Relationship between maximum aerobic power and resting metabolic rate in young adult women

D. A. Smith, J. Dollman, R. T. Withers, M. Brinkman, J. P. Keeves, and D. G. Clark. Relationship between maximum aerobic power and resting metabolic rate in young adult women. J. Appl. Physiol. 82(1): 156–163, 1997.—The literature is inconclusive as to the chronic effect of aerobic exercise on resting metabolic rate (RMR), and furthermore there is a scarcity of data on young women. Thirty-four young women exhibiting a wide range of aerobic fitness (maximum aerobic power \( \text{VO}_{2\text{max}} = 32.3–64.8 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \)) were accordingly measured for RMR by the Douglas bag method, treadmill \( \text{VO}_{2\text{max}} \), and fat-free mass (FFM) by using Siri's three-compartment model. The interclass correlation \((n = 34)\) between RMR (kJ/h) and \( \text{VO}_{2\text{max}} / \text{FFM}^2 \) (ml·kg\(^{-1} \cdot \text{min}^{-1} \)) was significant \((r = 0.39, P < 0.05)\). However, this relationship lost statistical significance when RMR was indexed to FFM and when partial correlation analysis was used to control for FFM differences. Furthermore, multiple linear-regression analysis indicated that only FFM emerged as a significant predictor of RMR (kJ/h). When high-fit \((n = 12)\) and low-fit \((n = 12)\) groups were extracted from the cohort on the basis of \( \text{VO}_{2\text{max}} \) scores, independent \( t \) tests revealed significant between-group differences \((P < 0.05)\) for RMR \((\text{kJ} / \text{kg} \cdot \text{h}^{-1})\) and \( \text{VO}_{2\text{max}} \) \((\text{ml} / \text{kg} \cdot \text{h}^{-1})\), but not for RMR \((\text{kJ} / \text{h})\), RMR \((\text{kJ} / \text{kg} \cdot \text{FFM}^{-1} \cdot \text{h}^{-1})\), and FFM. Analysis of covariance of RMR \((\text{kJ} / \text{h})\) with FFM as the covariate also showed no significant difference \((P = 0.56)\) between high- and low-fit groups. Thus the results suggest that 1) FFM accounts for most of the differences in RMR between subjects of varying \( \text{VO}_{2\text{max}} \) values and 2) the RMR per unit of FFM in young healthy women is unrelated to \( \text{VO}_{2\text{max}} \).

**METHODS**

Subjects. Thirty-four women of excellent general health and spanning a wide range of maximal aerobic power \( ([\text{VO}_{2\text{max}}] = 32.3–64.8 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) \) were recruited from the local community. Subjects were young \((19.3–31.4 \text{ yr}), \) nonobese \([\text{Quetelet's index} = 18.4–27.3 \text{ kg/m}^2, \text{body fat (BF)} = 16.5–35.0\%]\), self-reported mass stable \((\pm 2 \text{kg})\) during the preceding year, nonsmokers, and not suffering from diseases or taking any medications that are known to affect energy metabolism or restrict exercise testing, and none had a history of any clinical eating disorders.

Written informed consent was obtained from each subject after the nature, purpose, and possible risks of the study were explained. Ethical approval for this study was obtained from the Committee on Clinical Investigation, Flinders Medical Centre.

Habitation visit. Subjects visited the laboratory before the collection of any data for an habituation RMR test and treadmill run. In addition to the benefits of reducing subject anxiety for the following RMR and \( \text{VO}_{2\text{max}} \) tests, each subject's heart rate \((\text{HR})\) response to \( \text{VO}_{2\text{max}} \) test helped identify the optimal running speed for her \( \text{VO}_{2\text{max}} \) test.

RMR. RMR was determined by open-circuit indirect calorimetry on 2 days during the middle-to-late follicular phase of the menstrual cycle (days 1–7 after menstruation). The lower of these two measurements was used in further calculations. Subjects were 12-h fasted, having consumed a standardized meal before 8 p.m. of the preceding evening; were euedrated; and had refrained from exercise for at least 36 h. After being transported to the laboratory for arrival between 7:00 and 8:30 a.m., in a relaxed state, subjects voided and then donned a preweighed hospital gown before having their nude body mass measured to the nearest 25 g. After supine rest for 50 min in a thermoneutral environment \((24 ± 0.5 {\circ}\text{C})\), oxygen consumption \((\text{VO}_{2})\) was measured by the collection of expirate through an R2600 Hans Rudolph respiratory valve \((\text{Kansas City, MO})\) and into a 150-liter Douglas bag \((\text{Plysys, Bucking-}

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THE RESTING METABOLIC RATE (RMR) is the energy required by the rested and postabsorptive body to maintain physiological processes. It normally comprises 60–75% of daily energy expenditure, and most of the interindividual variability is explained by such factors as age, sex, genetics, body composition, body temperature, and energy balance (27). Factors that potentiate interindividual variability is explained by such factors as age, sex, genetics, body composition, body temperature, and energy balance (27). Factors that potentiate RMR will, therefore, impact on energy balance and reduce the risk of health disorders associated with excess fat stores.

Recent studies examining the effect of aerobic fitness on RMR have been equivocal in their outcomes. Some investigations report a positive relationship between aerobic fitness and RMR (cross-sectional studies: 3, 4, 31, 33, 38, 47; longitudinal studies: 20, 23, 30, 47), whereas others do not (cross-sectional studies: 1, 7, 14, 19, 34, 51; longitudinal studies: 5, 8, 49). These disparate results can be attributed to various methodological factors, including design of longitudinal and cross-sectional studies; sample sizes and statistical power; measurement errors for RMR and body composition; statistical treatment of the data to account for age, gender, body composition, and other covariates known to influence RMR; short-term energy balance; pretest-conditions of subjects; time span between the previous bout of exercise and RMR measurement; and criteria for selecting and classifying subjects into trained and untrained groups. Furthermore, few studies have investigated the influence of aerobic fitness on RMR in premenopausal women, presumably because of the periodicity of RMR with the menstrual cycle (6, 26). These issues were acknowledged in the design of the present cross-sectional study that investigated the influence of aerobic fitness and body composition on the RMR of young healthy women.
hamshire, UK) that had been previously flushed with the subject’s expirate and evacuated. Collections were made for two 10-min periods separated by 15 min during which time the mouthpiece and noseclip were removed while the subject remained relaxed in the supine position. A third 10-min collection was made if the VO₂ of the first two trials differed by >5%. This occurred on only 4 of the 68 days of RMR testing, and on those occasions the two closest values were averaged. The CO₂ (model LB-2, Sensormedics, Yorba Linda, CA) and O₂ (model S-3A, Ametek, Pittsburgh, PA) concentrations of the dry mixed expirate were determined by gas analyzers that were calibrated before each expire collection by using Lloyd-Haldane-verified gases that spanned the physiological range of measurement. Gas volumes were measured by a Parkinson Cowan CD-4 dry gas meter; the accuracy of this instrument was checked daily against a 350-liter Tissot gasometer (Warren E. Collins, Braintree, MA). The resultant VO₂ and respiratory exchange ratio (RER) values were then converted to kilojoules per hour (18), and the average of the two trials was regarded as the RMR for that day. Our intraday (subject 1: 5 RMR trials on the same day) and interday (subject 2: 5 RMR trials on alternate days) coefficients of variation were 2.2 and 2.4%, respectively.

HR was monitored continuously during the RMR trials by using an electrocardiogram (ECG; B-D Electrodyne model ST-219, Becton Dickinson, Sharon, MA), and oral temperature (Toral) was measured by a calibrated digital clinical thermometer on three occasions during each RMR trial.

Fat-free mass. All tests were conducted in the morning when subjects were 12-h fasted, were euhydrated, and had refrained from exercise for 36 h. To minimize inter- and intra- subject biological variability, all tests of body composition were conducted on the same day and within 3 days of the RMR measurements. Fast-free mass (FFM) was determined by using Siri’s three-compartment body composition model (45) as follows.

1) Body density (BD) was determined by underwater weighing at residual volume (RV). The ventilated RV was measured by helium dilution before and after the underwater mass trials with the subject immersed to neck level. The average of the three heaviest immersed masses, body mass in air, the mean RV, and a correction for water density were used to calculate BD. The intraclass correlation for test-retest reliability for the BD measurement of 6 women (19–34 yr, 20.1–33.9% BF) was 0.98, and the mean of absolute differences was 0.0018 g/cm³.

2) Total body water (TBW) was measured by isotopic dilution using a deuterium (²H) dose of 40 mg H₂O/kg. A saliva sample was taken from the subjects on arrival at the laboratory to determine the background enrichment of ²H₂O. Subjects then ingested the ²H₂O dose (~100 g), which was followed by three distilled water rinsings of ~30 g each. Subjects were then required to remain seated until a second saliva sample was taken 3.5 h later. The ²H concentrations in the doses and saliva samples were measured on an isotope-ratio mass spectrometer (model 602D, V. G. Micromass, Manchester, UK), which was calibrated against Vienna Standard Mean Ocean Water and International Atomic Energy Agency enriched standards 302A and 302B. In the calculation of the isotope dilution space, corrections were made for the volume of urine passed during the equilibration period and the 4% exchange of ²H with nonaqueous hydrogen (42). The intraclass reliability for repeated measurements of TBW in five women (20–28 yr, TBW = 23.22–35.79 kg, 20.1–37.0% BF) was 0.995, and the mean of absolute differences was 0.38 kg.

VO₂max. VO₂max was measured by using a model 18–60 Quinton treadmill (Seattle, WA). Minute ventilation was monitored by a calibrated volume transducer (P. K. Morgan, Kent, UK) that was connected to the inspiratory port of an R2700 Hans Rudolph respiratory valve. HR was measured during the VO₂max test as previously described for RMR, and a medically qualified doctor monitored the ECG display for abnormalities.

After a warm-up period of horizontal running at 7.5 km/h for 3–5 min, the treadmill speed was increased to either 10 (untrained) or 12 km/h (trained) for 2 min and then was held constant while the elevation was augmented by 2%min until the subjects were exhausted. The criterion for the attainment of VO₂max was a change of <2 ml • kg⁻¹ • min⁻¹ between successive workloads. Test-retest reliability for VO₂max (l/min) of 6 subjects (23–41 yr, VO₂max = 2.12–5.61 l/min) yielded an intraclass correlation of 0.997 and a mean of absolute differences of 0.07 l/min.

Estimated energy intake and expenditure. Daily energy intake and macronutrient intake were estimated before testing by using a self-reporting 7-day food diary (Wednesday to Tuesday inclusive). Each subject was supplied with a 0–2 kg portable digital scale with a taring function and taught how to accurately complete the food diary. Subjects were also informed of the importance of maintaining usual eating habits during the study period. Body mass was measured daily, and records were reviewed with the subjects at the completion of the 7 days. The CSIRO Australia, Division of Human Nutrition computer program, which is based on both the Australian (15) and British (29) food tables, was used to calculate total daily energy intake (kJ/day). Daily energy expenditure (kJ/day) was also recorded for the same 7-day period by using an activity diary. Each day was divided into 1-h periods, and subjects were instructed to record to the nearest 5 min how long they spent sleeping, sitting relaxed, sitting erect, standing, strrolling, walking, jogging, running, or sprinting. All other activities that could not be listed under one of the nine major headings (e.g., swimming, cycling, and ironing) were itemized separately, together with an assessment of the intensity at which they were performed. We also tabulated aerobic-type activities that were designed to either maintain or improve fitness. This category included activities with an energy expenditure greater than normal pace walking (25). Energy expenditure (kJ/day) was estimated by using the subject’s body mass on that day and the appropriate energy expenditure values compiled by McArdle et al. (25).

Statistical analyses. All variables were tested for normality, and variables being compared were tested for homogeneity of variance by using SPSS (28). The RMR and VO₂max values, which were indexed for mass and FFM by simple division, were also corrected for mathematical bias (40). Interclass correlations (n = 34) indicated the association between RMR and other measured variables. Partial correlation analyses were used to measure the association between RMR (kJ/h) and VO₂max (l/min) while controlling for individual variation in body composition and anthropometric variables, Toral, RER, and resting HR (HRrest). Similarly, the partial coefficients for the regression of RMR (kJ/h) on FFM and VO₂max were tested for significance. This technique is a better measure of association if the independent variables (FFM and VO₂max) are correlated because only the component of each independent variable that is unique to that variable is regressed against the dependent variable (RMR, kJ/h; Ref. 12). A power analysis (16) indicated that 12 subjects per group were required to detect a 10% potentiation of RMR (kJ • kg FFM⁻¹ • h⁻¹) with a power of 0.80 at P = 0.05 (2-tailed test), assuming a coefficient of variation of 8.5%. The data from the
12 subjects with the highest and lowest fitness on the basis of VO_{2max} (ml·kg^{-1}·min^{-1}) were, therefore, extracted from the cohort. Independent t-tests were used to compare these groups for RMR, VO_{2max}, and FFM. After confirmation that the data did not violate the assumptions of linearity and homogeneity of regression, RMR (kJ/h) was also analyzed for between-group differences by using analysis of covariance (ANCOVA) with FFM as the covariate. The 0.05 probability level was used for all two-tailed tests of statistical significance.

**RESULTS**

Whole group comparisons. The descriptive statistics for all subjects (n = 34) are presented in Table 1. By design, the subjects differed in their aerobic fitness far more than any other variable. Energy metabolism parameters are presented in Table 2. The values for RMR indexed to mass (kJ·kg^{-1}·h^{-1}) and FFM (kJ·kg FFM^{-1}·h^{-1}) are presented in both their corrected (40) and uncorrected forms. Average energy intake estimated from the 7-day diet diary was 2,381 kJ/day less (P = 0.0001) than energy expenditure derived from the 7-day activity diary (9,511 ± 2,589 vs. 11,892 ± 2,277 kJ/day). Table 3 contains the bivariate correlations between RMR (kJ/h), kJ·kg^{-1}·h^{-1}, and kJ·kg FFM^{-1}·h^{-1} and indicators of aerobic fitness, body composition, and other independent variables. Whereas absolute RMR (kJ/h) was significantly correlated (r < 0.05) with many variables, including VO_{2max} (ml·kg^{-1}·min^{-1}), only T_{oral} was significantly correlated with RMR (kJ·kg FFM^{-1}·h^{-1}; r = 0.52, P < 0.05). Table 4 shows the partial correlations between RMR (kJ/h; dependent variable) and VO_{2max} (l/min; independent variable), when controlled for age, T_{oral}, and body composition parameters. Significant correlations between RMR and VO_{2max} are maintained when the influences of percent BF, fat mass (FM), age, T_{oral}, height, RER, and HR_{rest} are controlled for, but significance is lost when FFM is partialed out (r = 0.16, P > 0.05). Multiple linear regression of RMR (kJ/h) on FFM (kg) and corrected VO_{2max} (ml·kg^{-1}·min^{-1}; Ref. 40) resulted in the following equation:

\[
RMR (kJ/h) = 3.39 FFM (kg) + 0.45 VO_{2max} (ml·kg^{-1}·min^{-1}) + 77.41
\]

FFM and VO_{2max} explain a significant percentage of the RMR variance (adjusted R^2 = 41.4%, P = 0.0001), but only the partial regression coefficient for FFM (3.39) was significant (P = 0.0003). This indicates that an increase in FFM results in a significant rise in predicted RMR. In contrast, the partial regression coefficient for VO_{2max} of 0.45 (P = 0.45) indicates that an increase in VO_{2max} has a nonsignificant effect on RMR. A similar conclusion was reached when VO_{2max} was expressed absolutely (l/min) or on a relative (ml·kg^{-1}·min^{-1}) but uncorrected basis.

Two-group comparisons. The physical characteristics of the high- and low-fitness groups are presented in Table 1. By design, the groups differed in VO_{2max} (l/min and ml·kg^{-1}·min^{-1}; P = 0.0001). A difference was also present for percent BF (P = 0.0002), and the high-fitness group had an average of 3.3 kg more FFM than did the low-fitness group (P = 0.09). The RMR, energy intake, energy expenditure, T_{oral}, and HR_{rest} data are presented in Table 2. On average, the high-fitness group had a lower HR_{rest} (P = 0.014) but expended more energy at rest (P = 0.05 for kJ·kg^{-1}·h^{-1}) than did the low-fitness group, and they had 16.1 and 24.3% greater daily energy requirements as assessed by activity (1,749 kJ/day) and diet diaries (2,097 kJ/day), respectively. The high-fitness group was also involved in significantly more aerobic activity than was the low-fitness group (3,332 ± 2,418 vs. 745 ± 839 kJ/day; P = 0.002), and this may partially explain the differences in their energy requirements. Student's t-tests revealed no group differences for absolute RMR (kJ/h; P = 0.14) and RMR corrected for FFM differences (kJ·kg FFM^{-1}·h^{-1}; P = 0.64). Additionally, an ANCOVA demonstrated no significant between-group difference in RMR (kJ/h) controlled for individual variation in FFM (P = 0.56; F ratio for group main effect = 0.36).

**DISCUSSION**

This study investigated the relationship between RMR and aerobic fitness in adult women (n = 34, 19–31 yr) exhibiting a wide range of VO_{2max} values (32.3–64.8 ml·kg^{-1}·min^{-1}). There was no relationship between VO_{2max} (ml·kg^{-1}·min^{-1}) and RMR controlled for individual FFM differences by using the three following statistical methods: the corrected ratio of RMR to FFM (kJ·kg FFM^{-1}·h^{-1}; Ref. 40), partial correlation analysis, and significance testing of the partial regression coefficients from the regression of RMR (kJ/h) on FFM and VO_{2max} (ml·kg^{-1}·min^{-1}, l/min; Ref. 12). When our
Table 2. Metabolic data of combined, high, and low fitness groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Combined (n = 34)</th>
<th>High (n = 12)</th>
<th>Low (n = 12)</th>
<th>P Value</th>
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</thead>
<tbody>
<tr>
<td>RMR kJ/h</td>
<td>243.4 ± 25.7</td>
<td>246.3 ± 20.9</td>
<td>230.7 ± 28.2</td>
<td>0.14</td>
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<tr>
<td></td>
<td>(183.3–304.3)</td>
<td>(222.3–298.7)</td>
<td>(185.3–288.8)</td>
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<tr>
<td>kJ · kg⁻¹ · h⁻¹ (uncorr)</td>
<td>4.12 ± 0.38</td>
<td>4.30 ± 0.40</td>
<td>3.95 ± 0.41</td>
<td>0.047</td>
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<td></td>
<td>(3.32–5.00)</td>
<td>(3.40–5.00)</td>
<td>(3.32–4.86)</td>
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<tr>
<td>kJ · kg⁻¹ · h⁻¹ (corr)</td>
<td>2.81 ± 0.24</td>
<td>2.90 ± 0.24</td>
<td>2.68 ± 0.28</td>
<td>0.051</td>
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<td></td>
<td>(2.22–3.41)</td>
<td>(2.40–3.41)</td>
<td>(2.22–3.25)</td>
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<tr>
<td>kJ · kg FFM⁻¹ · h⁻¹ (uncorr)</td>
<td>5.54 ± 0.48</td>
<td>5.53 ± 0.51</td>
<td>5.59 ± 0.57</td>
<td>0.78</td>
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<td></td>
<td>(4.45–6.81)</td>
<td>(4.45–6.19)</td>
<td>(4.90–6.81)</td>
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<tr>
<td>kJ · kg FFM⁻¹ · h⁻¹ (corr)</td>
<td>3.67 ± 0.29</td>
<td>3.62 ± 0.33</td>
<td>3.68 ± 0.30</td>
<td>0.64</td>
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<td>(3.09–4.37)</td>
<td>(3.09–4.24)</td>
<td>(3.12–4.37)</td>
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<tr>
<td>RER</td>
<td>0.804 ± 0.043</td>
<td>0.799 ± 0.05</td>
<td>0.801 ± 0.03</td>
<td>0.90</td>
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<td></td>
<td>(0.737–0.898)</td>
<td>(0.744–0.898)</td>
<td>(0.763–0.859)</td>
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<tr>
<td>Toral, °C</td>
<td>36.2 ± 0.3</td>
<td>36.1 ± 0.5</td>
<td>36.2 ± 0.2</td>
<td>0.49</td>
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<td></td>
<td>(35.5–36.9)</td>
<td>(35.5–36.9)</td>
<td>(35.8–36.6)</td>
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<tr>
<td>HRrest, beats/min</td>
<td>55.5 ± 9.2</td>
<td>50.2 ± 9.5</td>
<td>59.9 ± 8.2</td>
<td>0.014</td>
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<tr>
<td></td>
<td>(40.8–77.0)</td>
<td>(40.8–70.0)</td>
<td>(47.8–77.0)</td>
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<tr>
<td>Energy intake, kJ/day</td>
<td>9.511 ± 2.589</td>
<td>10.728 ± 3.204</td>
<td>8.631 ± 1.980</td>
<td>0.067</td>
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<tr>
<td></td>
<td>(5,073–16,372)</td>
<td>(5,156–16,372)</td>
<td>(5,073–11,531)</td>
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<tr>
<td>Energy expenditure, kJ/day</td>
<td>11,892 ± 2,277</td>
<td>12,646 ± 2,472</td>
<td>10,897 ± 1,775</td>
<td>0.059</td>
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<td></td>
<td>(7,821–17,796)</td>
<td>(9,733–17,796)</td>
<td>(7,821–14,150)</td>
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<tr>
<td>Aerobic activity, kJ/day</td>
<td>2,120 ± 2,060</td>
<td>3,332 ± 2,418</td>
<td>745 ± 839</td>
<td>0.002</td>
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<td>(0–9,002)</td>
<td>(1,137–9,002)</td>
<td>(0–2,667)</td>
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<tr>
<td>Aerobic activity/exercise energy expenditure, %</td>
<td>16.2 ± 12.2</td>
<td>24.6 ± 12.7</td>
<td>6.5 ± 6.5</td>
<td>0.002</td>
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<td></td>
<td>(0–50.6)</td>
<td>(11.7–50.6)</td>
<td>(0–18.9)</td>
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Values are means ± SD with range in parentheses; n, no. of subjects. RMR, resting metabolic rate; RER, respiratory exchange ratio; Toral, oral temperature; HRrest, resting heart rate; uncorr, uncorrected ratio; corr, corrected ratio (40). FFM from Siri’s 3-compartment body composition model (45). Energy intake from 7-day diet diary. Energy expenditure from 7-day activity diary. Energy expended during aerobic exercise (kJ/day) estimated by 7-day activity diary. *Three of the subjects in low-fitness group reported zero for aerobic activities, which were designed to either maintain or improve fitness. Significance of independent t-tests between groups of high and low fitness, *P ≤ 0.05; **P ≤ 0.01.

The literature is equivocal as to the relationship between aerobic fitness and RMR. This situation remains unchanged when attention is focused on studies that have been conducted on nonobese premenopausal women. Approximately equal numbers of investigations have reported that aerobic fitness is associated with an increase (cross-sectional studies: 3, 11, 38; longitudinal studies: 23, 47) or no change (cross-sectional studies: 1, 51, present investigation; longitudinal study: 49) in RMR per kilogram of FFM. Whereas the untrained subjects have more FM, which has a much lower metabolic rate than does the FFM. Also, whereas Tremblay et al. (47) found an 8% elevation in RMR per kilogram of FFM consequent to an 11-wk training program for eight subjects they classified as moderately obese, neither VO₂max nor submaximal work test data were reported. It is, therefore, impossible to relate the increase in RMR to changes in aerobic fitness even though there were statistically significant decreases in both mass and FM. The lack of agreement in the literature regarding the relationship between aerobic fitness and RMR (kJ · kg FFM⁻¹ · min⁻¹) may be related to the following, which will be discussed individually: measurement error, statistical power, and sample size; subject selection criteria; methodologies for RMR and FFM determinations; experimental design; and strategies for statistical analyses of the data. Measurement error, statistical power, and sample size. Few investigators report the reliability of their measurements, yet unless the difference between groups for the dependent variable exceeds the precision of the method, the results cannot be interpreted as statistically significant. While most laboratories have reported coefficients of variation of 1.5–3.0% for their RMR techniques, others have published reliability estimates >4% (34, 50). These latter errors seem excessive for laboratories using the latest equipment, fully trained technicians, and properly habituated subjects; and they may hinder the interpretation of statistically significant results. One study highlighting this problem is that by Ballor and Poehlman (3) in which the RMR (adjusted for interindividual FFM differences by using ANCOVA) of aerobically trained subjects was found to...
be significantly higher ($P < 0.05$) than for sedentary (6%) and resistance-trained (3%) subjects. However, the reported coefficient of variation for 4.3% for the reproducibility of RMR measurement in their laboratory (33) was larger than the 3% difference between the aerobic- and resistance-trained groups. Thus the reported significant between-group difference for RMR was less than the error of a single measurement.

The use of power analysis to calculate the number of subjects required to detect physiologically significant between-group differences has been acknowledged by only a few investigators (7, 8). With insufficient power a researcher can wrongly conclude that there is no significant between-group difference. A study by Hill et al. (21) illustrates the possible problem of inadequate subject numbers. These researchers reported a nonsignificant 9.5% higher RMR in four trained men compared with four untrained men. In contrast, a similar between-group difference of 10% for RMR has reached statistical significance ($P < 0.05$) in other studies (31, 36) using more subjects. The present study required 12 subjects per group to detect an effect size of 10% with a power and $\alpha$ of 0.80 and 0.05, respectively (16).

Subject selection criteria. The importance of selecting subjects free of conditions that can affect valid measurements cannot be overstated, yet many studies (14, 21, 23, 49) fail to acknowledge the confounding influence of some of the following variables on energy metabolism: energy imbalance over the preceding 6 mo, diabetes and other diseases, medications, smoking status, caffeine ingestion, and obesity. The present study screened volunteers for such factors.

RMR methodology. Pretesting protocols for RMR determinations vary between studies and may account for some of the variance in results. While recent studies (7, 8, 11, 31–38, 41) have tended to apply more stringent conditions regarding the physical activity, menstrual status, prior sleeping arrangements, medications, and food intake, other investigations (5, 14, 19, 23, 49, 51) have failed to control for some of these known confounding variables. Because an acute elevation of $V_O2$ has been reported for up to 12–24 h postexercise (2), our study prohibited exercise training on the previous day. This 36-h restriction of exercise before RMR testing is consistent with the protocols of Ballor and Poehlman (3), Poehlman and colleagues (30, 31, 33, 38), Schulz et al. (43), and Broeder et al. (7, 8).

The timing of the RMR measurement in relation to the menstrual cycle may also be an important consideration. As indicated by Bisdee et al. (6), resting energy metabolism is lower in the late follicular phase compared with the late luteal phase, and while some studies involving women have acknowledged this source of variation (1, 3, 11, 38), others failed to consider this problem (51). Our study restricted RMR determinations to the mid-to-late follicular phase of the menstrual cycle.

Because RMR is assessed in the morning, the preceding night’s sleeping arrangements have been the focus of some investigations (4, 10, 48). Although Berke et al. (4) found a significantly lower RMR (7–8%; $P < 0.01$) for inpatient compared with outpatient conditions for elderly subjects, two other research groups (10, 48) reported no difference for previously habituated young adults. The inpatient procedure is more expensive, time consuming, and inconvenient for both subjects and researchers. Furthermore, it may upset the subjects because of a lack of quality sleep due to an unfamiliar bed and foreign surroundings. We, therefore, chose to let our subjects sleep at home, and they were then driven to the laboratory by one of the researchers.

Being a participant in a scientific investigation is a unique experience for most people; this is associated with the increased likelihood of anxiety, which may elevate RMR. However, few studies (7, 14, 21, 33)
report habituating their subjects to the laboratory environment, technical staff, and the testing procedures before data collection. Subjects in this study were habituated to all testing procedures during a preliminary visit to the laboratory. Previous trials in this laboratory (unpublished observations) demonstrated a further reduction in the RMR of some subjects between the second and third RMR test. This prompted us to measure the RMR twice after the habituation trial with the subjects’ true RMR being the lower of these two testing sessions.

The method of gas collection for indirect calorimetric determination of RMR has varied between studies. Segal (44) concluded that there were no statistically significant differences (P > 0.05) among the RMRs of habituated subjects when expire was collected via a mouthpiece with nooseclips, ventilated hood, or face mask. Our study, using mouthpiece and noseclip, involved two 10-min collection periods that were separated by 15 min when the mouthpiece and noseclip were removed and the subject remained at rest in a supine position. This contrasts with those studies that incorporated longer continuous collection periods of 30 (1, 7, 11, 35, 36), 45 (20, 30, 31, 38), 60 (5), or 90 min (23). Our protocol was based on the assumption that subjects become increasingly restless in a motionless supine position and that coughing, swallowing, and minor body movements are more likely to contribute to an elevated RMR over a protracted collection period.

To maintain energy balance, the athlete in heavy training must increase energy intake to match the requirements of the exercise plus recovery. While the trained subjects in most RMR studies are restricted from exercise for a period >24 h before RMR measurement, it is presently unclear whether energy intake during this period of inactivity matches a lower energy expenditure or remains elevated, thereby sustaining a state of positive energy balance before the RMR determination. The impact of a changing energy intake in the days before RMR testing was first investigated in the 1920s by Kleitman (cited in Ref. 22) and more recently by several investigators (13, 22, 27, 52). Daucey (13) found a significant increase in RMR (measured at least 14 h after the previous meal) of 12 ± 3% when subjects consumed an additional 4,000 kJ during the previous 24 h. It was also evident that the individual response of RMR to overeating was large (range 0–25%; 14). Woo et al. (52) reported that the postprandial RMR of six normal-weight young men was elevated by both an overfeeding-induced positive energy balance and increases in physical activity. When subjects were in positive energy balance from overeating 1,177 kcal during the previous day, RMR was increased relative to a control day (248 ± 6 vs. 235 ± 4 ml O2/min). Furthermore, when subjects consumed this additional intake (1,177 kcal/day) but maintained energy balance by increasing energy expenditure, RMR was further elevated (259 ± 9 ml O2/min). It is interesting to note that the mean rise in RMR due to the overeating-induced positive energy balance of 1,177 kcal/day (13 ml O2/min) was almost equivalent to that when physical activity was augmented by a further ~1,177 kcal/day (11 ml O2/min). The larger SDs for the two experimental conditions indicate a greater variability for the individual response to changes in energy input and energy expenditure. To date, only the study by Schulz et al. (43) restricted the energy intake of trained subjects to their sedentary requirements before RMR measurement. They found no RMR difference between trained and untrained subjects. Undereating is unlikely in most groups, but the influence of this may not be dire because the lowering of RMR due to underfeeding appears to take a few days to a week (27). Furthermore, if subjects are aware that they will miss the following day’s breakfast and perhaps lunch, then the possibility of overfeeding, particularly on the preceding night’s meal, is high. With the possibility of a hypermetabolic state that varies in magnitude between people, it would appear prudent to control pretesting energy intake (22, 27).

FFM determination. The two-compartment underwater-weighing model involves the measurement of BD, which is then fed into either the Brozek et al. (9) or Siri (45) equation to estimate the percent BF. The body mass can therefore be partitioned into the FM and FFM; most studies of resting energy metabolism have used this model to estimate the FFM (1, 3, 7, 8, 19, 30–38, 43). However, both the Brozek et al. (9) and Siri (45) equations assume that the overall density of the four FFM components (water, protein, bone mineral, nonbone mineral) is invariant at 1.1000 g/cm3. We estimated the FFM via the three-compartment model of Siri, which uses measurements of BD and TBW to partition the body mass into FM, water, and fat-free dry tissue. This model is more valid than the traditional two-compartment underwater-weighing model because it controls for biological variability in TBW, which possesses both the largest percentage (73.7%) and lowest density (0.9937 g/cm3) of the four FFM components. The error of ±2% body mass for estimating FM by using this three-compartment model is considerably smaller than that of ±4% for the two-compartment underwater-weighing method (45). Hence, our methodology enables the RMR to be indexed against a more valid measure of the FFM.

Experimental design. Failure to agree about the relationship between exercise training and RMR has emerged from both cross-sectional and longitudinal study designs. In cross-sectional studies, a comparison of RMR is made between individuals or groups differing in training status or $\dot{V}_{O_2}^{\text{max}}$. To reduce the effect of confounding factors on the relationship between aerobic fitness and RMR, investigators usually try to recruit subjects who are homogeneous for these confounding factors; if this is not possible then statistical manipulations are used to remove or “partial” out their influence. Cross-sectional investigations of metabolism are expedient and cost effective, but their results may be compromised by the fact that there is no control for the genetic influence on both RMR and $\dot{V}_{O_2}^{\text{max}}$. Genotype can represent up to 45% of the variance in RMR.
remaining after adjustment for FFM, age, and gender (40).

Statistical treatment of the data. A statistical bias is introduced when absolute RMR is simply divided by body mass or FFM. This is of concern when a comparison is made of individuals or groups who differ in these variables (40, 46) because the nonzero intercept of the relationship between RMR and body mass or FFM results in an underestimate of the indexed RMR of the larger compared with the smaller person (40). This bias is also present for the comparison of $V_{O2max}$ indexed to body mass (ml·kg$^{-1}$·min$^{-1}$) and FFM (ml·kg FFM$^{-1}$·min$^{-1}$); hence, the present study corrected both RMR and $V_{O2max}$ for statistical bias.

The statistical techniques of partial correlation and ANCOVA have also been used to compare RMR between groups or individuals differing in FFM (7, 33, 43). These techniques are not without some limitations (12, 17, 24). The partial correlation is considered less meaningful than regression techniques, especially if the primary assumption of bivariate normality is not maintained (12). This study also used the method of partial regression coefficients to test for the influence of $V_{O2max}$ on RMR independent of FFM. The coefficients from the regression of RMR (kJ/h) on the independent variables (FFM and $V_{O2max}$ in ml·kg$^{-1}$·min$^{-1}$ or l/min) are significance tested for their contribution to the variance in RMR (12). This technique is preferred to the use of partial correlations (24). Regardless of the use of any of the aforementioned statistical methods to remove the influence of FFM on RMR and $V_{O2max}$ there was neither a significant relationship between RMR and $V_{O2max}$ nor a significant difference for RMR between our high- and low-fitness groups.

Relationship between RMR and other variables. The previously reported (7, 32) positive correlation between FFM and absolute RMR was confirmed in this study (r = 0.66, P = 0.0001). Furthermore, absolute RMR was also related to other variables indicative of body size such as height and mass (Table 3). Whereas a number of variables were associated with RMR (kJ·kg$^{-1}$·h$^{-1}$), only $T_{oral}$ was significantly related to RMR (kJ·kg FFM$^{-1}$·h$^{-1}$; r = 0.52, P < 0.01). This finding is in agreement with those of Rising et al. (41). However, $T_{oral}$ is considered a poor indicator of average body temperature if indeed there is such a measure, and it can be quantitated, because it is normally lower than other sites thought to reflect core temperature (e.g., tympanic, esophageal, and rectal) and is quite sensitive to external conditions (39). Further research is, therefore, needed to quantify better whole body temperature to confirm this suspected correlation with RMR.

Conclusion. This study investigated the relationship between RMR, $V_{O2max}$, and FFM in young women with a wide range of $V_{O2max}$. While a high-fitness group expended more energy at rest (kJ·kg$^{-1}$·h$^{-1}$) than did a low-fitness group, there was no evidence to suggest the existence of a positive relationship between RMR and $V_{O2max}$ when statistical control was exerted for the influence of FFM.

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