The Relationship of Mode and Intensity of Training on Resting Metabolic Rate in Women

Heidi K. Byrne and Jack H. Wilmore

The present cross-sectional study was designed to investigate the relationship between exercise training and resting metabolic rate (RMR). The focus of this investigation was to compare RMR in aerobically trained (AT), resistance trained (RT), and untrained (UNT) women. Subjects were also classified as highly trained (HT), moderately trained (MT), or untrained (UNT) in order to examine the relationship between RMR and level of training. Sixty-one women between the ages of 18 and 46 years volunteered to serve as subjects in this study. Each subject completed measurements of body composition, maximal oxygen uptake ($\text{VO}_{2\text{max}}$), and two consecutive measurements of RMR. The data presented show that there was no significant difference in resting metabolic rate between resistance-trained, aerobically trained, and control subjects. However, when grouped by intensity of training, there was a trend for an increased resting metabolic rate (kcal/day) in the highly trained subjects, regardless of mode of training.

Key Words: resting energy expenditure, exercise training, females, body composition

Introduction

Resting metabolic rate (RMR) is the summation of energy expended to sustain the integrated systems of the body, and it constitutes 60% to 75% of an individual’s total daily energy expenditure (9). Several factors have been shown to directly influence RMR, including thyroid hormones, $\beta$-adrenergic stimulation, substrate flux, genetics, body and/or environmental temperature, and stress. Other factors have been shown to be related to RMR, such as body surface area, total body weight, fat-free mass (FFM), gender, age, and aerobic fitness. Of these related factors, the strongest correlation exists between a person’s FFM and RMR (26).

Due to the increasing incidence of obesity in the U.S. (7) and related diseases such as hypertension, diabetes, and elevated blood lipids, scientists are interested in identifying interventions that might increase RMR to facilitate weight loss in obese and overweight populations, and/or to sustain a healthy weight in those who are not obese or overweight. Exercise training has been one of the proposed interventions.
In longitudinal studies of exercise training, RMR has been reported to increase (10, 12, 24), decrease (15, 27), or remain unchanged (5, 21, 25, 29) consequent to training. It has also been suggested that a certain threshold level of aerobic fitness must be attained before there is an elevation in RMR (9). Cross-sectional studies have shown both a positive correlation (14, 16) and no correlation (4, 18, 19) between a person’s aerobic fitness level and RMR. Since RMR is highly correlated with FFM, and since resistance training can substantially increase FFM, it has been postulated that this form of exercise could increase RMR. Whether or not there is an increase in RMR above and beyond the increase associated with increased FFM remains unclear. Previous cross-sectional studies have shown an elevated RMR, independent of FFM, when comparing resistance trained subjects to sedentary controls (11, 22), as well as no difference between the two (1).

Reasons for the discrepancy between studies is unclear but could include differences in sample size, differences in the timing of the RMR measurement in relation to the last bout of exercise, methodological differences in how RMR is measured, differences in how RMR is expressed (i.e., units of measure), age, gender, or body composition of subjects. Well-controlled cross-sectional studies are needed in order to understand the interrelationships between exercise training and RMR. The focus of this investigation was to compare RMR in aerobically trained (AT), resistance trained (RT), and untrained (UNT) women. Subjects were also classified as highly trained, moderately trained, or untrained, in order to examine the relationship between RMR and level of training.

**Methods**

**Subjects**

Sixty-one women between the ages of 18 and 46 years, recruited from The University of Texas at Austin and the surrounding community, volunteered to serve as subjects in this study. Sixty of the subjects were normally menstruating, and 1 subject was amenorrheic. None of the subjects had a history of oral contraceptive use for the past year prior to participation. All subjects were weight-stable (±3 kg) for the past year, had not been clinically diagnosed with an eating disorder, and had less than 37% body fat. 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. Each subject completed measurements of body composition, maximal oxygen uptake (VO\textsubscript{2max}), and two consecutive measurements of RMR.

**Procedures**

During the initial screening visit, each subject completed questionnaires to determine health status, exercise history, and menstrual history. 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. The health history questionnaire was completed to ensure that each subject was in good health and did not have a history of cardiovascular or other chronic limiting diseases.

During the first visit each subject performed a graded exercise protocol on a
motorized treadmill to assess $\dot{V}O_2 \text{max}$. 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 3.5 mph at 0% grade for 2 min. The speed was then increased by 1.0 mph every minute until a peak speed that the subject could comfortably maintain was achieved. At this time the speed was kept constant, and the grade increased 2.5% every minute until the subject reached volitional exhaustion. The $\dot{V}O_2$, volume of expired carbon dioxide ($\dot{V}CO_2$), 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. Heart rate (HR) was measured by telemetry at 5-s intervals and recorded at 1-min intervals using a Polar™ heart rate monitor (Montvale, NJ). $\dot{V}O_2 \text{max}$ 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, the respiratory exchange ratio was greater than 1.10, and the maximal heart rate was $\geq 95\%$ of the subject’s age-predicted value.

Subjects were then categorized, based on training status, into one of the previously determined groups: untrained (UNT), moderately trained (MT), and highly trained (HT). The UNT group was comprised of 18 subjects who had not participated in any current regular exercise and 2 subjects who had participated in very low levels of activity. The moderately trained group was divided into individuals who only participated in aerobic activity two to three times per week (moderately aerobically trained or MAT) and those who also performed resistance training 2–3 days per week (moderately resistance trained or MRT). All subjects in the MAT group were required to have $\dot{V}O_2 \text{max}$ values of between 35–50 ml · kg$^{-1}$ · min$^{-1}$. There were no moderately trained subjects in the study who reported only resistance training, thus the combination of activities in the MRT group. The subjects in the MRT group considered RT their most likely used mode of exercise, with aerobic training secondary. The highly trained individuals were also further divided into those individuals who participated predominantly in aerobic training a minimum of 5 days per week (highly aerobically trained or HAT) and those who participated predominantly in resistance-type training a minimum of 4 days per week (highly resistance trained or HRT). Of the 10 HAT subjects, 3 also performed minimal resistance training. Of the 10 HRT subjects, 4 also participated in moderate aerobic training, and 1 participated in intense resistance and aerobic training. Each subject in the study was carefully placed into the appropriate group based on fitness level and/or current training status.

Body composition was assessed during a subsequent 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 (2), with residual lung volume determined by the oxygen dilution method of Wilmore et al. (30). Relative body fat was estimated from body density by the equation of Lohman (8). Fat mass (FM) and FFM were obtained by the following equations: FM = (mass * relative fat) / 100; and FFM = mass – FM.

During this visit, or on a subsequent visit to the laboratory, each subject was familiarized with the face mask or dilution 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 refrain from all strenuous activity for a minimum period of 42 hours prior to the start of the first of two 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. 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 and to eat similarly on days prior to 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). Leads were attached to the chest electrodes and interfaced to a Colin automated blood pressure monitor (Colin Medical Instruments, San Antonio, TX), which also has the capability to measure heart rate. 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 at 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. The vast majority of subjects were tested using the dilution mask, while several were tested using the face mask due to laboratory testing conflicts and the availability of only one dilution mask.

A SensorMedics 2900 Metabolic Measurement Cart (MMC) was used to obtain RMR using 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 both measurement days. Our laboratory has found very close agreement between the two masks when used on the same individuals (within 20 ml/min). 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.

**Statistical Analyses**

Sample size for this study was designed to provide a power probability of 0.80 for identifying group differences significant at the $p \leq .05$ level (6). An intraclass correlation and an ANOVA with a repeated measure were performed to determine between-trial reliability between the repeat trials for RMR (ml/min), overnight sleeping heart rate (HRsleep), heart rate during the rest period prior to the RMR (HRpreRMR), and heart rate during the RMR (HRRMR). An analysis of variance (ANOVA) was used to analyze the differences between groups for RMR expressed as ml · min⁻¹, ml · kg⁻¹ · min⁻¹, kcal · day⁻¹, and kcal · kgFFM⁻¹ · day⁻¹, and for all other dependent variables (i.e., relative fat, body weight, FFM, FM, VO₂max, HRRMR). Data were analyzed with subjects classified by fitness levels as previously described (HAT, HRT, MAT, MRT, UNT), by type of training used (AT vs. RT vs. UNT), and also by level of training regardless of mode.
(HT vs. MT vs. UNT). Tukey’s post hoc test was used to explore significant main effects and interactions when groups of equal number were compared. Single degree of freedom contrasts were used when groups of unequal number were compared. In addition, an analysis of covariance (ANCOVA) was used to determine if there was a significant difference between the groups for RMR when the relationship between FFM and RMR was accounted for in the present population. Multiple regression analyses were conducted using RMR as the dependent variable and \( \text{VO}_{2\text{max}} \), training mode and intensity, and kilograms of FFM as the independent predictors for the entire subject population. The analyses were conducted using the SPSS v. 6.1.1 statistical program for the Macintosh computer. Data are reported as mean ± SE.

**Results**

**Subject Characteristics**

Subject characteristics are presented in Tables 1 and 2. Table 1 shows characteristics when subjects were categorized by type of training (AT vs. RT vs. UNT). Table 2 shows characteristics when subjects were categorized by level of training (HT vs. MT vs. UNT). As expected by the experimental design, there was a large range of values for aerobic capacity and relative body fat, consistent with the recruitment of a widespread population of varying fitness levels.

**Aerobic Capacity**

Cardiovascular endurance capacity data are presented in Tables 1 and 2. Table 1 shows that both AT and RT subjects had greater \( \text{VO}_{2\text{max}} \) values than UNT subjects when expressed in either L · min\(^{-1}\) or ml · kg\(^{-1}\) · min\(^{-1}\). When expressed in ml · kg\(^{-1}\) · min\(^{-1}\), the AT group had higher \( \text{VO}_{2\text{max}} \) values than the RT group. When expressed relative to fitness level (Table 2), both the HT and MT groups had greater \( \text{VO}_{2\text{max}} \) values in L · min\(^{-1}\) and ml · kg\(^{-1}\) · min\(^{-1}\) compared to the UNT group. The HT group had greater \( \text{VO}_{2\text{max}} \) values in L · min\(^{-1}\) and ml · kg\(^{-1}\) · min\(^{-1}\) compared to the MT group.

**Body Composition**

Body composition data are presented in Tables 1 and 2. Table 1 shows that the AT group had a lower body mass than the UNT group, but there was no difference in mass between the AT and RT groups. Both AT and RT subjects had significantly lower percentages of body fat when compared to the UNT subjects when measured hydrostastically. There were no differences in percent body fat between AT and RT subjects. AT and RT subjects also had greater FFM and less FM than the UNT subjects, with no difference between the AT and RT groups. When expressed relative to the level of training (Table 2), the HT and MT groups had lower percentages of body fat than the UNT group, and the HT group had a lower percentage of body fat than the MT group when measured hydrostastically. Both the HT and MT groups had significantly greater FFM and lower FM than the UNT group. The HT group also had less FM than the MT group, but their FFM values were similar.

**Reliability of RMR and HR Measurements**

Both an intraclass correlation and an ANOVA with repeated measures were used to examine the reliability for RMR (ml · min\(^{-1}\) and kcal · day\(^{-1}\)), HR\(_{\text{sleep}}\), HR\(_{\text{preRMR}}\), and
Table 1  Characteristics of the 61 Female Subjects by Type of Training

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Total</th>
<th>Aerobic (AT)</th>
<th>Resistance (RT)</th>
<th>Untrained (UNT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 61)</td>
<td>(n = 21)</td>
<td>(n = 20)</td>
<td>(n = 20)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>31.0 ± 1.0</td>
<td>29.3 ± 1.4†</td>
<td>27.8 ± 1.7†</td>
<td>36.0 ± 1.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166.5 ± 0.8</td>
<td>167.6 ± 1.1</td>
<td>165.3 ± 1.1</td>
<td>166.6 ± 1.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>62.8 ± 0.9</td>
<td>59.7 ± 1.1†</td>
<td>62.5 ± 1.7</td>
<td>66.4 ± 1.6</td>
</tr>
<tr>
<td>BMI (m² · kg⁻¹)</td>
<td>22.7 ± 0.3</td>
<td>21.3 ± 0.4†</td>
<td>22.9 ± 0.6*</td>
<td>23.9 ± 0.4</td>
</tr>
<tr>
<td>Hydrostatic relative fat (%)</td>
<td>24.0 ± 1.0</td>
<td>18.9 ± 1.3†</td>
<td>20.7 ± 1.3†</td>
<td>32.6 ± 0.9</td>
</tr>
<tr>
<td>Fat free mass (kg)</td>
<td>47.3 ± 0.6</td>
<td>48.2 ± 1.7†</td>
<td>49.2 ± 1.0†</td>
<td>44.5 ± 0.9</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>15.4 ± 0.8</td>
<td>11.4 ± 1.0†</td>
<td>13.2 ± 1.2†</td>
<td>21.8 ± 1.0</td>
</tr>
<tr>
<td>VO₂max (L · min⁻¹)</td>
<td>2.65 ± 0.06</td>
<td>2.97 ± 0.08†</td>
<td>2.83 ± 0.09†</td>
<td>2.13 ± 0.05</td>
</tr>
<tr>
<td>VO₂max (ml · kg⁻¹ · min⁻¹)</td>
<td>42.0 ± 1.20</td>
<td>49.2 ± 1.60†</td>
<td>45.0 ± 1.08†*</td>
<td>31.4 ± 0.76</td>
</tr>
</tbody>
</table>

*Note. Values are mean ± SE.
†Significantly different than UNT group (p ≤ .05).
*Significantly different than AT group (p ≤ .05).
Table 2  Characteristics of the 61 Female Subjects by Level of Training

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Highly trained (HT) (n = 20)</th>
<th>Moderately trained (MT) (n = 21)</th>
<th>Untrained (UNT) (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>30.7 ± 1.3</td>
<td>26.5 ± 1.7†</td>
<td>36.0 ± 1.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166.9 ± 1.1</td>
<td>166.1 ± 1.1</td>
<td>166.6 ± 1.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>59.7 ± 1.2†</td>
<td>62.3 ± 1.6</td>
<td>66.4 ± 1.6</td>
</tr>
<tr>
<td>BMI (m²·kg⁻¹)</td>
<td>21.5 ± 0.5†</td>
<td>22.6 ± 0.6</td>
<td>23.9 ± 0.4</td>
</tr>
<tr>
<td>Hydrostatic relative fat (%)</td>
<td>16.3 ± 0.8†</td>
<td>23.0 ± 1.3†*</td>
<td>32.6 ± 0.9</td>
</tr>
<tr>
<td>Fat free mass (kg)</td>
<td>49.8 ± 0.8†</td>
<td>47.6 ± 0.9†</td>
<td>44.5 ± 0.9</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>9.8 ± 0.6†</td>
<td>14.6 ± 1.2†*</td>
<td>21.8 ± 1.0</td>
</tr>
<tr>
<td>VO₂max (L·min⁻¹)</td>
<td>3.09 ± 0.09†</td>
<td>2.72 ± 0.07†*</td>
<td>2.13 ± 0.05</td>
</tr>
<tr>
<td>VO₂max (ml·kg⁻¹·min⁻¹)</td>
<td>51.2 ± 1.39†</td>
<td>43.2 ± 0.89†*</td>
<td>31.4 ± 0.76</td>
</tr>
</tbody>
</table>

Note. Values are mean ± SE.
†Significantly different than UNT group (p ≤ .05).
*Significantly different than HT group (p ≤ .05).

HR<sub>RMR</sub>. The ANOVA procedures indicated that there were no significant differences between the two measurements for RMR in ml/min or kcal · day⁻¹. The intraclass correlations were also high [i.e., R = 0.89 (ml · min⁻¹) and 0.90 (kcal · day⁻¹)]. There were no significant differences between the two measurements for HR<sub>sleep</sub>, HR<sub>preRMR</sub>, or HR<sub>RMR</sub>. Additionally, high intraclass correlations were found between each set of measures, with coefficients of R = 0.96, 0.95, and 0.96 for HR<sub>sleep</sub>, HR<sub>preRMR</sub>, and HR<sub>RMR</sub>, respectively. There was a high correlation and no significant difference between HR<sub>sleep</sub> and HR<sub>RMR</sub> (R = .92), suggesting that the RMR measurements were made under true resting conditions.

**Resting Metabolic Rate**

RMR data are presented in Table 3. When compared by training mode, there were no significant differences in RMR between AT, RT, or UNT when expressed in ml · min⁻¹, kcal · day⁻¹, or kcal · kgFFM⁻¹ · day⁻¹. When expressed in ml · kg⁻¹ · min⁻¹, RMR was higher in the AT and RT subjects than in the UNT subjects. There was no difference in RER between the groups when compared by training mode. When compared by level of training, there were no significant differences in RMR between HT, MT, or UNT when expressed in ml · min⁻¹, kcal · day⁻¹, or kcal · kgFFM⁻¹ · day⁻¹. When expressed in ml · kg⁻¹ · min⁻¹, RMR was higher in the HT and MT subjects than in the UNT subjects. There was no difference in RER between the groups when compared by training level.

Correlation analyses revealed the relationship between RMR and fitness levels for all 61 subjects. A significant positive correlation was found between VO₂max and RMR when expressed in kcal · day⁻¹ (r = .25, p ≤ .05) or ml · kg⁻¹ · min⁻¹ (r = .68, p ≤ .05) and was very close to achieving significance (r = .25, p = .055) when expressed in ml · min⁻¹. However, when RMR was expressed relative to FFM (i.e., kcal · kgFFM⁻¹
Table 3    Metabolic Rate Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>By training mode</th>
<th>By training level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AT</td>
<td>RT</td>
</tr>
<tr>
<td>RMR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ml · min⁻¹</td>
<td>206 ± 4</td>
<td>207 ± 4</td>
</tr>
<tr>
<td>kcal · day⁻¹</td>
<td>1442 ± 26</td>
<td>1451 ± 28</td>
</tr>
<tr>
<td>ml · kg⁻¹ · min⁻¹</td>
<td>3.43 ± 0.08†</td>
<td>3.29 ± 0.06†</td>
</tr>
<tr>
<td>kJ · day⁻¹</td>
<td>6033 ± 109</td>
<td>6071 ± 117</td>
</tr>
<tr>
<td>kJ · kg FFM⁻¹ · day⁻¹</td>
<td>125 ± 2.5</td>
<td>124 ± 2.1</td>
</tr>
<tr>
<td>RER</td>
<td>0.82 ± .01</td>
<td>0.84 ± .01</td>
</tr>
</tbody>
</table>

Note. Data are expressed as mean ± SE.
†Significantly different from UNT, same mode or level (p ≤ .05).
*Significantly different from HT, same level (p ≤ .05).
· day$^{-1}$), there was no relationship between RMR and $\dot{V}O_{2\text{max}}$.

Multiple regression analyses using RMR as the dependent variable and $\dot{V}O_{2\text{max}}$, training mode and level, kilograms of FFM, minutes per week spent training, and years of training as the independent predictors indicated that only FFM was a significant predictor of RMR when expressed as either kcal · day$^{-1}$ ($p = .00$) or ml · min$^{-1}$ ($p = .00$).

**Discussion**

This study was designed to determine if RMR is different in aerobically trained and resistance trained women when compared to untrained women, and whether a difference exists between highly and moderately trained women when compared to untrained women. It was hypothesized that the women who were trained either aerobically or through resistance training would have an elevated RMR when compared to untrained subjects. It was also hypothesized that subjects with the greatest level of training would demonstrate the highest RMR. The results of this study do not support the hypotheses that aerobically or resistance trained subjects have an elevated RMR, or that highly trained subjects have a greater RMR compared to moderately trained or untrained subjects. RMR was found to be correlated to $\dot{V}O_{2\text{max}}$ (ml · kg$^{-1}$ · min$^{-1}$) when RMR was expressed as either kcal · day$^{-1}$ or ml · kg$^{-1}$ · min$^{-1}$, and was close to being significant when expressed in ml · min$^{-1}$. However, when RMR was expressed relative to FFM, there was no correlation between fitness level and RMR.

These results are in agreement with several studies but are in conflict with others. Several studies have shown a higher RMR in endurance trained athletes when compared to untrained individuals. Poehlman et al. (13) found a higher RMR in highly trained men compared to untrained men when RMR was measured 24 hours after the last exercise session. This elevation was persistent when RMR was expressed relative to FFM. In a related study, Poehlman et al. (14) found an elevated 24-hour post-exercise RMR, expressed both in absolute terms and relative to FFM, in highly trained male runners when compared to moderately trained or untrained men. In a further study, Poehlman et al. (16) found a significant relationship between RMR and $\dot{V}O_{2\text{max}}$ in nonobese women when RMR was measured 36 hours after any previous exercise bout. The relationship remained significant even after controlling for FFM. Tremblay et al. (23) found an elevated RMR in elite endurance athletes when compared to untrained individuals when RMR was measured 16 hours after the last bout of previous exercise. Measurements of RMR made 16–24 hours post-exercise are difficult to interpret due to the possible confounding effects of the acute increase in metabolism associated with the excess post-exercise oxygen consumption (EPOC).

Several studies have not shown a relationship between fitness level and RMR once RMR was expressed relative to FFM. Sharp et al. (19) examined the relationship between aerobic fitness level and total daily energy expenditure (including, but not limited to, RMR) as measured by whole room calorimetry in a group of adult men and women. Results indicated that, after accounting for FFM, $\dot{V}O_{2\text{max}}$ did not explain a significant amount of the remaining variation in energy expenditure. Metabolic rate in this study was measured 36 hours after the last bout of exercise. Broeder et al. (3) also failed to show any significant differences in RMR between trained and untrained men when expressed relative to FFM when RMR was measured at least 48 hours after the last exercise session. Additionally, regression analyses did not show a
relationship between fitness level and RMR relative to FFM. In a more recent study by Smith et al. (20), a significant correlation between RMR and aerobic fitness levels in 34 young women was shown to exist. However, this relationship was no longer evident when RMR was expressed relative to FFM.

In three cross-sectional studies that incorporated resistance trained individuals, Poehlman et al. (11) found that RMR relative to FFM was 5% higher in aerobically trained males compared with resistance trained males, and was 10% higher in aerobically trained males compared to untrained males. RMR in this study was measured 36 to 48 hours after the last exercise bout. In a study examining RMR in young women subjects (1), both aerobically trained and resistance trained women were found to have higher 36-hour post-exercise absolute RMR values when compared to control subjects. Once RMR was adjusted for differences in FFM between groups, the aerobically trained group showed an elevated RMR when compared to both the resistance trained or control subjects. In a follow-up study on middle-aged women (22), RMR measured 48 hours after the last bout of exercise was found to be significantly higher in aerobically and resistance trained women, independent of differences in FFM. No differences in RMR were noted between resistance trained and aerobically trained groups.

There are several factors that could account for the discrepancies among cross-sectional studies, including a lack of statistical power due to a low number of subjects, timing of RMR measurements, and actual training status of subjects. Units of measure used to express RMR might also account for the differences in results observed between studies investigating training status and RMR. Several procedures were instituted in this study to ensure quality control. Replicate measures of RMR were made on all subjects. The high intraclass correlations found between measurements for RMR in ml · min⁻¹ and kcal · day⁻¹ attest to the reproducibility of the data. The use of the heart rate monitor for the measurement of HRsleepl and HRmRMR (R = .92), suggesting that the RMR measurements were made under true resting conditions. Additionally, the first of the two consecutive RMR measures was made approximately 42 hours after the last bout of exercise in order to avoid the confounding factor of EPOC. Training status was also controlled. In order to qualify for the MT or HT groups, each subject had to have the appropriate pre-defined VO2max and had to be concurrently training at a level that would place her into that specific group. All but 2 of the subjects in the UNT group were not exercising on a regular basis, while 2 engaged in very light exercise.

Although steps were taken to ensure quality control, some care should be taken when interpreting the data from this study. Subjects were assigned to level and mode of training based on VO2max values, perceived levels of training (all highly trained individuals reported their training as “very hard” or “intense,” whereas moderately trained individuals reported their training sessions as “moderate”), and the investigators’ specific knowledge of the subjects. Maximal strength data and percentages of 1-RM training efforts were not measured. Although we feel confident that each subject was placed in the appropriate group, the lack of objective measurements regarding this assignment is a limitation of the study. Additionally, there was some overlap between subject and mode of training in the MRT, HRT, and HAT groups. Specifically, subjects involved in only moderate resistance training could not be found. Therefore, subjects in the MRT group considered RT to be their most likely
mode of exercise, but they also typically jogged or did some other type of aerobic exercise twice a week (primarily for weight control). Of the 10 HAT subjects, 3 also did minimal resistance training. Of the 10 HRT subjects, 4 participated in moderate aerobic training, and 1 was highly aerobically trained as well as resistance trained. Therefore, although we feel justified with the mode and level of exercise assignments, these are caveats to this study. Ideally, this study should be replicated with subjects who exercise exclusively with one mode of training or the other and where training intensity levels are measure relative to maximal strength.

In the present study, RMR was expressed in ml · min⁻¹, ml · kg⁻¹ · min⁻¹, and/or \( \dot{V}O_2 \text{max} \), kcal · day⁻¹, and kcal · kgFFM⁻¹ · day⁻¹ in order to elucidate whether differences in RMR were due to differences in metabolic size or to an altered metabolic rate of the FFM. When RMR was expressed in ml · min⁻¹, kcal · day⁻¹, or kcal · kgFFM⁻¹ · day⁻¹, there were no differences between any of the groups by mode or intensity of training. When RMR was expressed in ml · kg⁻¹ · min⁻¹, a significant difference in RMR was observed between groups, with both the AT and RT or HT and MT groups exhibiting higher RMR values than UNT subjects. However, expressing the data in this manner is thought possibly to bias the results. Since the UNT subjects have a larger mass and greater percentage of body fat, by dividing RMR in ml · min⁻¹ by body weight, RMR is lower in the UNT group. In order to more accurately examine metabolic differences between groups, RMR was expressed in kcal · kgFFM⁻¹ · day⁻¹. 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 also bias the results (17). In order to correct for this possible bias, an analysis of covariance (ANCOVA) was also conducted so that regression equations between groups could be compared. The results of these comparisons can be seen in Figures 1 and 2. These figures show that there were no differences between the slopes of the regression lines for the AT, RT, or UNT groups (Figure 1, \( p = .75 \)), or for the HT, MT or UNT groups (Figure 2, \( p = .94 \)). That is, the relationship between RMR and FFM was not different between groups when compared by mode or level of training.

In summary, the data presented show that there were no significant differences in RMR between aerobically trained or resistance trained women versus untrained women. Additionally, highly trained women (either aerobically or resistance trained) did not exhibit elevated RMR values when compared to untrained women. However, although it has been suggested that comparisons of RMR should be made relative to

![Figure 1 — RMR versus FFM by training mode.](image-url)
FFM, in the context of this study, it is important to realize that when comparing RT and AT to UNT subjects, one of the reasons for an elevated RMR in the trained subjects, particularly those who resistance train, could be an increased metabolic size or an increased FFM. In this study, the HT group was close to achieving a significantly higher metabolic rate in kcal · day\(^{-1}\) when compared to the UNT group \((p < .07)\), and the HT and MT groups both had greater FFM than the UNT group. Once expressed relative to FFM, a trend toward an increased RMR in the HT group disappeared, suggesting that at least part of a potential increase in RMR could have been due to an increase in FFM. The multiple regression analyses, which showed that FFM was the only significant predictor of RMR, would also suggest that FFM is an important factor in the potentiation of RMR in trained individuals. Although the HT group did not exhibit a statistically greater FFM, the FFM in this group was 2.2 kg greater than in the MT group. Other mechanisms, such as increased sympathetic nervous system activity or a higher substrate flux, could also increase RMR in HT individuals.

Regardless of mechanism, an increased RMR in trained individuals could have the very important function of contributing to the prevention of weight gain. The average American gains a pound of body weight per year beginning at age 25 \((28)\). For RMR to have any effect on chronic energy balance and thus obesity risk, caloric expenditure over an extended period of time must be considered. Although not statistically different (although HT was close at \(p < .07\)), the RMR values in the experimental groups could have important implications for weight management. The average RMR values in the experimental groups were higher than controls by between 60 and 90 kcal · day\(^{-1}\), depending on group. This higher average RMR translates into between a 21,900 to 32,850 greater kcal expenditure per year, which when divided by 3,500 kcal · pound\(^{-1}\) (per pound of weight change) has significant implications for the prevention of obesity (6–9 pounds). When interpreted from this point of view, the findings of this study suggest that exercise training, regardless of intensity or mode, most likely plays an important role in the prevention of obesity, through both an elevation in RMR and the caloric expenditure associated with the exercise bout itself. Due to the limitations of cross-sectional studies, future longitudinal studies examining mode and intensity of training on changes in RMR will be valuable.

References


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