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Moderate-to-high levels of exercise are associated with higher resting energy expenditure in community-dwelling postmenopausal women

Andrew W. Froehle¹,

Department of Anthropology University of California, San Diego 9500 Gilman Dr. La Jolla, CA 92093-0532

Susan R. Hopkins,

Division of Physiology School of Medicine University of California, San Diego 9500 Gilman Dr. La Jolla, CA 92093-0623 shopkins@ucsd.edu

Loki Natarajan, and

Division of Biostatistics and Bioinformatics Department of Family and Preventive Medicine University of California, San Diego 9500 Gilman Dr. La Jolla, CA 92093-0901 lnatarajan@ucsd.edu

Margaret J. Schoeninger

Department of Anthropology and Center for Academic Research and Training in Anthropogeny University of California, San Diego 9500 Gilman Dr. La Jolla, CA 92093-0532 mjschoen@ucsd.edu

Abstract

Postmenopausal women experience an age-related decline in resting energy expenditure (REE), which is a risk factor for energy imbalance and metabolic disease. Exercise, by association with greater lean tissue mass and other factors, has the potential to mediate REE decline, but the relationship between exercise and REE in postmenopausal women is not well characterized. This study tests the hypothesis that exercise energy expenditure (EEE) is positively associated with REE, opposing the effects of age and menopause. The study tests this hypothesis in a cross-sectional sample of healthy postmenopausal women (N = 31, aged 49 - 72 years) with habitual exercise volumes at or above levels consistent with current clinical recommendations. Subjects kept four weeks of exercise diaries quantifying exercise activity, and were measured for body composition, maximal oxygen uptake, and REE. Multiple regression analysis was used to test for relationships between EEE, age, body composition, and REE. EEE and lean tissue mass (fat-free mass: FFM; and fat-free mass index: FFMI) exhibited significant, positive relationships with REE. The relationship between REE and EEE remained significant even after controlling for lean tissue mass. These results support the hypothesis that exercise is positively associated with REE, counter to the negative effects of age and menopause, and indicate a continuous relationship between exercise and REE across the moderate-to-high exercise range. Exercise at levels at and above current clinical guidelines may, in part, ameliorate risk for energy imbalance and metabolic disease through a positive relationship with REE.

(corresponding author) Phone: 937.775.1413 Fax: 937.775.1456 andrew.froehle@wright.edu.

¹Current affiliation: Division of Morphological Sciences and Biostatistics Lifespan Health Research Center Department of Community Health Wright State University Boonshoft School of Medicine 3171 Research Blvd. Kettering, OH 45420 United States

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Keywords

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INTRODUCTION

Resting energy expenditure (REE) is an indicator of metabolic function, representing the energy cost of fundamental physiological processes and accounting for 60-75% of daily energy expenditure (Ravussin et al. 1986). Low REE correlates with energy imbalance, weight gain, and increased risk for obesity and related metabolic syndrome diseases (Must et al. 1999). Although both men and women experience a general, age-related decline in REE that raises risk for energy imbalance (Bosy-Westphal et al. 2003; Roberts and Rosenberg 2006; Westerterp and Meijer 2001), postmenopausal women are at potentially greater risk due to a sharp, 70-80% drop in circulating levels of the 17 β -estradiol across the menopausal transition (Bosy-Westphal et al. 2003; Carr 2003; Randolph et al. 2011; Sowers et al. 2008).

A high level of circulating 17 β -estradiol, which up-regulates several enzymes and transcription factors related to β -oxidation of fatty acids in skeletal muscle mitochondria (Campbell et al. 2003; Campbell and Febbraio 2001; Spangenburg et al. 2012a), contributes to sex differences in metabolic physiology, including greater reliance on fatty acid metabolism for energy in women compared to men (Tarnopolsky 2000). In premenopausal women, higher levels of 17 β -estradiol are associated with maintenance of muscle mass (Cable and Elliott 2004) as well as higher REE (Day et al. 2005). The substantial and irreversible decrease in 17 β -estradiol levels during menopause, therefore, is thought to at least partly underlie the postmenopausal reduction in REE and its associated cardiovascular and metabolic health risks (Carr 2003). Whereas hormone replacement therapy (HRT) provides a potential method of preventing changes in REE associated with reduced 17 β -estradiol, evidence of increased breast cancer risk with HRT (Narod 2011) has led to a reduction in its prescription (Ettinger et al. 2012). It is thus of critical public health importance to find alternative solutions for reducing metabolic disease risk due to menopausal declines in REE.

One potential solution is the promotion of regular exercise, which The American College of Sports Medicine (ACSM 2006) defines as "...planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness". Recent work suggests that exercise may have metabolic effects that protect against the consequences of estradiol loss (Spangenburg et al. 2012b). In older adults, most evidence points to a positive correlation between regular exercise and improved metabolic function (Hunter et al. 2000; Kirwan et al. 1993; Sial et al. 1998; Treuth et al. 1995), and exercise has the potential to promote higher REE via greater lean tissue mass (Chodzko-Zajko et al. 2009; Stiegler and Cunliffe 2006; Westerterp et al. 1992; Westerterp 1998), enhanced mitochondrial function or density (Betik and Hepple 2008; Derbré et al. 2012), or other mechanisms (Bell et al. 2004; Borsheim and Bahr 2003; Laforgia et al. 2006).

Despite exercise's potential to mitigate the effects of aging and menopause on REE, relatively few studies have addressed this topic in postmenopausal women, and have produced conflicting results. Whereas short-term exercise interventions (4-12 months) initiated after menopause have shown little-to-no effect on REE (Ryan et al. 1995; Santa-Clara et al. 2006; Taaffe et al. 1995; Thompson et al. 1997), very high levels of exercise, roughly two-to-four times higher than recommended levels, over the long term are associated with higher REE in highly-trained, postmenopausal competitive athletes (Van Pelt et al. 1997). Little is known, however, about the effects on postmenopausal REE of

exercise levels in the range between these two extremes. This is an important topic to address, because the current guideline for maintaining metabolic health in older adults is 150-300 minutes of moderate to vigorous exercise, or 500-1000 metabolic equivalent of task minutes per week ($\text{MET} \cdot \text{min} \cdot \text{wk}^{-1}$) (Chodzko-Zajko et al. 2009). Above 300 minutes of exercise, or 1000 $\text{MET} \cdot \text{min} \cdot \text{wk}^{-1}$, women are considered highly-active (World Health Organization 2010), yet their exercise habits can still be considerably lower than the levels of habitual exercise reported in previous studies of postmenopausal REE. It is therefore unclear whether regular exercise across the moderate-to-high range is associated with higher REE in postmenopausal women.

To address this problem, the present study uses a cross-sectional design and a sample of healthy, community-dwelling, postmenopausal women ($N = 31$) to test the hypothesis that moderate-to-high exercise volume at or above currently recommended levels (expressed as exercise energy expenditure: EEE) is positively related to REE. Furthermore, whereas changes in muscle mass largely explain the postmenopausal decline in REE and exercise's mitigating potential (Chodzko-Zajko et al. 2009; Harber et al. 2009; Westerterp and Meijer 2001), exercise may affect REE outside of its relationship to body size/composition (Van Pelt et al. 1997). Thus, the study tests the secondary hypothesis that exercise also exhibits a relationship with REE independent of body size or body composition.

SUBJECTS AND METHODS

Subjects

Women were recruited through the San Diego Senior Olympics, the La Jolla YMCA, by posting fliers on the University of California, San Diego campus, and word of mouth by subjects already enrolled in the study. All study procedures were approved by the Institutional Review Board of the University of California, San Diego (active project #091528), and all subjects gave their informed consent prior to enrollment. Potential subjects completed a screening interview and a health and general exercise questionnaire, conducted by the first author. This initial exercise questionnaire for screening asked only how many hours per week each subject exercised; the formal assessment of exercise levels, for conversion to $\text{MET} \cdot \text{min} \cdot \text{week}^{-1}$ and EEE is detailed below. Subjects also underwent a medical history and physical exam, performed by the project physicians (see Acknowledgements), to determine eligibility. Inclusion in the study required women to be naturally (i.e., non-surgically) postmenopausal, defined at screening as one year since last menstruation and confirmed by serum hormone assays: women were excluded for follicle stimulating hormone $< 30 \text{ mIU/mL}$ or estradiol $> 25 \text{ pg/mL}$ (Strauss and Barbieri 2004). All subjects had estradiol levels $\leq 14 \text{ pg/mL}$, below the minimum reference values for pre- and perimenopausal women. Women were also required to exercise for $\geq 500 \text{ MET} \cdot \text{min} \cdot \text{wk}^{-1}$ to be included in the present analysis.

Other exclusion criteria included: smoker, heavy user of alcohol/other drugs; hypo- or hyperthyroid (serum thyroid stimulating hormone < 0.3 or $> 5.5 \mu\text{U/mL}$: (Pittas and Lee 2003; Spaulding and Utiger 1981); body mass index (BMI) < 18.5 or $\geq 30 \text{ kg/m}^2$; $> 5\%$ change in body weight within the past six months; hormone replacement therapy, which may raise REE (Aubertin-Leheudre et al. 2008), within the past six months; metabolic, respiratory or cardiovascular disease, or high blood pressure; contraindication for maximal aerobic testing as determined by the Physical Activity Readiness Questionnaire (Thomas et al. 1992). A total of 50 women signed the consent form and underwent the full screening; 19 were excluded for insufficient exercise, BMI, contraindications to exercise testing, hormonal levels, or noncompliance; 31 women met all inclusion criteria and completed the study protocol.

Resting Energy Expenditure and Body Composition

REE and body composition measurements were made at the UCSD General Clinical Research Center in the morning between 0700 and 0930. Subjects spent the previous night at home, and for the 12 hours prior to testing refrained from physical activity and fasted. Subjects wore light clothing and socks for all measurements. Upon arrival at the testing facility (transported by automobile), subject height and weight were measured on a stadiometer (Ayrton S100, Prior Lake, MN) and digital scale (Scale-Tronix 5005, White Plains, NY), respectively. Subjects then lay supine on a hospital bed in a thermoneutral, temperature-controlled room (Kashiwazaki et al. 1990) for a 20-minute rest period, followed by respiratory gas collection ($\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$) using a ventilated-hood and open-circuit respirometry system (VMax Encore VS-29, CareFusion, San Diego, CA). Respiratory gas collection lasted 30 minutes, during which one-minute average gas volumes were recorded. To ensure that gas exchange data came from fully relaxed subjects, only the final 10 minutes of recorded gas volumes were used, and were converted to REE in kcal following established methods (Weir 1949). Body composition was assessed by whole body dual-energy x-ray absorptiometry on a Hologic Discovery W scanner (Bedford, MA), which computed fat and lean mass components, and body fat percentage. Lean tissue mass was quantified not only as FFM, but also as fat-free mass index (FFMI), the ratio of FFM to ht^2 and an indicator of relative muscularity (Schutz et al. 2002).

Maximal Oxygen Uptake

Maximal oxygen uptake ($\dot{V}_{O_{2peak}}$) was measured at the Human Exercise Physiology Laboratory in the UCSD Division of Physiology. Subjects were instructed to refrain from vigorous physical activity and consumption of caffeine for the duration of the day prior to testing. Tests were performed on an electronically-braked cycle ergometer (Quinton Instruments Co., Groningen, Netherlands), and subjects breathed through a two-way breathing valve (Hans-Rudolph, Kansas City, MO, USA) with a mouthpiece while wearing a nose-clip. Respiratory gas exchange (15-second average) was measured using a metabolic cart (TrueMax, ParvoMedics, Salt Lake City, UT, USA) calibrated for air composition and flow volume before each test. Room temperature, humidity and atmospheric pressure were recorded for conversion of gas volumes to STPD. The mean of the four highest consecutive 15-second $\dot{V}_{O_2}$ averages was used to calculate $\dot{V}_{O_{2peak}}$, expressed per kg body mass.

Because older adults tend to lose aerobic capacity with age (Tanaka et al. 1997), the testing protocol was slightly modified from standard rates of workload increase in younger adults (ACSM 2006). A recent review of exercise testing in older adults (Huggett et al. 2005) served as a template for the protocol used: subjects warmed up for 5 minutes at a resistance of 25 watts (W); at the 5-minute mark and at one-minute intervals thereafter, resistance was increased by 15 W until the subject reached volitional fatigue, at which point the test was ended. For safety, cardiac rhythm and arterial oxygen saturation were continuously monitored, respectively, via Lead II EKG and pulse oximetry using a forehead sensor (RS-10, Nellcor N-395 Oxismart XLTM, Mallinckrodt, St. Louis, MO, USA). Heart rate was recorded at each workload change and a physician monitored each subject for signs of distress.

Exercise Assessment

Exercise levels and EEE were assessed using diaries in which subjects kept records of their exercise activities for four weeks prior to testing. Exercise was defined using ACSM guidelines (ACSM 2006). Accordingly, subjects were instructed to record on a daily basis all exercise behaviors in which they engaged, along with details about type and duration of exercise, distance covered if applicable, and perceived level of exercise intensity. Records were collected and screened by the investigators for missing data, and subjects were asked to

fill in any gaps by recall. Diaries of this type have been shown to be reliable and have been validated against other methods of activity assessment (Haskell and Kiernan 2000).

The exercise diary records were used as the basis for calculating average daily EEE values for each individual. Standardized energy intensity coefficients (metabolic equivalent of task: MET) from the Compendium of Physical Activities (Ainsworth et al. 2000) were assigned to each recorded exercise. Published descriptions accompanying coefficients were used to match them as closely as possible to the recorded exercises. For each exercise bout, time spent exercising was multiplied by the corresponding MET coefficient to arrive at MET · min values. All MET · min values for each subject each day were summed and converted to EEE values in kcal/d by multiplying by REE. The mean of all such daily values across the four weeks was derived for each subject to represent average daily EEE, and these mean values were used in all subsequent statistical analyses. Average MET · min · week⁻¹ values were also calculated to assess exercise levels in this sample relative to clinical recommendations.

Statistical Analysis

Data were analyzed with SAS version 9.2 for Windows. Each variable was tested for normal distribution (Shapiro-Wilk test) and outliers, and subsequent analyses were run with and without outliers to determine their effect on the outcomes. Because no differences in outcome occurred with or without the outliers, the results reported below are for analyses of the full sample including outliers. Descriptive characteristics of the sample were computed. Bivariate correlation techniques were used to evaluate relationships between REE, EEE, age, body composition variables [weight, height, BMI, FFM, FFMI, fat mass (FM), fat mass index (FMI), and body fat percentage (Fat%)], and $\dot{V}O_{2peak}$ (absolute and mass-specific). Partial correlation was also used to investigate relationships between REE and EEE while controlling for body composition. Relationships between REE (dependent variable) and age, EEE, and body composition variables were further investigated with multiple linear least squares regression analysis. Hypothesis testing was conducted at a two-sided 5% significance level so that p-values less than 0.05 are reported as statistically significant. At $\alpha = 0.05$ and 80% power, a priori power calculations estimated that the sample of N=31 was sufficient to detect correlation coefficients 0.46 and minimum regression beta values for age, EEE, FFM, and FFMI of 10.5, 0.3, 6.7, and 33.0, respectively, compared to null hypotheses of zero correlation and beta values equal to zero. Standard deviations from the present study's data set were used for the power calculations.

RESULTS

Descriptive statistics are presented in **Table 1**. Subjects engaged in a wide variety of different exercise activities, including soccer, running, walking, cycling, swimming, yoga, weight lifting, and calisthenics. Of 31 subjects, 15 engaged only in aerobic exercise, and 16 performed varying combinations of aerobic and resistance training over the course of the record-keeping period. The majority of subjects had relatively low average daily EEE, with 29% of the sample expending less than 100 kcal/d on exercise per day. In terms of relative exercise levels, however, 71% of the sample exceeded clinical guidelines for exercise volume, obtaining more than 1000 MET · min · week⁻¹. Overall, the women in this sample tended to engage in a greater amount of regular exercise compared to other, larger samples of women (Morrow et al. 2011).

The results of the bivariate correlation analysis, presented in **Table 2**, were used to build the regression models. The key findings were that exercise energy expenditure (EEE) was positively correlated with REE ($r_s = 0.37$, $P = 0.04$), and that the partial correlation between EEE and REE remained significant when controlling for FFM ($r_s = 0.40$, $P = 0.03$).

Regression analysis showed a significant, negative relationship between REE and age ($b = -7.3 \pm 3.5$; $r^2 = 0.13$; $P = 0.05$). In contrast, REE was positively related to EEE (see **Figure 1a**), FFM and FFMI ($P < 0.01$ for each; EEE: $b = 0.30 \pm 0.1$, $r^2 = 0.22$; FFM: $b = 18.3 \pm 2.4$, $r^2 = 0.66$; FFMI: $b = 44.5 \pm 15.9$, $r^2 = 0.21$). There was also a positive trend in REE with greater relative exercise volume, as represented by $\text{MET} \cdot \text{min} \cdot \text{week}^{-1}$, but this relationship did not reach significance ($b = 0.03 \pm 0.02$, $r^2 = 0.11$, $P = 0.07$; see **Figure 1b**).

Multipleregression analysis was used to test four different models with two or more independent variables (see **Table 3** for regression statistics). Because FFM explained more variation in REE than did FFMI, FFM was used as the body composition variable for multiple regression analysis. All four models were significant overall (all $P < 0.01$) with significant intercepts (all $P < 0.01$). Model 1 included age and EEE as independent variables, each of which was significantly related to REE (age: $b = -9.0 \pm 3.0$, $P < 0.01$; EEE: $b = 0.35 \pm 0.1$, $P < 0.01$). Model 2 included age and FFM as independent variables, and only FFM was significantly related to REE (age: $b = -2.2 \pm 2.3$, $P = 0.36$; FFM: $b = 17.6 \pm 2.6$, $P < 0.01$). Model 3 included EEE and FFM as independent variables, each of which was significantly related to REE (EEE: $b = 0.14 \pm 0.1$, $P = 0.05$; FFM: $b = 16.7 \pm 2.5$, $P < 0.01$). Finally, Model 4 included age, EEE and FFM as independent variables; only EEE and FFM were significantly related to REE (age: $b = -3.8 \pm 2.2$, $P = 0.10$; EEE: $b = 0.18 \pm 0.1$, $P = 0.02$; FFM: $b = 14.9 \pm 2.6$, $P < 0.01$). All regression relationships met the assumptions of homoscedasticity and normally distributed residuals.

DISCUSSION

The results of this study support the primary hypothesis that there is a positive association between exercise and REE in postmenopausal women who exercise at or above the current clinically recommended level of $500\text{--}1000 \text{ MET} \cdot \text{min} \cdot \text{wk}^{-1}$ (Chodzko-Zajko et al. 2009), and that this relationship counters the effect of age. With regard to the secondary hypothesis, exercise appears to be related to REE at least partially independently of body composition, as evidenced by the retained significant partial correlation between EEE and REE when controlling for FFM, and the significant regression effect of EEE even when FFM was also included as an independent variable. Interestingly, EEE was not related to FFM or FFMI, suggesting that more exercise was not associated with greater absolute or relative lean tissue mass in this sample. This may be at least partly due to the large proportion (half) of subjects who engaged only in aerobic exercise (Toth et al. 1999). As expected, however, EEE was negatively correlated with body fat measures (FM, FMI and body fat percentage), suggesting that at least one aspect of body composition was associated with exercise volume.

To date, most studies of the relationship between exercise and REE in postmenopausal women have consisted of short-term (< 1 year) exercise interventions in previously sedentary subjects. Whether the interventions have consisted of aerobic exercise, resistance exercise, or both, the preponderance of studies of postmenopausal women have found no change in REE with exercise, in particular when the interventions also failed to increase FFM (Santa-Clara et al. 2006; Taaffe et al. 1995; Thompson et al. 1997). Interventions in postmenopausal women that have led to significant increases in muscular strength and FFM, however, have generally been shown to also increase REE by $\sim 7\%$ (Bonganha et al. 2011; Hunter et al. 2000). This suggests that resistance training may be the best mode of exercise to elevate REE via muscle-building in postmenopausal women.

On the other hand, the results of the present study suggest that even when exercise is not related to FFM, more exercise may still be associated with greater REE. Roughly half of the women in this sample engaged in aerobic exercise only, and the remainder combined

aerobic with resistance exercise. Thus, despite an overall emphasis on aerobic training in this group, exercise volume was nonetheless positively associated with REE without any apparent relationship between exercise and lean tissue mass. These results are consistent with those of a previous study, which found that aerobically-trained postmenopausal runners and swimmers had elevated REE compared to an age-matched sedentary cohort (Van Pelt et al. 1997). With aerobic training, mechanisms such as improved muscle mitochondrial oxygen uptake via angiogenesis and mitochondrial biogenesis (Betik and Hepple 2008) may explain the association between higher REE and exercise.

Adaptations to muscle oxygen uptake, however, would be expected to occur relatively rapidly, within 4-12 weeks of the initiation of an exercise intervention (Holloszy 2008; Laughlin and Roseguini 2008), and do not explain disagreement as to the REE/exercise relationship between short-term postmenopausal interventions and studies of habitually-active postmenopausal women. There is emerging evidence that 17β -estradiol is an important up-regulator of growth hormone secretion (Fanciulli et al. 2009; Veldhuis et al. 2005), which can affect rates of angiogenesis, and may also be involved in mitochondrial biogenesis (Klinge 2008). In sedentary postmenopausal women, the combination of accumulated metabolic adaptations to inactivity (Booth and Lees 2007) and a blunted response to exercise due to low levels of 17β -estradiol may increase the amount of time or the intensity of exercise required to elicit positive effects on REE and other factors related to oxygen consumption and energy balance. Previous intervention studies in sedentary postmenopausal women may have therefore been of insufficient length, intensity, or both, to overcome hormonal limitations and generate such adaptations. In contrast, studies of habitually-active women, including this one, may be able to detect exercise effects because of the length of time over which their subjects have maintained moderate-to-high levels of exercise. Although speculative, these mechanisms have potentially important implications for the timing, duration, and intensity of clinical recommendations and exercise interventions, and thus warrant further study.

Even in active women, it is possible that low postmenopausal 17β -estradiol levels have a blunting effect on the metabolic response to exercise, illustrated by a comparison of this study to published data for older men (Van Pelt et al. 2001). Although the present study did not test for the effects of 17β -estradiol on the REE/exercise relationship, comparison to men suggests a sex difference in the magnitude of the effect exercise on REE, and thus a potential influence of menopausal hormonal changes. Van Pelt et al. (2001) found that highly-active older men (age 63 ± 1 years) had significantly higher REE (adjusted for FFM) than age-matched, sedentary peers, but did not differ from younger, active men (age 27 ± 1 years) matched for exercise volume. These results indicated an effect of exercise on REE counter to age-related declines, mirroring their earlier findings among postmenopausal women (Van Pelt et al. 1997), which the present study's results corroborate.

The consistency of the pattern in men and women could be taken to indicate the absence of a sex difference in the metabolic response to exercise in older people, but a closer comparison of our results to the men's results suggests otherwise. Whereas the slope of REE vs. exercise volume (in $\text{hr} \cdot \text{wk}^{-1}$) in men was approximately ~ 1.2 (derived from Fig. 2A in Van Pelt et al. 2001), in our sample of postmenopausal women the slope was 0.57 ($P = 0.05$), roughly half the magnitude of the male value. Although the male REE values were adjusted for FFM and our female values were not, male adjusted values differed from reported raw REE values by only $\sim 3\%$, such that a comparison of unadjusted male and female REE values would likely provide essentially the same result. This suggests that the dose-response effect of exercise on REE is about half as strong in postmenopausal women as it is in older men, possibly as a result of the metabolic challenges women incur as a result of menopausal

reductions in 17β -estradiol. Additional research on the exercise dose-response in women compared to men is needed to further test for and clarify such sex differences.

This study's main strength is its analysis of the effects of exercise on REE in women with free-living exercise habits across the moderate-to-high range. To our knowledge, no previous study has investigated variation in REE over this full range. The results are suggestive of a continuous dose-response relationship between REE and exercise across moderate-to-high exercise levels in postmenopausal women, indicating that greater benefits in energy balance may accrue from exercise above currently recommended levels. Activity habits in the present study's sample, however, which was constrained to women whose exercise levels were at or above the recommended range, are not representative of the general population. Accelerometer data from the 2003-2004 NHANES survey suggest that only ~3% of adult women in the United States met or exceeded recommended exercise levels (Troiano et al. 2008). Similarly, Canadian women are generally far less active than the present study's sample, with only 4-5% meeting clinical recommendations for exercise (Colley et al. 2011). Thus, the great majority of postmenopausal women in both Canada and the United States are insufficiently active, and it is unclear from this study whether such activity below recommended levels exhibits any relationship with REE.

The study's main limitation is its cross-sectional design, which constrains the analysis to simply demonstrating a positive association between EEE and REE. A longitudinal study could better determine whether more active women exhibited smaller decreases in REE with advancing age. Nevertheless, this study demonstrates that exercise at or above clinically-recommended levels is associated with higher REE, contrary to the effects of age and menopause. The assessment of exercise using diaries and calculation of EEE using those data and measured REE is also a potential limitation. Short-term exercise diaries may produce data of lesser quality (e.g. decreased accuracy and increased measurement error) than longer-term measurement using more objective methods such as accelerometry. The fact that EEE correlated with $\dot{V}O_{2peak}$ and body fat percentage in the expected directions, however, suggests that the exercise data are valid.

This study tested the hypotheses that moderate-to-high levels of exercise are associated with higher REE, and that the relationship between exercise and REE is at least partly independent of the effects of body size and body composition. Results of this cross-sectional analysis support both hypotheses, suggesting that exercise at or above levels in accordance with current clinical recommendations (Chodzko-Zajko et al. 2009) is associated with higher REE. Thus, in addition to effects on other factors such as aerobic capacity and strength (Westerterp and Meijer 2001) that are important to health and quality of life, it is possible that exercise may also help maintain REE with age and menopausal hormonal changes, offering further protection against metabolic syndrome and related diseases. Further longitudinal testing is required, however, to determine whether maintenance of regular exercise at these levels can indeed ameliorate the decline in REE among postmenopausal women.

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Fig. 1. Regression relationships between (A) REE and EEE ($b = 0.30 \pm 0.1$, $r^2 = 0.22$, $P < 0.01$), and (B) REE and exercise volume in $\text{MET} \cdot \text{min} \cdot \text{wk}^{-1}$ ($b = 0.03 \pm 0.02$, $r^2 = 0.11$, $P = 0.07$). Solid lines: least squares regression; dashed lines: 95% confidence interval of the regression. Filled circles indicate subjects who engaged only in aerobic exercise; open circles indicate subjects who engaged in a mixture of aerobic and resistance exercise.

Table 1

Sample characteristics (N=31)^a

Variable	Mean ± SE	Range
Age (years)	60.8 ± 1.2	(49 - 72)
REE (kcal/d)	1242 ± 23	(951 - 1514)
Exercise hours · wk ⁻¹	6.5 ± 0.6	(2.2 - 12.4)
EEE (kcal/d)	284 ± 36	(48 - 848)
MET · min · wk ⁻¹	2260 ± 266	(504 - 5646)
Weight (kg)	62.7 ± 1.7	(43.8 - 84.9)
Height (cm)	164.2 ± 1.5	(150.5 - 185.3)
BMI (kg/m ²)	23.2 ± 0.5	(17.8 - 29.0)
FFM (kg)	42.5 ± 1.0	(31.1 - 59.1)
FFMI (kg/m ²)	15.7 ± 0.2	(13.6 - 18.7)
FM (kg)	20.2 ± 1.0	(10.0 - 33.2)
FMI (kg/m ²)	7.5 ± 0.4	(4.1 - 11.9)
Fat %	31.8 ± 1.0	(23.0 - 41.0)
$\dot{V}O_{2peak}$ (mL O ₂ /kg/min)	24.7 ± 1.3	(12.9 - 35.8)
$\dot{V}O_{2peak}$ (L O ₂ /min)	1.5 ± 0.1	(0.6 - 2.7)

^a REE (resting energy expenditure); EEE (exercise energy expenditure); MET · min · wk⁻¹ (metabolic equivalent of task minutes of exercise per week); BMI (body mass index); FFM (fat-free mass); FFMI (fat-free mass index); FM (fat mass); FMI (fat mass index); Fat % (body fat percentage); $\dot{V}O_{2peak}$ (maximal oxygen uptake).

Table 2

Correlations between study variables^a

	Age	REE	EEE	Weight	Height	BMI	FFM	FFMI	FM	FMI	Fat %	$\dot{V}O_{2peak}$ ^b
REE	$r = -0.36^{\dagger}$											
EEE	$r_s = 0.20$	$r_s = 0.37^{\dagger}$										
Weight	$r = -0.37^{\dagger}$	$r = 0.69^{\dagger}$	$r_s = -0.11$									
Height	$r = -0.31$	$r = 0.68^{\dagger}$	$r_s = 0.13$	$r = 0.64^{\dagger}$								
BMI	$r = -0.22$	$r = 0.25$	$r_s = -0.20$	$r = 0.72^{\dagger}$	$r = -0.06$							
FFM	$r = -0.33$	$r = 0.81^{\dagger}$	$r_s = 0.17$	$r = 0.83^{\dagger}$	$r = 0.78^{\dagger}$	$r = 0.36^{\dagger}$						
FFMI	$r = -0.16$	$r = 0.46^{\dagger}$	$r_s = 0.16$	$r = 0.54^{\dagger}$	$r = -0.002$	$r = 0.67^{\dagger}$	$r = 0.62^{\dagger}$					
FM	$r = -0.29$	$r = 0.32$	$r_s = -0.36^{\dagger}$	$r = 0.83^{\dagger}$	$r = 0.28$	$r = 0.84^{\dagger}$	$r = 0.37^{\dagger}$	$r = 0.27$				
FMI	$r_s = -0.17$	$r_s = 0.01$	$r_s = -0.51^{\dagger}$	$r_s = 0.55^{\dagger}$	$r_s = -0.10$	$r_s = 0.82^{\dagger}$	$r_s = 0.06$	$r_s = 0.26$	$r_s = 0.82^{\dagger}$			
Fat %	$r = -0.15$	$r = -0.02$	$r_s = -0.54^{\dagger}$	$r = 0.49^{\dagger}$	$r = -0.06$	$r = 0.72^{\dagger}$	$r = -0.07$	$r = -0.01$	$r = 0.89^{\dagger}$	$r_s = 0.93^{\dagger}$		
$\dot{V}O_{2peak}$ ^b	$r = -0.10$	$r = 0.15$	$r_s = 0.62^{\dagger}$	$r = -0.31$	$r = 0.10$	$r = -0.50^{\dagger}$	$r = 0.10$	$r = 0.03$	$r = -0.63^{\dagger}$	$r_s = -0.75^{\dagger}$	$r = -0.76^{\dagger}$	
$\dot{V}O_{2peak}$ ^c	$r = -0.34$	$r = 0.64^{\dagger}$	$r_s = 0.57^{\dagger}$	$r = 0.28$	$r = 0.52^{\dagger}$	$r = -0.08$	$r = 0.63^{\dagger}$	$r = 0.39^{\dagger}$	$r = -0.16$	$r_s = -0.48^{\dagger}$	$r = -0.47^{\dagger}$	$r = 0.80^{\dagger}$

^a Coefficients: r -values are Pearson's product-moment correlation, where both variables are normally distributed in this sample; r_s -values are Spearman's rank-order coefficient, where at least one variable in the bivariate comparison is not normally distributed in this sample. REE (resting energy expenditure); EEE (exercise energy expenditure); BMI (body mass index); FFM (fat-free mass); FFMI (fat-free mass index); FM (fat mass); FMI (fat mass index); Fat % (body fat percentage); $\dot{V}O_{2peak}$ (maximal oxygen uptake).

^b Mass-specific $\dot{V}O_{2peak}$ (mL O₂/kg/min).

^c Absolute $\dot{V}O_{2peak}$ (L O₂/min).

[†] $P < 0.05$.

[‡] $P < 0.01$.

Table 3

Regression statistics where REE is the dependent variable

Overall Model					Parameter Estimates				
Model ^a	r ²	F (df)	P	Intercept ^b	Variable	b ± s _b ^c	β ^d	t (df)	P
1. Age, EEE	0.41	9.77 (2,28)	< 0.01	1688	Age	-9.0 ± 3.0	-0.44	-3.03 (1,28)	< 0.01
					EEE	0.35 ± 0.1	0.54	3.65 (1,28)	< 0.01
2. Age, FFM	0.67	28.66 (2,28)	< 0.01	627	Age	-2.2 ± 2.3	0.11	-0.94 (1,28)	0.36
					FFM	17.6 ± 2.6	0.78	6.80 (1,28)	< 0.01
3. EEE, FFM	0.70	33.04 (2,28)	< 0.01	492	EEE	0.14 ± 0.1	0.21	1.96 (1,28)	0.05
					FFM	16.7 ± 2.5	0.74	6.75 (1,28)	< 0.01
4. Age, EEE, FFM	0.73	24.51 (3,27)	< 0.01	790	Age	-3.8 ± 2.2	-0.19	-1.71 (1,27)	0.10
					EEE	0.18 ± 0.1	0.27	2.45 (1,27)	0.02
					FFM	14.9 ± 2.6	0.66	5.68 (1,27)	< 0.01

^a REE (resting energy expenditure); EEE (exercise energy expenditure); FFM (fat-free mass).

^b For all intercepts $P < 0.01$.

^c Unstandardized regression coefficients.

^d Standardized regression coefficients.