obese women. It was hypothesized that exercise training would increase resting metabolic rate. Nineteen previously sedentary, moderately obese women (age = 38.0 ± 0.9 years, percent body fat = 37.5 ± 0.8) trained for 20 weeks using either resistance training (RT) or a combination of resistance training and walking (RT/W). The high intensity resistance training program was designed to increase strength and fat-free mass and the walking program to increase aerobic capacity. There was also a non-exercising control group (C) of 9 subjects in this study. Fat-free mass was significantly increased in both the RT (+1.90 kg) and RT/W (+1.90 kg) groups as a result of the training program. No group showed significant changes in fat mass or relative body fat from pre- to post-training. Aerobic capacity was slightly, though significantly, increased in the RT/W group only. The RT group showed a significant increase ($+44 \text{ kcal} \cdot \text{day}^{-1}$), while the RT/W group showed a significant decrease ($-53 \text{ kcal} \cdot \text{day}^{-1}$) in resting metabolic rate post-training. RT can potentiate an increase in RMR through an increase in fat-free mass, and the decrease in RMR in the RT/W group may have been a result of heat acclimation from the walk training.

Key Words: resting energy expenditure, resistance training, women, obesity, body composition, energy balance

Introduction

Resting metabolic rate (RMR) is defined as the energy expenditure required to maintain normal physiological processes during rest in a postabsorptive state, and it accounts for 60 to 75% of total daily energy expenditure. Since RMR comprises such a large percentage of total energy expenditure, small increases in RMR could have long term benefits for the prevention or treatment of obesity.

It has been suggested that exercise training has the potential to alter RMR. Both cross-sectional (1, 24-27, 29, 38, 39) and longitudinal (22, 39) studies have

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shown that endurance training increases a person's RMR, but almost an equal number of studies have been unable to demonstrate this effect (6–8, 10, 11, 28, 35–37, 40). Additionally, few studies have been conducted to examine the effects of resistance training on RMR. Fat-free mass (FFM) has been shown to be the factor most highly correlated to RMR when the variables shown to influence RMR are examined (18, 32, 43). It therefore seems feasible that high intensity resistance training, which can elicit an increase in skeletal muscle mass and FFM, could result in the possible potentiation of RMR. Longitudinal resistance training studies have shown both an increase in RMR (30, 33, 41) and no increase in RMR (7, 42) from pre- to post-treatment measurements.

The effects of exercise on RMR can be obscured by those of caloric restriction and substantial weight loss. Caloric restriction results in an immediate reduction in RMR, and the combination of an intense exercise program with caloric restriction could result in an increased negative energy balance and further reduced RMR. Similarly, rapid weight loss, resulting from severe caloric restriction, may be associated with undue losses of FFM (45). Efforts to increase FFM under such conditions are likely to be suboptimal.

The present study assessed the effects of strength training, as well as strength training combined with aerobic exercise, on changes in RMR and FFM in obese women who did not diet. We believed that the absence of caloric restriction would provide the best opportunity to observe beneficial effects of exercise on FFM and RMR. Strength training was selected because of findings that FFM is strongly correlated with RMR. Thus, increasing FFM could increase RMR which, in turn, could facilitate weight control. The combination of strength training and aerobic exercise was included to see if there was an additive effect of the two modes of exercise on RMR. Changes in these subjects in weight, FFM, and RMR were compared with those in control subjects who did not exercise.

Methods

Subjects

Thirty-six sedentary, normally menstruating women between the ages of 18 and 45 years, recruited from The University of Texas at Austin and the surrounding community, volunteered to serve as subjects in this study. None of the subjects had a history of menstrual dysfunction or oral contraceptive use for the past year prior to participation. All subjects were screened for weight-stability (± 3 kg) in the past year, had not been clinically diagnosed with an eating disorder, and were required to have at least 30% body fat in order to participate. Each subject received an extensive verbal and written description of the study and signed a form of informed consent approved by the Institutional Review Board of The University of Texas at Austin.

Procedures

Twenty-five subjects were recruited to participate in the training program, and 11 subjects were recruited to serve as controls. Unfortunately, subjects in the two groups had to be recruited separately due to the unwillingness of subjects to participate if assigned to a non-exercising control group. The 25 experimental subjects were then randomly assigned to either a resistance training only group (RT) or a resistance training plus walking group (RT/W). Six experimental subjects either

dropped out of the study or failed to complete the minimum number of workouts (i.e., 75%). Two of the control group subjects were dropped from the study, one due to pregnancy and the other due to the onset of menopause. Final group subject numbers were RT = 10, RT/W = 9, and C = 9.

During the initial screening visit, each subject completed questionnaires to determine health status, exercise history, and menstrual history. To meet the criterion for "sedentary" status, a subject could not have performed systematic, repetitive exercise sessions for a minimum of the past 2 years. A subject was considered regularly menstruating if she reported regular menstrual cycles between 25 and 35 days in length for one year prior to participation in the study.

Body composition was assessed during the first visit. Subjects were instructed to refrain from eating or ingesting caffeine 4 hours prior to the test. Hydrostatic weighing to determine body density was conducted as described by Behnke and Wilmore (4), with residual lung volume determined by the oxygen dilution method of Wilmore et al. (46). Relative body fat was estimated from body density by the equation of Lohman (13) for Caucasian subjects or Ortiz (20) for the one African-American subject. Fat mass (FM) and fat-free mass (FFM) were obtained by the following equations: $FM = (\text{mass} \cdot \text{relative fat})/100$; and $FFM = \text{mass} - FM$.

On the second visit to the laboratory, each subject received detailed instructions on completing the diet history forms that would be used to characterize the subject's typical daily total caloric intake. Each subject was trained by a registered dietitian using food models for standardizing serving sizes and providing detailed instructions to accurately record the diet. Each subject was provided with record sheets for keeping track of daily food intake. Recording days were chosen by the subjects during each follicular phase of the menstrual cycle. Subjects were encouraged to maintain and record their normal diet at monthly intervals throughout the duration of the study. Each subject chose 2 weekdays and 1 weekend day each month to represent a typical eating pattern throughout the duration of the study. Dietary histories were completed for the 3-day period immediately prior to the RMR measurement to allow the investigator to determine whether each subject was in a state of energy balance prior to metabolic measurements.

During this second visit, or on a subsequent visit to the laboratory, each subject was familiarized with the face mask to be used during the RMR measurement. Each subject was fitted with the mask to ensure comfort and to prevent leakage. This also provided acclimation to the mask.

RMR was then measured on 2 consecutive days for each subject during the follicular phase of the menstrual cycle, which was defined as within the first 10 days from onset of menses. Subjects were asked to remain sedentary for a period of 36 hours prior to the start of the two pre-training RMR tests. Before each test, subjects were provided a heart rate monitor (Polar Vantage XL) and instructed on its use the afternoon or evening prior to the first day of measurement. In order to compare sleeping heart rate to resting heart rate and to ensure that the RMR was taken under resting conditions, the heart rate monitor was worn from when the subject went to bed the evening before each day of testing until the subject arrived at the laboratory on the subsequent test day. Subjects were encouraged to get 8 hours of restful sleep prior to the RMR measurements. On the morning of the tests, subjects were instructed to minimize physical activity to include only slow movement for a brief period of time. Subjects were transported to the laboratory by car and were asked to minimize any walking while in route from the car to the laboratory.

Upon arrival to the laboratory, subjects were weighed, and three electrodes were placed on the subject for measurement of heart rate (HR) during the resting period. Subjects were seated in a recliner chair in a semi-recumbent position, and body temperature was taken using an oral thermometer. The laboratory used for RMR measurement was maintained quiet and dimly lit. Room temperature was maintained between 21 and 24 °C. Subjects were provided a light blanket to cover them during the test period. Subjects were then allowed to rest quietly for 30 min. If the subject was going to be tested using the face mask, the last 10 min prior to RMR measurement were used to further acclimate the subject to breathing while wearing the face mask. Several subjects had to be tested using the dilution mask due to leakage while using the face mask.

A SensorMedics 2900 Metabolic Measurement Cart (MMC) was used to obtain RMR using either a dilution mask (Scott-O-Vista Facepiece Assembly) or a face mask (Hans Rudolph). The type of mask used was consistent for each subject for all measurement days pre- and post-training. Our laboratory has found very close agreement between these two masks when used on the same individuals. The RMR measurement was terminated at the end of the 30-min measurement period, and the heart watch receiving unit was downloaded into an IBM computer for an analysis and print-out of the previous night's sleeping heart rate.

On the next visit to the laboratory, following the 2 consecutive days for RMR assessment, each subject performed a graded exercise test on a motorized treadmill to assess maximal oxygen consumption. Each subject was allowed to familiarize herself with the treadmill and walk at a comfortable pace until she felt at ease. The test began at 3.0 mph, 0% grade for 2 min. The speed was then increased by 0.5 mph every minute until a maximal speed that the subject could maintain was achieved (usually 5 mph). At this time the speed was kept constant, and the grade increased 2.5% every minute until volitional exhaustion. The $\dot{V}O_{2}$, volume of expired carbon dioxide ($\dot{V}CO_{2}$), expired ventilation (\dot{V}_{E}), and respiratory exchange ratio (RER) responses were measured continuously using a Sensormedics 2900 metabolic cart (Yorba Linda, CA), which was calibrated before and after each exercise test with certified standard gases. HR was measured by telemetry at 5-s intervals using a Polar heart rate monitor (Montvale, NJ). $\dot{V}O_{2max}$ was defined as the point at which oxygen consumption plateaued with an increase in the rate of work, or the peak value, if a plateau was not achieved and the respiratory exchange ratio was greater than 1.10, or the maximal heart rate was $\geq 95\%$ of the subject's age-predicted value. All subjects met at least one of these test criteria.

On the final 2 days of testing, subjects were tested for maximal strength using a three repetition maximum (3-RM) lift. Prior to the 3-RM assessment period subjects were trained on how to properly and safely use each piece of resistance training equipment and allowed a 10-day familiarization period to practice using the machines properly in order to prevent injury during testing and to achieve true 3-RM values. After the familiarization period, each subject was tested for strength using the 3-RM method on the following: lat pulldown, standing chest press, lying down row, leg press, leg extension, and leg curl. The upper body was measured on the first 3-RM test day, and the lower body was measured the following day.

After completing all pre-treatment tests, all subjects in the training groups were randomly assigned to participate in either the RT or RT/W program. Subjects in all three groups were instructed not to change either their activity or dietary habits during the 5-month period of the training study other than the additional activity imposed by the experimental treatment to which they were assigned.

Each subject in the RT and RT/W groups participated in a 5-month training program designed to increase fat-free mass and strength. Subjects trained using a combination of Schnell (Schnell, Gachenback, Germany) and Nautilus (Independence, VA) resistance training equipment and free-weights 4 days a week (i.e., Monday, Tuesday, Thursday, Friday), with the exercises divided into primarily upper and lower body emphasis on alternating days. The Monday/Thursday workout included the following: standing chest press, incline chest flies, lying down row, assisted dips, overhead press, side lateral raises, tricep kick back, and abdominal crunches. The Tuesday/Friday workout included: leg press, leg extension, leg curl, lat pulldown, assisted pull-ups, barbell curl, and abdominal crunches. For safety and motivational reasons, subjects trained in pairs. A stretching period preceded and followed each training session.

The resistance training program was graded in nature to prevent injury and maintain interest and adherence to the training protocol. For the first 6 weeks of the study, subjects performed three sets of 10–12 RM of each exercise. For the remainder of the study subjects completed three sets of 10–12 RM, 8–10 RM, and 6–8 RM, respectively. In addition to the resistance training program described above, the subjects in the RT/W group also walked 3 days of the week. Subjects were trained to monitor their heart rates using palpation of the carotid artery. Accuracy of the palpation method was verified on two occasions using a Polar heart rate monitor. Subjects were paired in order to use the “buddy system” for walking workouts. Duration of walk time and average heart rate during the walk were recorded on a designated form and verified by the walking partner, as the walking sessions were not directly supervised. These forms were turned in to the principal investigator each Monday.

The walking program was graded in nature, with intensity and duration increased from 20 min at a heart rate corresponding to 50% of the pre-determined $\dot{V}O_{2max}$ to 40 min at a heart rate corresponding to 70% of the pre-determined $\dot{V}O_{2max}$.

Subjects were tested for strength (3-RM) during the last week of the training program. At the end of the 20-week training period subjects were assessed again for RMR, body composition, and $\dot{V}O_{2max}$. Two consecutive RMR measurements were made 36 to 48 and 60 to 72 hours after the last exercise session.

Statistical Analyses

This study was designed to provide a power probability of 0.80 for identifying treatment differences significant at the $p \leq .05$ level. An intraclass correlation and an ANOVA with a repeated measure were performed to determine the between-trial reliability between the repeat trials for RMR ($\text{ml} \cdot \text{min}^{-1}$), overnight sleeping heart rate (HR_{sleep}), heart rate during the rest period prior to the RMR ($\text{HR}_{\text{preRMR}}$), and heart rate during the RMR (HR_{RMR}). An analysis of variance (ANOVA) with repeated measures was used to analyze the differences between each of the groups for RMR, expressed as $\text{ml} \cdot \text{min}^{-1}$, $\text{kcal} \cdot \text{day}^{-1}$, and $\text{kcal} \cdot \text{kgFFM}^{-1} \cdot \text{day}^{-1}$, and for all other dependent variables (i.e., relative fat, body mass, FFM, FM, BMI, $\dot{V}O_{2max}$, RER, HR, and strength [3-RM]). When the F ratio was significant at $p \leq .05$ for a Group by Time interaction, a simple main effect test was used to compare the change from pre- to post-treatment for each group. Significant main effect results were further investigated using single degree of freedom contrasts. The analyses were conducted using the SPSS v. 6.1.1 (SPSS, Chicago, IL) statistical program for the Macintosh computer. Data are reported as mean \pm SE.

Reliability of RMR and HR Measurements

Both an intraclass correlation and an ANOVA with repeated measures were used to examine the reliability for RMR ($\text{ml} \cdot \text{min}^{-1}$ and $\text{kcal} \cdot \text{day}^{-1}$), HR_{sleep} , $\text{HR}_{\text{preRMR}}$, and HR_{RMR} (Table 1). The ANOVA procedures indicated that there were no significant differences between the two pre-treatment and between the two post-treatment measurements for RMR in $\text{ml} \cdot \text{min}^{-1}$ or $\text{kcal} \cdot \text{day}^{-1}$. The correlation for these variables was also high, ranging from $R = 0.90$ to 0.93 . The ANOVA procedure indicated that there were no significant differences between the two pre-treatment and between the two post-treatment measurements for HR_{sleep} , $\text{HR}_{\text{preRMR}}$, or HR_{RMR} . Additionally, high correlations were found between each set of pre- and post-treatment measures, with coefficients of $R = 0.92$, 0.89 , and 0.89 for the pre-treatment, and $R = 0.89$, 0.96 , and 0.95 for the post-treatment HR_{sleep} , $\text{HR}_{\text{preRMR}}$, and HR_{RMR} , respectively.

Results

Subject Characteristics

As expected by the experimental design, the subjects were higher than average for their age in relative body fat ($37.5 \pm 0.8\%$) as determined by hydrostatic weighing and lower than average for their age in aerobic fitness as indicated by their $\text{VO}_{2\text{max}}$ ($29.5 \pm 0.70 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). These findings are consistent with the recruitment of a sedentary, overweight population.

Training Program Adherence

The combined attendance for the RT and RT/W groups for the resistance training program was 90% of the workouts attended. The RT group had an attendance of 92%, while the RT/W group had an 88% attendance for the resistance training workouts and an 85% attendance for the walking workouts.

Subjects in the RT/W group were able to maintain close to the prescribed HR during the four phases of the walking protocol; heart rates corresponding to 50%, 60%, 65%, and 70% of their $\text{VO}_{2\text{max}}$ values were prescribed. Subjects walked at heart rates corresponding to 51%, 58%, 62%, and 64% of their $\text{VO}_{2\text{max}}$ values for the four phases of the training program.

Aerobic Capacity and Strength

The resistance training program proved to be effective for increasing strength in both the RT and RT/W groups, significantly increasing their 3-RM strength on all six exercises. The RT group showed a 37% increase in overall body strength, comprised of a 38% increase in upper body strength and a 36% increase in lower body strength. The RT/W group showed an almost identical increase of 36% in overall body strength, with increases of 41% in upper and 34% in lower body strength. The control group did not change overall body strength ($\leq 3\%$), upper body strength ($\leq 1\%$), or lower body strength ($\leq 5\%$).

In terms of aerobic capacity, the RT/W group was the only group to show a small (6%) but significant increase in $\text{VO}_{2\text{max}}$ in $\text{L} \cdot \text{min}^{-1}$. There were no significant

Table 1 Reliability for the Measurements of RMR and Resting HR

Variable	Pre-treatment values				Post-treatment values			
	Trial 1	Trial 2	Intraclass correlation	Repeated measure ANOVA	Trial 1	Trial 2	Intraclass correlation	Repeated measure ANOVA
RMR ml · min ⁻¹	204.1 ± 3.9	202.3 ± 4.1	.90	NS	203.8 ± 4.5	203.8 ± 4.4	.93	NS
RMR kcal · day ⁻¹	1422 ± 27.7	1413 ± 29.1	.91	NS	1420 ± 31.5	1423 ± 30.8	.93	NS
HR _{sleep}	66.3 ± 1.9	69.1 ± 2.4	.92	NS	64.8 ± 1.3	65.4 ± 1.8	.89	NS
HR _{preRMR}	65.6 ± 1.8	65.4 ± 1.7	.89	NS	62.6 ± 1.6	63.1 ± 1.6	.97	NS
HR _{RMR}	64.6 ± 1.7	63.9 ± 1.7	.89	NS	60.4 ± 1.5	60.9 ± 1.4	.95	NS

Note. Values are mean ± SE.

differences in the pre- to post-treatment analyses or between any of the groups when $\dot{V}O_{2\max}$ was expressed in $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. A likely explanation for this small increase in $\dot{V}O_{2\max}$ when expressed in $\text{L} \cdot \text{min}^{-1}$, and a lack of an increase when expressed relative to body weight, is the variation in weight gain between subjects.

Body Composition Data

Changes in body composition are presented in Table 2. FFM in the RT group was shown to be significantly higher than the C group in the pre-treatment measures. This was the only significant difference in any of the variables between any of the groups for pre-treatment measurements. Body mass values did not differ significantly between groups, although the differences in body weight were as great as 14 kg, due to a large standard deviation within groups. FFM was the only variable that showed a significant group by time interaction. Both the RT and RT/W groups showed a significant increase in FFM with training, whereas the C group did not change.

Resting Metabolic Rate

The results of the RMR measurements can be found in Table 3. All RMR data is the average of two measurements: one taken 36–48 hours post-exercise and another taken 24 hours later, or 48–60 hours post-exercise. When expressed in $\text{ml} \cdot \text{min}^{-1}$ or $\text{kcal} \cdot \text{day}^{-1}$, there were no significant differences between the three groups in the pre-treatment measures. When expressed as $\text{kcal} \cdot \text{kgFFM}^{-1} \cdot \text{day}^{-1}$, RMR was shown to be significantly lower in the RT group when compared to the C group in the pre-treatment measurements.

The RT group showed a significant increase in RMR post-training when expressed in $\text{ml} \cdot \text{min}^{-1}$ or $\text{kcal} \cdot \text{day}^{-1}$. When expressed relative to the increase in FFM as $\text{kcal} \cdot \text{kgFFM}^{-1} \cdot \text{day}^{-1}$, there was no difference between pre- and post-treatment measures in the RT group. The RT/W group showed a significant decrease in RMR post-training when expressed in $\text{ml} \cdot \text{min}^{-1}$, $\text{kcal} \cdot \text{day}^{-1}$, and $\text{kcal} \cdot \text{kgFFM}^{-1} \cdot \text{day}^{-1}$. The C group showed no changes in RMR pre- to post-treatment, irrespective of the units of measure.

In order to further examine the changes in RMR with training, an analysis of covariance (ANCOVA) was also performed with age, FM, and FFM as covariates. FFM was the only variable found to be a significant covariate. With FFM as the covariate, no significant differences in RMR were found between any of the groups pre-treatment when expressed as $\text{ml} \cdot \text{min}^{-1}$ or $\text{kcal} \cdot \text{day}^{-1}$. The RT/W group showed a significant decrease in RMR from pre- to post-treatment in both $\text{ml} \cdot \text{min}^{-1}$ and $\text{kcal} \cdot \text{day}^{-1}$.

An analysis of covariance (ANCOVA) was also conducted so that regression equations pre- and post-training could be compared. The results of these comparisons can be seen in Figure 1 (A–C). The regression lines are not statistically different pre- to post-training in the RT (Figure 1-A) or C (Figure 1-C) groups. RMR decreased post-training in the RT/W group. Figure 1-B shows that the slopes of the regression lines for the RT/W group pre- and post-training are not different, but the y-intercept is lower post-training. In this group, for every kilogram of FFM, RMR was lower post-training, suggesting a decrease in the metabolic rate of the FFM post-training.

Table 2 Age, Height, and Body Composition Data

Variable	Pre-treatment			Post-treatment		
	RT (n = 10)	RT/W (n = 9)	C (n = 9)	RT (n = 10)	RT/W (n = 9)	C (n = 9)
Age (years)	39.1 ± 1.8	35.9 ± 1.4	38.9 ± 1.4	Data not available; assumed to be same as pre.		
Height (cm)	168.3 ± 2.3	163.9 ± 1.7	166.4 ± 3.0	Data not available; assumed to be same as pre.		
Mass (kg)	81.1 ± 2.4	74.7 ± 3.3	67.9 ± 2.2	83.1 ± 2.9	76.4 ± 3.2	68.9 ± 2.1
Relative (%) body fat	38.9 ± 0.9	38.7 ± 1.8	35.1 ± 1.2	38.1 ± 0.9	37.7 ± 1.5	35.4 ± 1.1
FFM (kg)	49.5 ± 1.7†	45.6 ± 2.0	43.9 ± 1.2	51.4 ± 1.9*	47.5 ± 2.2*	44.4 ± 1.2
FM (kg)	31.5 ± 1.0	29.0 ± 2.1	23.9 ± 1.4	31.6 ± 1.4	28.8 ± 1.7	24.4 ± 1.4

Note. Data are expressed as mean ± *SE*.

*Significantly different from pre-treatment for same group ($p \leq .05$).

†Significantly different from control, same time ($p \leq .05$).

Table 3 Metabolic Rate Data

Variable	Pre-treatment			Post-treatment		
	RT (n = 10)	RT/W (n = 9)	C (n = 9)	RT (n = 10)	RT/W (n = 9)	C (n = 9)
RMR ml · min ⁻¹	208 ± 9	199 ± 6	202 ± 5	215 ± 9*	191 ± 7*	204 ± 5
kcal · day ⁻¹	1451 ± 62	1389 ± 39	1409 ± 39	1495 ± 63*	1336 ± 42*	1426 ± 38
kJ · day ⁻¹	6071 ± 259	5812 ± 163	5895 ± 163	6255 ± 264*	5590 ± 176*	5966 ± 159
kJ · kgFFM ⁻¹ · day ⁻¹	123.0 ± 2.5†	127.6 ± 2.9	134.7 ± 3.8	122.2 ± 3.3	118.0 ± 2.1*	135.1 ± 4.2
RER	0.82 ± 0.01	0.83 ± 0.01	0.82 ± 0.01	0.81 ± 0.01	0.83 ± 0.01	0.83 ± 0.01
RHR (b · m ⁻¹)	63.4 ± 2.5	66.5 ± 3.2	63.0 ± 3.1	60.5 ± 1.9	59.3 ± 3.0*	62.2 ± 2.8

Note. Data are expressed as mean ± SE.

*Significantly different from pre-treatment for same group ($p \leq .05$).

†Significantly different from control, same time ($p \leq .05$).

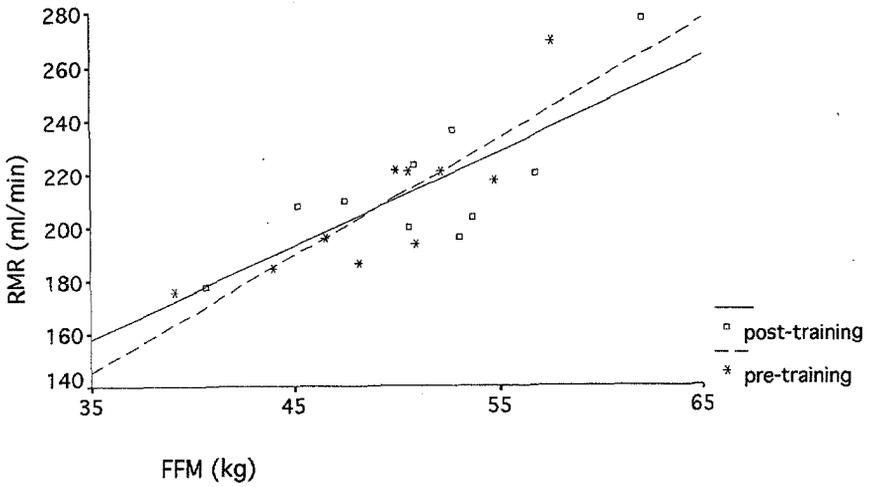


Figure 1-A — RT group.

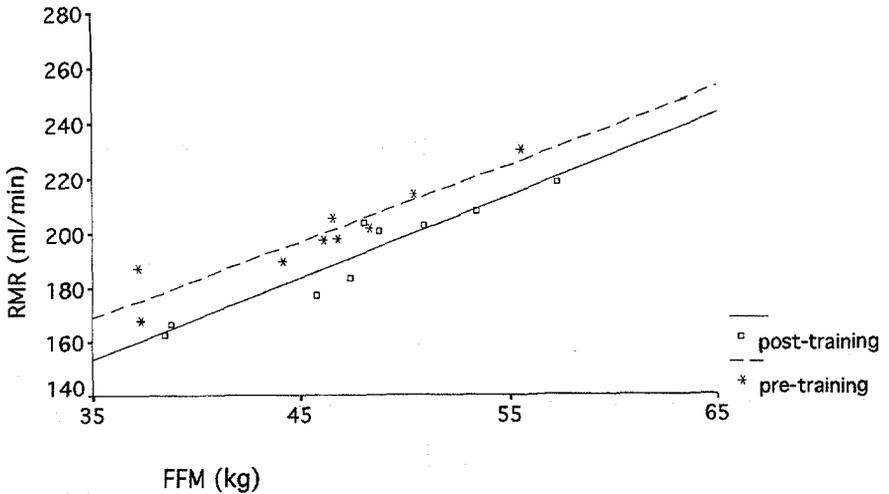


Figure 1-B — RT/W group.

Discussion

This study was designed to determine if RMR is altered following 20 weeks of either resistance training or a combination of resistance training and walking in moderately obese women. It was hypothesized that the resistance training program would significantly increase FFM and thus potentiate RMR. Previous studies have shown that endurance training results in an elevation of RMR. It was therefore hypothesized that the combination of resistance training and walking would further elevate RMR through the additive effects of the increase in FFM and possibly an activation of the sympathetic nervous system (SNS), one explanation that has been suggested

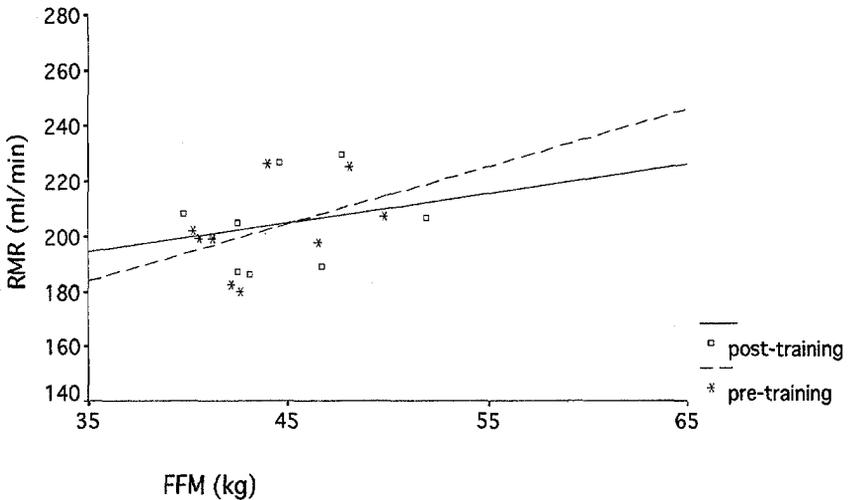


Figure 1-C — C group.

as the mechanism for an increased RMR with endurance training. The results of this study do support the hypothesis that an increase in FFM as the result of RT can increase RMR post-training, while the results do not support the increase in RMR as a result of the RT/W program.

The present study used a 20-week, high frequency and intensity RT protocol in order to maximize possible changes in FFM. The RT/W group followed the RT protocol but also walked for aerobic training. The significant and similar increases in FFM and strength in both the RT and RT/W groups suggests that the resistance training program did result in a significant training effect. The significant increase in $\dot{V}O_{2\max}$ in $L \cdot \text{min}^{-1}$ and decrease in resting HR in the RT/W group is indicative that the walking protocol was a sufficient aerobic training stimulus.

Before continuing with the discussion, it is important to realize that several procedures were instituted in the present study to ensure quality control. Replicate measures of RMR were made both pre- and post-training. The high intraclass correlations found between the two pre- and between the two post-training measurements for RMR in $\text{ml} \cdot \text{min}^{-1}$ and $\text{kcal} \cdot \text{day}^{-1}$ attest to the reproducibility of the data. The use of the heart rate monitor for the measurement of HR_{sleep} for the 8–10 hours prior to the RMR testing was to assure true resting conditions of the subjects. There was excellent agreement between HR_{sleep} and HR_{RMR} both pre- ($R = .91$) and post-training ($R = .89$), suggesting that the RMR measurements were made under true resting conditions.

Consecutive RMR measurements were made at 36–48 and 48–60 hours both pre- and post-training in order to avoid the complication of the acute post-exercise increase in metabolism. RMR was expressed in $\text{ml} \cdot \text{min}^{-1}$, $\text{kcal} \cdot \text{day}^{-1}$, and $\text{kcal} \cdot \text{kgFFM}^{-1} \cdot \text{day}^{-1}$ in order to elucidate whether changes in RMR were due to changes in metabolic size or to an altered metabolic rate of FFM. However, it has been clearly established that the y-intercept of the regression equation of RMR over FFM is not equal to zero, thus expressing the data per kgFFM may bias the results (31). In order to correct for this possible bias, an analysis of covariance (ANCOVA) was also

conducted so that regression equations pre- and post-training could be compared. The results of these comparisons can be seen in Figure 1 (A-C). The regression lines are not statistically different pre- to post-training in the RT (Figure 1-A) or C (Figure 1-C) groups. That is, once the increase in FFM is accounted for in the RT group, RMR is not different, suggesting that the increase in RMR post-training can be at least partially explained by the increase in FFM. The relationship between RMR and FFM is not different in the C group pre- to post-treatment. Irrespective of the method used, RMR decreased post-training in the RT/W group. Figure 1-B shows that the slopes of the regression lines for the RT/W group pre- and post-training are not different, but the y-intercept is lower post-training. In this group, for every kilogram of FFM, RMR was lower post-training, suggesting a decrease in the metabolic rate of the FFM post-training. This was an unexpected finding in the study. Endurance training (ET) has been previously shown to increase (1, 21-26, 29, 38, 39), decrease (44), or have no effect (6, 7, 10, 11, 28, 35-37, 40) on RMR. A tendency for a decrease in SMR was shown in a study by Westerterp (44), where subjects were training for a marathon and lost body mass over the course of the 40-week training period. However, one would not expect a decrease in RMR when subjects are in positive energy balance (i.e., gaining body mass), as was the case in this study.

One possible explanation for the decrease in RMR in the RT/W group is that the subjects might have become heat acclimated from the pre- to the post-training measurement periods. It has been established (2, 19) that submaximal exercise heat production decreases after subjects have undergone a heat acclimation protocol. It has also been documented in the literature that RMR decreases in individuals relocating to live in a tropical climate from temperate zones (14, 16, 17). Resting body core temperature has also been shown to decrease with heat acclimation (2, 19), which might be accompanied by a decrease in RMR. Results from research conducted in Japan (12) suggests that there is an inverse relationship between basal metabolism and ambient temperature. All of the subjects who were in the RT/W protocol in the present study did their walk training outdoors and finished the 20-week training program in either June or August. The average monthly temperatures in Austin, Texas for June and August are 82 °F (54% relative humidity) and 85 °F (49% relative humidity), respectively, compared to 49 °F (59% relative humidity) and 60 °F (53% relative humidity) when they first started training (National Weather Service). It is possible that the subjects had become heat acclimated prior to the post-training RMR measurements.

Another possibility for the decrease in RMR in the RT/W group is that the subjects were in negative energy balance at the time of the post-training measurements. A negative energy balance as a result of exercise has been associated with a decrease in RMR (28, 44). During the last 8 weeks of this study, subjects in the RT/W group increased their walk time and intensity. This could have put them in negative energy balance. Body mass was not monitored throughout the study, making it difficult to determine the state of energy balance. However, it is very unlikely that the subjects were in negative energy balance, since the weight gain in the RT and RT/W groups were similar. The reason for the decrease in RMR in the RT/W group remains unclear.

Analyses of dietary intakes might help to examine energy balance. Dietary intake in the present study was controlled only in the sense that subjects were asked to maintain their current eating habits throughout the duration of the study. Dietary histories were obtained on a monthly basis throughout the study. Results of the

dietary analyses for 16 of the subjects revealed that mean caloric intake did not change from pre- to post-treatment. However, it is obvious from looking at individual subject data that underreporting of calories or under-eating on days of reporting must have occurred. For example, 1 subject gained 5.9 kg of body mass pre- to post-treatment, yet her dietary history indicated that she had not changed her eating patterns. Underreporting of calories has been reported in the literature and confirmed using the doubly labeled water method of measuring energy expenditure (3, 34, 47). This underreporting is especially prevalent in obese women and elite athletic women (34, 47). Although the mean increase in body mass was not significant in any group in the current study, there was a trend for an increase in body mass from pre- to post-treatment in both experimental and control groups. It appears that dietary histories did not provide an accurate measure of normal caloric intake in this population.

It is important to realize that the overall responses in the present study were not the result of outliers in the data. In the RT group, 9 of the 10 subjects showed an increase in RMR. One subject showed a decrease of $17 \text{ ml} \cdot \text{min}^{-1}$. In the RT/W group, 7 of the 9 subjects demonstrated a decrease in RMR, with 2 subjects showing small increases of 3 and $1 \text{ ml} \cdot \text{min}^{-1}$.

Although there have been several longitudinal studies investigating the effects of endurance training on RMR, few studies have been conducted using RT. The results of the RT group in the present study agree with those of previous longitudinal studies (30, 33, 41), while there have been other longitudinal studies (7, 42) that have been unable to demonstrate an increase in RMR with RT. It is important to look closely at the methods used in each of the longitudinal studies in order to determine possible explanations for the discrepancy in their results. It appears that some differences found among these longitudinal studies might be due to the frequency and duration of training, age of the subjects, post-exercise timing of the RMR measurements, and energy balance of the subjects.

The study by Pratley et al. (30) measured RMR after 16-weeks of high-intensity resistance training in 50- to 65-year-old men. RMR increased significantly post-training, when expressed in $\text{kJ} \cdot \text{day}^{-1}$ and per kilogram of FFM. The post-training RMR measurements were made 22–24 hours after the last training session, making it difficult to conclude with certainty that this elevation in RMR was a true increase in RMR and not a part of the excess post-exercise oxygen consumption (EPOC). However, increases in energy expenditure 24 hours post exercise have been associated with intense, long duration exercise (5, 9, 15) as opposed to high intensity resistance training. In a similar study on postmenopausal women (41), resting energy expenditure measured by whole-room calorimetry was determined 48 hours after the last exercise bout. The women in this study (age: 67 ± 1 years) showed a significant increase in mid-thigh muscle area as determined by a CT-scan after 16 weeks of training. The increase seen in RMR was not significant after the increase in muscle area was taken into account, suggesting that the increase in FFM was at least partially responsible for the increase in RMR. Postmenopausal women also served as subjects in the study by Ryan et al. (33). In this study 15 women trained 3 days of the week for 16 weeks. Seven of the women dieted throughout the duration of the study, while the other 8 were instructed to maintain their body weight. The women on the diet lost body mass, while the other 8 showed no change from pre- to post-training. Both groups of subjects showed a trend for an increase in RMR in $\text{kcal} \cdot \text{day}^{-1}$. Once the groups were added together to increase statistical

power, there was a significant increase in RMR post-training. However, the authors of the study did not indicate when the RMR measurements were made relative to the last bout of exercise.

Broeder (7) and Van Etten (42) were unable to demonstrate increases in RMR or sleeping metabolic rate (SMR), respectively, with 12-week RT protocols using young male subjects. Although there was no increase in RMR 48-hours post-exercise in the study by Broeder (7), there was a significant correlation between the changes in pre- to post-treatment FFM and changes in RMR in $L \cdot \text{min}^{-1}$, thus suggesting that an increase in FFM was associated with an increase in RMR. Irrespective of the how the data were expressed there was no significant difference between the pre- and 30-hours post-training SMR in the study by Van Etten et al. (42). In both of these studies the subjects either lost or had no change in body mass from pre- to post-training measurements. These results suggest that although RMR did not increase in these studies, perhaps the RT helped to prevent an attenuation in RMR normally observed during extended periods of negative energy balance.

The reasons for the disagreement between studies that have observed no change in RMR with exercise training compared to the present study and others that have shown an increase or a decrease are not immediately obvious. The present study indicates that RT for a duration of 20 weeks increases RMR in moderately obese women, at least partially due to their increase in FFM. RT/W, however, resulted in a decrease in RMR. Future well-controlled studies that examine the effects of RT and RT/W on RMR will help to provide further insight into what type, intensity, and duration of training is needed to alter RMR. Even small changes in RMR as a result of exercise training can have an impact on a person's total energy expenditure over an extended period of time, which has important implications for long-term weight management. However, other factors that need to be considered for subsequent research include the age and gender of subjects, eating patterns in different subject populations consequent to training, and environmental temperature during training.

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