Lower Body Versus Whole Body Resistive Exercise Training and Energy Requirements of Older Men and Women

Wayne W. Campbell, Laura J. Kruskall, and William J. Evans

A person's energy requirement is defined as the metabolizable energy intake (MEI) consumed over a period of body weight stability. Controversy exists regarding whether resistive exercise training (RT) influences the energy requirement of older people. The aim of this study was to assess the effect of RT on the energy requirement of older people. The subjects were 11 men (M) and 17 women (W); age range, 55 to 78 years. During a 14-week precisely controlled diet study, each subject consumed foods and beverages portioned to provide sufficient MEI to match their energy requirement and to keep body weight stable at ± 0.5 kg of their starting weight. MEI was determined from bomb calorimeter analyses of the gross energy (GE) content of food, urine, and feces samples collected during 4-day intake-balance periods at study weeks 2, 8, and 14 (baseline, week RT6, and week RT12, respectively). MEI = $GE_{food} - GE_{urine} - GE_{feces}$. Resting energy expenditure (REE) was measured using an indirect calorimeter. From study weeks 3 to 14, 10 subjects (4 M, 6 W) remained sedentary (SED), 9 subjects (4 M, 5 W) performed lower body RT (LBRT) 3 times/week, and 9 subjects (3 M, 6 W) performed whole body RT (WBRT) 3 times/week. Body weight was not different among the SED, LBRT, and WBRT groups at baseline and were not changed over time or influenced by RT. At baseline, MEI was not different among the 3 groups. From weeks RT1 to RT12, MEI had to be increased by 17% ± 5% (mean ± SEM), 14% ± 7%, and 12% ± 7% in the SED, LBRT, and WBRT groups, respectively, to maintain stable body weights. At week RT12, the MEI required to maintain stable body weight was not significantly different among the SED, LBRT, and WBRT groups (9.45 ± 0.95, 9.40 ± 0.83, and 8.64 ±0.53 MJ/d, respectively). At week RT12, the MEI and MEI/REE ratio were higher in men versus women, independent of group assignment. These data suggest that RT, whether performed using the lower body only or the whole body, does not increase the energy requirement of older people. Also, these data show that the energy requirement of older men is greater than that of older women.

THE ENERGY REQUIREMENT of an individual was defined in 1985 by the joint Food and Agriculture Organization of the United Nations, the World Health Organization, and the United Nations University (FAO/WHO/UNU) Expert Consultation on energy and protein requirements as "that level of energy intake from food which will balance energy expenditure when the individual has a body size and composition, and level of physical activity, consistent with long-term good health. . . ."[1] According to the United States National Research Council,[2] "Recommended energy allowances are stipulated as kilocalories (kcal) per day of physiologically available energy (ie, the amount of potential food energy that can be absorbed and utilized)." For older and elderly people (ie, people age 51+ years), the Recommended Dietary Allowance (RDA) for metabolizable energy intake (MEI) is set at 1.5 times resting energy expenditure (REE). The accuracy and adequacy of this RDA have been questioned.[3-5]

Resistive exercise training (RT) is currently promoted as a highly effective way for older and elderly people to maintain and improve muscle strength, size, and function.[6,7] However, the effect of RT by older people on energy expenditure and energy requirement is unresolved. The results from several longitudinal studies show that REE may be increased with RT.[8-11] The results from Campbell et al[11] and Hunter et al[12] suggest that the energy requirement of older people is increased with RT. However, the results from Treuth et al,[8] as well as a recent review by Poehlman and Melby,[13] suggest that RT does not enhance the energy requirement of older people.

The aim of this study was to assess the effect of RT on the MEI required by healthy, free-living, older people to achieve and to maintain stable body weights during a 14-week period of precise dietary control. Based on previous observations in our laboratory,[11] we hypothesized that the MEI required for body weight maintenance would be higher in previously untrained older people who completed a 12-week period of RT compared with older people who remained sedentary.

SUBJECTS AND METHODS

Subjects

Eleven men and 17 women (age range, 55 to 78 years) were recruited from the central Pennsylvania area via advertisements in a local newspaper. Before being accepted into the study, prospective subjects were deemed apparently healthy and capable of successfully completing the protocol after undergoing a medical evaluation and interviews with the study coordinators and research dietitian. The medical screening included written and oral medical histories, a physician-administered physical examination, a resting electrocardiogram, a resistive exercise stress test, and routine blood and urine chemistries. For the resistive exercise stress test, heart rate, blood pressure, and electrocardiogram

From the Noll Physiological Research Center, The Pennsylvania State University, University Park, PA; Department of Foods and Nutrition, Purdue University, West Lafayette, IN; Department of Nursing, Nutrition Sciences Program, The University of Nevada Las Vegas, Las Vegas, NV; Nutrition, Metabolism, and Exercise Laboratory, Donald W. Reynolds Department of Geriatrics, University of Arkansas for Medical Sciences, Little Rock; and the Central Arkansas Veterans Healthcare System, Geriatric Research, Education, and Clinical Center, Little Rock, AR.

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Address correspondence to Wayne W. Campbell, PhD, Department of Foods and Nutrition, Purdue University, 1264 Stone Hall, Rm 204, West Lafayette, IN 47907-1264.

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responses were monitored before and immediately after each subject performed a bilateral knee extension exercise (2 sets of 8 repetitions at 80% of maximal strength). The subjects who entered into the study were free from any known acute or chronic diseases, and none used medications known to affect energy or protein metabolism. Also, each subject was free from known physical conditions that might place him or her at increased risk to physical injury due to the muscle strength testing and resistive exercise. All of the subjects had clinically normal heart, liver, thyroid, and kidney function and were nonsmokers. None of the women were taking any estrogen replacement medications. All of the subjects were provided with oral and written explanations of the purpose and procedures of the study and signed an informed consent agreement. The study protocol and consent forms were reviewed and approved by the Institutional Review Board, The Pennsylvania State University, University Park, PA and the Clinical Investigation Committee, The Pennsylvania State University, The Milton S. Hershey Medical Center, Hershey, PA.

Experimental Design

All of the subjects participated in a 14-week precisely controlled diet study at a General Clinical Research Center (GCRC) located at the Noll Physiological Research Center on the University Park campus of The Pennsylvania State University. The 14-week study started with a 2-week 'baseline' period in which all of the participants consumed the controlled diet, remained sedentary, and completed all testing (during week 2). The baseline period was immediately followed by a 12-week period of RT, with testing repeated at study weeks 8 and 14. The men and women were randomly assigned to 1 of 3 experimental groups: (1) sedentary (SED; n = 4 men and n = 6 women); (2) lower body resistive training (LBRT; n = 4 men and n = 5 women); and (3) whole body resistive training (WBRT; n = 3 men and n = 6 women). Separate randomization schemes were used for the men and women. Statistical power calculations (PC-SIZE; Consultant software, G.E. Dallal STATools, Boston, MA) indicated that n = 9 subjects/group would be required to show a 15% ± 1.5% difference (80% power, $P < .05$) in energy requirement due to RT.[11] For descriptive purposes, the methods and results of the study are presented in relationship to the week of RT, ie, baseline (study week 2), week RT6 (study week 8), and week RT12 (study week 14).

Residency at the GCRC was required during study weeks 2, 3, 8, and 14. During these weeks, the subjects slept at the GCRC, were available for all testing and procedures, and ate all of their meals at the GCRC dining facility. For the other 10 weeks of the study, 26 of the 28 subjects resided at home and maintained their usual lifestyles and daily physical activities as much as possible. During these 10 weeks, these subjects came to the GCRC each weekday to be weighed and to consume breakfast. All weekday lunches and dinners, and all weekend meals, were packed out for consumption away from the GCRC. Two subjects (1 man and 1 woman) who lived a considerable distance from University Park, PA, resided at the GCRC throughout the 14-week study period and consumed all of their meals at the GCRC dining facility.

Terminology

In this report, energy intake is described using 3 terms: 'total energy intake (TEI)', 'metabolizable energy intake (MEI)', and 'gross energy intake'. According to the United States National Research Council in the 1989 publication of the RDA,[2] "Recommended energy allowances are stipulated as kilocalories (kcal) per day of physiologically available energy (i.e., the amount of potential food energy that can be absorbed and utilized). The conventional general energy conversion factors of 4 kcal/g [16.7 kJ/g] of food protein or food carbohydrate and 9 kcal/g [37.7 kJ/g] of food fat [i.e., the classic general Atwater values] are adequate for computation of the energy content of typical diets in the United States, but not of specific foods nor diets based heavily on fibrous plant foods." Thus, the general Atwater values are used to estimate the metabolizable energy content of diets. For this study, the general Atwater values were used to calculate the metabolizable energy contents of the menus provided to each subject, and for descriptive purposes, the term TEI is used to represent these estimates. The term MEI is specifically used to describe the direct measurement of physiologically available energy determined from the gross energy contents of the food, urine, and stool samples collected during the study and analyzed using a bomb calorimeter after the study was completed. Gross energy intake is the amount of combustible energy contained in the diets provided to the subjects. Gross energy intake is greater than TEI and MEI. Theoretically, TEI and MEI are the same; however, the direct measurement of MEI strengthens the results of this study.

Diet

All of the subjects were provided daily menus on a 3-day rotating basis that consisted of foods and beverages portioned to provide 0.8 g protein $\cdot$ kg^{-1} $\cdot$ d^{-1}, a nonprotein energy content of 60% carbohydrate and 40% fat, and sufficient TEI to maintain body weight (Table 1). Dietary protein intake was set at 0.8 g protein $\cdot$ kg^{-1} $\cdot$ d^{-1}, because it is

Table 1. Dietary Energy, Protein, Carbohydrate, Fat, and Fiber Intakes at Baseline of the Men and Women in the SED, LBRT, and WBRT Groups

Parameter	SED	LBRT	WBRT
No. of men (M) and women (W)	4 M, 6 W	4 M, 5 W	3 M, 6 W
Energy intake* (MJ/d)	9.99 ± 0.75	10.14 ± 0.75	9.75 ± 0.43
kJ $\cdot$ kg^{-1} $\cdot$ d^{-1}	148 ± 6	148 ± 4	138 ± 5
Protein (g/d)	53 ± 3	56 ± 5	57 ± 3
g $\cdot$ kg^{-1} $\cdot$ d^{-1}	0.78 ± 0.01	0.81 ± 0.01	0.80 ± 0.01
Carbohydrate (g/d)	347 ± 43	331 ± 24	318 ± 14
g $\cdot$ kg^{-1} $\cdot$ d^{-1}	5.08 ± 0.40	4.85 ± 0.13	4.51 ± 0.18
Fat (g/d)	96 ± 7	97 ± 7	96 ± 4
g $\cdot$ kg^{-1} $\cdot$ d^{-1}	1.41 ± 0.06	1.43 ± 0.04	1.32 ± 0.05
Fiber (g/d)	24.9 ± 1.0	26.4 ± 1.3	25.2 ± 1.2
g $\cdot$ kg^{-1} $\cdot$ d^{-1}	0.38 ± 0.01	0.40 ± 0.02	0.36 ± 0.02

NOTE. Values are mean ± SEM.

*Energy intake was calculated from the gram weights of macronutrients in the menus times the corresponding general Atwater value; TEI = (g protein × 16.7 kJ/g) + (g carbohydrate × 16.7 kJ/g) + (g fat × 37.7 kJ/g). The macronutrient and dietary fiber contents of each subject's menus were determined using Nutritionist IV software (version 4.0, N-squared Computing, First Data Bank, San Bruno, CA).

the amount currently recommended by the National Research Council for older people to consume.[2] We have previously published a more detailed description of the menu scheme, including examples of specific menus and a detailed description of the guidelines followed by the subjects to enhance compliance and to help insure consumption of all of the foods and beverages provided.[3]

Initially, each subject's TEI was set to equal 1.70 times REE. TEI was calculated from the gram weights of macronutrients in the menus times the corresponding general Atwater value: TEI = (g protein × 16.7 kJ/g) + (g carbohydrate × 16.7 kJ/g) + (g fat × 37.7 kJ/g). The macronutrient and dietary fiber contents of each subject's menus were determined using Nutritionist IV software (version 4.0, N-squared Computing; First Data Bank, San Bruno, CA). REE was estimated using the sex-specific equations of Harris and Benedict[14] and confirmed via indirect calorimetry measurements (described later) made on 1 of the first 3 mornings of the study. The factor of 1.70 was chosen based on previous research by Roberts et al,[4] indicating that the current RDA factor of 1.50 underestimated the actual energy needs of older men. The goal of the study was to provide sufficient TEI to maintain body weight throughout the 14-week study. To achieve this goal, adjustments to TEI were made as necessary during the free-living study weeks to maintain body weight at ± 0.5 kg of each subject's mean body weight during study days 4 to 15. An adjustment to TEI was initiated if a subject's body weight was greater than 0.5 kg different than their baseline weight for 3 consecutive days. Either adding or subtracting very low-protein or protein-free foods and beverages from the daily menus while maintaining the nonprotein energy ratio at 60% carbohydrate to 40% fat accomplished this.

RT Program

From study weeks 3 to 14 (weeks RT1 to RT12), the men and women assigned to either the LBRT or WBRT groups participated in a progressive RT program 3 times/week, with each exercise session structured as previously described by Campbell et al.[15] For each exercise, each subject performed 2 sets of 8 repetitions and 1 set of repetitions continued until voluntary muscular fatigue. The intensity of each exercise was set at 80% of the 1 repetition maximum. When a subject performed 12 repetitions for the third set, the training resistance was increased by 5% for the next exercise session. People in the LBRT group performed unilateral knee extension and bilateral seated leg curl exercises only. People in the WBRT group performed unilateral knee extension and bilateral seated leg curl exercises (exactly the same as the LBRT group), and seated chest press and seated arm pull exercises. All exercises were performed on Keiser pneumatic resistive exercise equipment (Keiser Sports Health Equipment, Fresno, CA). One repetition maximum testing was performed during the first 2 exercise sessions and repeated during weeks RT6 and RT12. People assigned to the SED group completed all 1 repetition maximum testing, but did not participate in the RT program.

Body Composition Measurements

Body height (without shoes) was measured to the nearest 0.1 cm with a wall-mounted stadiometer during baseline. Fasting, nude body weight was measured to the nearest 0.1 kg each weekday throughout the study (model 2181; Toledo Scale, Toledo, OH; calibrated by standard dead weight testing).

Body density was measured at baseline, week RT6, and week RT12 by hydrostatic weighing,[16] with lung residual volume measured by nitrogen dilution[17] during the procedure. Total body water was determined using the deuterium oxide dilution technique, as previously described by Campbell et al.[11] A 3-compartment model equation of Siri[18] was used to calculate percent body fat, fat-free mass, and protein-mineral mass. One woman declined to participate in the hydrostatic weighing procedure. Twenty-four-hour urine collections were obtained on 4 consecutive days during each measurement period and aliquots of these samples measured for the creatinine concentration using a Technicon Autoanalyzer II (Technicon Instruments, Tarrytown, NY). Twenty-four-hour urinary creatinine excretion is used as an indirect indicator of whole-body muscle mass.[19,20]

REE Measurements

REE was measured using an indirect calorimeter at baseline week 1, baseline week 2, and week RT12, as previously described by Campbell et al.[3] The indirect calorimeter system included oxygen (Model Magnos 4G; Hartmann and Braun, Frankfurt, Germany) and carbon dioxide (model Uras 4; Hartmann and Braun) analyzers and used precise airflow control and temperature, humidity, and pressure measurements. Each measurement was made in the morning with the subject in a fasting state and having rested in a semirecumbent position for 20 minutes in a darkened thermoneutral room. For the subjects in the WBRT and LBRT groups, the measurements at week RT12 were made 48 hours after their most recent resistive exercise session. REE was calculated by multiplying the subject's rate of oxygen uptake (L/min) by the energy equivalent (kJ/L O_2) that was associated with the nonprotein respiratory exchange ratio of the expired breathes.[21]

Physical Activity Questionnaire

The energy expenditure associated with habitual physical activity (MJ/d) was determined at baseline, week RT6, and week RT12 using the Yale Physical Activity Survey.[22] The same interviewer administered the questionnaire during a private session with each subject throughout the study. The factor of 1 kcal = 4.184 kJ was used to convert the energy expenditure data from kilocalories/week to megajoules/day.

MEI Measurements

At baseline, week RT6, and week RT12, food, urine, and fecal samples were collected, processed, and aliquots stored frozen at −20°C. A duplicate composite of each of the 3 daily menus consumed by each subject was prepared and homogenized in a stainless steel blender. Four consecutive 24-hour urine collections were obtained. Four-day fecal collections were made between 2 fecal dye markers, and the composite feces samples were homogenized in a stainless steel blender. All food, urine, and feces aliquots were analyzed for gross energy content using a bomb calorimeter (model 1261; Parr Instrument, Moline, IL). Food homogenate aliquots were freeze-dried and pressed into pellets in preparation for the bomb calorimeter. The accuracy and precision of the bomb calorimeter was determined by running control samples of whole egg, egg white, and olive oil. The expected gross energy concentration of these compounds was 29.72 kJ/g, 23.89 kJ/g, and 39.62 kJ/g, respectively. These compounds were measured to contain 29.23 ± 0.03 kJ/g (mean ± SD, coefficient of variation [CV] = 0.11%), 23.70 ± 0.02 kJ/g (CV = 0.09%), and 39.31±0.03 kJ/g (CV = 0.09%), respectively. The MEI of each subject was calculated as: MEI (MJ/d) = dietary gross energy intake (MJ/d) minus gross energy of urine (MJ/d) minus gross energy of feces (MJ/d).

Statistical Analyses

Values are reported as means ± SEM. At baseline, differences among groups, and between men and women, in mean values for all independent variables were assessed using a 2-factor analysis of variance (ANOVA). The main effects and interactions of group and sex, over time, were assessed using 2-factor (group, sex) repeated measures (time) ANOVA. Statistical significance was assigned at $P < .05$ (2-sided). Statistical analyses established that there were no group-by-sex-by-time interactions for any of the variables measured. For descriptive purposes, the results for each dependent variable are presented in 2 ways; first, for the SED, LBRT, and WBRT groups, with data from the men and women combined; and second, for all of the men and women, with data from the 3 groups combined. The data are presented in these 2 ways to show the results based on the primary aim of the study (ie, the group effects) and to show the results based on the gender effects established from the statistical analyses. The study was not powered to assess the effect of sex on the group-specific responses to RT. Data processing was accomplished using Microsoft Excel 5.0 (Microsoft, Redmond, WA) software. Statistical evaluations were performed using JMP software (version 3.2.2, SAS Institute, Cary NC).

RESULTS

Body Composition

At baseline, there were no differences in age, height, weight, percent body fat, fat-free mass, total body water, protein-mineral mass, and urinary creatinine excretion (an indirect indicator of whole body muscle mass) among the subjects in the SED, LBRT, and WBRT groups (Table 2). Body weight and protein-mineral mass were not changed, percent body fat increased ($P = .011$), and fat-free mass ($P = .004$), total body water ($P = .013$), and urinary creatinine excretion ($P = .051$)

Table 2. Characteristics and Body Composition

Parameter	Group*	Baseline	Week RT6	Week RT12
Age (yr)	SED	66 ± 3		
	LBRT	67 ± 3		
	WBRT	67 ± 1		
	All men	68 ± 2		
	All women	66 ± 2		
Height† (cm)	SED	167 ± 3		
	LBRT	166 ± 3		
	WBRT	163 ± 3		
	All men	173 ± 2		
	All women	160 ± 1		
Weight†‡ (kg)	SED	67.7 ± 4.1	67.2 ± 4.0	67.7 ± 4.0
	LBRT	69.2 ± 5.9	68.6 ± 5.7	68.7 ± 5.7
	WBRT	71.2 ± 3.9	71.2 ± 4.1	71.1 ± 4.0
	All men	77.2 ± 1.0	76.2 ± 3.6	76.6 ± 3.6
	All women	64.2 ± 3.1	64.2 ± 3.1	64.2 ± 3.1
Body fat†§ (%)	SED	38.7 ± 2.8	38.2 ± 2.8	40.1 ± 2.8
	LBRT	37.8 ± 1.8	38.0 ± 1.8	39.4 ± 1.3
	WBRT	40.4 ± 3.5	41.4 ± 2.9	42.1 ± 3.2
	All men	33.0 ± 1.9	33.5 ± 1.7	34.7 ± 1.7
	All women	43.6 ± 1.7	43.7 ± 1.5	45.0 ± 1.5
Fat-free mass†§ (kg)	SED	42.1 ± 3.1	42.0 ± 3.1	41.0 ± 3.0
	LBRT	43.0 ± 4.0	42.6 ± 3.9	41.8 ± 3.8
	WBRT	42.6 ± 2.8	41.8 ± 2.3	41.1 ± 2.3
	All men	51.6 ± 2.0	50.6 ± 1.8	49.7 ± 1.6
	All women	35.8 ± 1.2	35.7 ± 1.2	35.0 ± 1.2
Total body water†§ (L)	SED	28.9 ± 2.3	29.1 ± 2.1	27.8 ± 2.0
	LBRT	30.4 ± 2.9	30.0 ± 2.8	29.5 ± 2.8
	WBRT	30.6 ± 2.0	29.0 ± 1.6	28.9 ± 1.5
	All men	36.4 ± 1.7	35.4 ± 1.4	34.6 ± 1.3
	All women	25.4 ± 0.9	25.1 ± 0.8	24.5 ± 0.8
Protein mineral mass† (kg)	SED	12.5 ± 0.9	12.2 ± 1.0	12.6 ± 0.9
	LBRT	12.6 ± 1.2	12.6 ± 1.3	12.3 ± 1.3
	WBRT	12.0 ± 1.0	12.8 ± 1.0	12.3 ± 1.0
	All men	15.2 ± 0.5	15.2 ± 0.6	15.1 ± 0.6
	All women	10.2 ± 0.5	10.5 ± 0.6	10.3 ± 0.5
Urinary creatinine†‡§ (g/d)	SED	1.08 ± 0.12	1.03 ± 0.10	1.00 ± 0.11
	LBRT	1.14 ± 0.17	1.10 ± 0.14	1.04 ± 0.12
	WBRT	1.00 ± 0.11	1.04 ± 0.09	1.03 ± 0.10
	All men	1.42 ± 0.10	1.30 ± 0.07	1.27 ± 0.08
	All women	0.82 ± 0.05	0.88 ± 0.06	0.84 ± 0.05

NOTE. Values are mean ± SEM.

*Groups: Men, n = 11; women, n = 17; SED, sedentary, n = 10 (4 men and 6 women); LBRT, lower body resistive training, n = 9 (4 men and 5 women); WBRT, whole body resistive training, n = 9 (3 men and 6 women).

†Women different than men, $P < .05$.

‡Sex-by-time interaction, $P \leq .05$.

§Change over time from weeks 2 to 8 to 14, $P \leq .05$.

decreased over time among the groups. There were no group-specific responses over time for any of these measures of whole body composition (ie, no group-by-time interactions).

At baseline, the men and women were not different in mean age. The men had more height ($P < .001$), weight ($P = .012$), fat-free mass (($P < .001$), total body water ($P < .001$), protein-mineral mass ($P < .001$), and urinary creatinine excretion ($P < .001$), and less percent body fat ($P < .001$) than the women. Over time, body weight decreased in the men and remained stable in the women (sex-by-time, $P = .040$). For the men, body weight decreased from baseline to week RT6 and did not change from week RT6 to week RT12. The changes over time in percent body fat, fat-free mass, total body water, and protein-mineral mass were not different in the men and women (ie, there were no sex-by-time interactions). The change over time in urinary creatinine excretion was different in the men versus women (sex-by-time interaction, $P = .020$). Mean urinary creatinine excretion decreased in the men and did not change in the women.

Muscle Strength

At baseline, the SED, LBRT, and WBRT groups were not different in upper body and lower body strength (Table 3). Over time, the groups responded differently in upper body and lower body strength (group-by-time interactions, $P = .001$ and $P = .001$, respectively). For upper body strength, the WBRT group increased compared with the SED group, with the LBRT response intermediate to these 2 groups. Compared with baseline, upper body strength was changed by −1% ± 2%, 10% ± 5%, and 18% ± 3% in the SED, LBRT, and WBRT groups, respectively. For lower body strength, the LBRT and WBRT groups increased strength compared with the SED group, with no difference in response between the LBRT and WBRT groups. Compared with baseline, lower body strength was changed by 0% ± 7%, 36% ± 11%, and 32% ± 6% in the SED, LBRT, and WBRT groups, respectively.

At baseline, the men were stronger than the women in both the upper body and the lower body. Over time, upper body and lower body strength increased ($P < .001$), with no differences in responses between the men and the women (ie, there were no sex-by-time interactions). These changes in strength for the men and women are presented without consideration of group assignment.

REE

At baseline, REE was not different among the SED, LBRT, and WBRT groups (Table 3). REE was not changed over time among the groups.

At baseline, REE was higher in the men than in the women. Over time, REE was changed differently for the men than for the women (sex-by-time interaction, $P = .019$). Mean REE increased by 0.16 ± 0.12 MJ/d (2.5% ± 2.0%) in the men and decreased by −0.20 ± 0.07 MJ/d (−3.7% ± 1.4%) in the women. These changes in REE for the men and women are presented without consideration of group assignment.

Energy Expenditure of Physical Activity

Based on the Yale Physical Activity Survey, the energy expenditure of physical activities was not different among the SED, LBRT, and WBRT groups at baseline and not changed over time among the groups. At baseline, week RT6, and week RT12, respectively, the estimated energy expenditures of physical activities were 3.10 ± 0.57, 2.55 ± 0.45, and 2.31 ± 0.32 MJ/d for the SED group, 2.70 ± 0.53, 2.52 ± 0.40, and 2.37 ± 0.40 MJ/d for the LBRT group, and 3.03 ± 0.56, 2.27 ± 0.36, and 2.72 ± 0.46 MJ/d for the WBRT group.

The estimated energy expenditure of physical activities was

Table 3. Muscle Strength and REE

Parameter	Group*	Baseline	Week RT12
Upper body strength†‡ (N)	SED	672 ± 98	657 ± 89
	LBRT	640 ± 106	668 ± 88
	WBRT	686 ± 76	810 ± 93§
	All men	920 ± 51	970 ± 54
	All women	482 ± 31	542 ± 34
Lower body strength†‡ (N)	SED	297 ± 42	288 ± 33
	LBRT	290 ± 50	357 ± 50§
	WBRT	280 ± 40	361 ± 43§
	All men	408 ± 30	457 ± 31
	All women	207 ± 16	256 ± 17
REE†‖ (MJ/d)	SED	5.77 ± 0.18	5.72 ± 0.21
	LBRT	5.89 ± 0.33	5.85 ± 0.44
	WBRT	5.77 ± 0.27	5.65 ± 0.27
	All men	6.50 ± 0.25	6.65 ± 0.27
	All women	5.31 ± 0.16	5.11 ± 0.18

NOTE. Values are mean ± SEM.

*Groups: Men, n = 11; women, n = 17; SED, sedentary, n = 10 (4 men and 6 women); LBRT, lower body resistive training, n = 9 (4 men and 5 women); WBRT, whole body resistive training, n = 9 (3 men and 6 women).

†Women different than men, $P < .05$.

‡Group-by-time interaction, $P = .001$.

§Change over time different than SED group, $P \leq .05$.

‖Sex-by-time interaction, $P \leq .05$.

not different between the men and women, independent of group assignment, at baseline, and was not changed over time. At baseline, week RT6, and week RT12, respectively, the estimated energy expenditures of physical activities were 2.67 ± 0.45, 2.51 ± 0.34, and 2.62 ± 0.36 MJ/d for the men, and 3.13 ± 0.43, 2.42 ± 0.32, and 2.36 ± 0.26 MJ/d for the women.

Metabolizable Energy Intake

There were no differences in dietary gross energy intake, gross energy excretion in urine, gross energy excretion in feces, and dietary MEI among the SED, LBRT, and WBRT groups at baseline (Table 4). The dietary gross energy intake and MEI were increased over time to achieve and maintain constant body weights among the subjects. These increases over time were necessary in all 3 groups (ie, there were no significant group-by-time interactions). MEI in the SED, LBRT, and WBRT groups was increased by 17% ± 5%, 14% ± 7%, and 12% ± 7%, respectively. Gross energy excretions in urine and feces did not change over time in any of the groups. At week RT12, there were no differences in MEI among the 3 groups.

At baseline, the men had higher dietary gross energy intake (P = .001), gross energy excretion in urine (P = .022), gross energy excretion in feces (P = .002), and dietary MEI (P = .024) than the women. Dietary gross energy intake and MEI had to be increased over time ($P < .001$ and $P < .001$, respectively) to stabilize and maintain constant body weight. These changes over time needed to be greater in the men than in the women (sex-by-time, P = .009 and P = .008, respectively). The mean increase in MEI was 14.4% ± 3.5% in men and women combined, 26.6% ± 3.9% in the men, and 6.6% ± 4.2% in the women. Gross energy excretions in urine and feces did not change over time. At week RT12, dietary gross energy intake and MEI were higher in the men than in the women.

We were also interested in how these results compared with the current RDA for energy in older people. At week RT12, at the time when body weight stability was achieved and maintained in all subjects, the mean MEI/REE was 1.68 for the men and 1.53 for the women (men different than women, P = .027). In relationship to the RDA, the value for the men (P = .010), but not the women, was higher than the RDA prediction of 1.50.

DISCUSSION

A main finding of this study was that RT did not significantly influence the energy requirement of older people. This finding was contrary to our hypothesis that the MEI required for body weight maintenance would be higher in older people who completed a 12-week RT period compared with older people who remained sedentary. Two lines of evidence suggest that the energy needs of older people were not greatly influenced by the 12-week RT program used in the present study. First, while the MEI needed to be increased from baseline to week RT12 by a mean of 14% ± 3%, there were no differences among groups in this response over time. Second, at week

Table 4. Gross and Metabolizable Energy Values

Parameter	Group*	Baseline	Week RT6	Week RT12
GE intake†‡§ (MJ/d)	SED	10.55 ± 0.80	11.66 ± 1.24	11.90 ± 1.18
	LBRT	10.88 ± 0.71	11.53 ± 0.90	12.12 ± 1.02
	WBRT	10.47 ± 0.51	11.42 ± 0.50	11.21 ± 0.53
	All men	12.08 ± 0.67	13.57 ± 0.93	14.22 ± 0.82
	All women	9.69 ± 0.31	10.23 ± 0.41	10.15 ± 0.39
GE in urine† (MJ/d)	SED	0.26 ± 0.03	0.28 ± 0.02	0.26 ± 0.03
	LBRT	0.31 ± 0.05	0.29 ± 0.03	0.30 ± 0.03
	WBRT	0.25 ± 0.02	0.32 ± 0.03	0.30 ± 0.02
	All men	0.33 ± 0.03	0.32 ± 0.02	0.33 ± 0.02
	All women	0.24 ± 0.02	0.28 ± 0.02	0.25 ± 0.02
GE in feces† (MJ/d)	SED	2.24 ± 0.15	2.47 ± 0.16	2.19 ± 0.30
	LBRT	2.39 ± 0.37	2.74 ± 0.35	2.43 ± 0.32
	WBRT	2.34 ± 0.15	2.58 ± 0.20	2.28 ± 0.17
	All men	2.80 ± 0.24	2.87 ± 0.25	2.66 ± 0.28
	All women	2.01 ± 0.10	2.41 ± 0.15	2.05 ± 0.15
MEI†‡§‖ (MJ/d)	SED	8.06 ± 0.71	8.90 ± 1.27	9.45 ± 0.95
	LBRT	8.18 ± 0.44	8.51 ± 0.66	9.40 ± 0.83
	WBRT	7.88 ± 0.58	8.52 ± 0.83	8.64 ± 0.53
	All men	8.96 ± 0.60	10.37 ± 1.10	11.22 ± 0.64
	All women	7.44 ± 0.33	7.54 ± 0.36	7.85 ± 0.36

NOTE. Values are mean ± SEM.

Abbreviations: GE, gross energy; MEI, metabolizable energy intake.

*Groups: Men, n = 11; women, n = 17; SED, sedentary, n = 10 (4 men and 6 women); LBRT, lower body resistive training, n = 9 (4 men and 5 women); WBRT, whole body resistive training, n = 9 (3 men and 6 women).

†Women different than men, $P < .05$.

‡Change over time, $P < .001$.

§Sex-by-time interaction, $P < .01$.

‖MEI, GE intake − GE in urine − GE in feces.

RT12, the MEI required for body weight stability was not different among the WBRT, LBRT, and SED groups.

Previously, we published data from a 14-week controlled feeding study that suggested that RT increased the energy requirement of older people by about 15%.[11] TEI was provided for that study in a similar fashion as used for the present study. This previous study was limited by the lack of a sedentary control group. It is now apparent that the 15% increase in energy needs attributed to the effects of RT might have been largely due to an initial underestimation of MEI in those subjects and the subsequent need to increase MEI to achieve and maintain stable body weight in those subjects, as shown in the present study.

Hunter et al[12] recently reported that total energy expenditure (TEE), assessed using a doubly-labeled water technique, increased by 12% in body weight-stable older men and women who completed a 26-week RT program, a finding consistent with an increase in energy requirement. This study was strengthened by the longer-term duration of the RT program and weakened by the lack of a sedentary control group. Other research suggests that RT does not positively influence energy requirement. Treuth et al[8] reported an increased REE, but no change in TEE, after 16 weeks of strength training in older women. REE and TEE were measured before and after the RT intervention using a room indirect calorimeter. Meijer et al[23] examined the effects of 12 weeks of aerobic and RT on total daily physical activity in 15 older men and women. Physical activity was measured using a triaxial accelerometer. Although physical fitness levels improved (increased maximal oxygen uptake, increased maximal power output, and decreased heart rate at an 100-W power output), exercise had no effect on total daily physical activity. The investigators concluded that training activity was compensated for by a reduced amount of nontraining physical activity. Nontraining physical activity was determined by subtracting the accelerometer output of a training session from the total accelerometer output on the day of training. The specific activities that contributed to the nontraining physical activity were not identified. This compensatory reduction in physical activity during nonexercising times of the day is also reported in studies of aerobic training in older adults. Goran and Poehlman[24] were the first to report such an observation. After 8 weeks of high-intensity aerobic training in older men and women, there was an increase in $\dot{V}O_2$ max, but no increase in TEE. More recent data suggest a different relationship between exercise and energy requirements. Bunyard et al[25] reported that endurance exercise increased energy requirements of previously inactive older men, and that energy needs decreased in elite athletes who stopped training for 8 weeks and then maintained that low $\dot{V}O_2$ max for another 4 weeks. The energy intake in this study was estimated using information based on food composition tables. Furthermore, subjects were weight stable for only 2 to 4 weeks before TEI was estimated. Actual MEI was not measured for comparison. While the results from this study may not be accurate for reporting actual energy requirement of these study groups, the data are useful, because it was the change with exercise or no exercise that was the focus of the study.

The experimental design used for this study provided an opportunity to assess whether the number of muscle groups trained (ie, the number of exercise movements performed; LBRT *v* WBRT) influenced RT-induced changes in whole body energy metabolism and dietary energy requirements of older people. A priori, we hypothesized that the MEI required to maintain body weight stability would be as follows: WBRT > LBRT > SED. The results of the study did not support this hypothesis and suggest that the number of muscle groups trained in older people did not influence whole body energy metabolism and energy requirement. To our knowledge, this is the first study to assess this issue. The modest increase in upper body strength of the LBRT group is consistent with the use of their arms to help stabilize them on the equipment while performing the lower body exercises. This result was not anticipated when the study was designed and should be considered for future studies evaluating lower body versus whole body RT.

The gender-specific response over time in REE is consistent with a growing awareness that older men and women have different metabolic and physiologic responses to RT. For example, Tracy et al[26] reported that older men showed greater increases in quadriceps muscle volume, measured by magnetic resonance imaging, than older women in response to a 9-week unilateral leg RT program. Research also showed that older men experienced greater absolute increases in maximal muscle strength and power due to RT than older women.[26,27] Joseph et al[28] documented that RT-induced changes in whole body composition and lipoprotein-lipid profile were different between older men and older women. Specifically, with RT fat-free mass increased and percent body fat decreased in older men and remained unchanged in older women. Also, high-density lipoprotein (HDL) cholesterol increased, and the total cholesterol to HDL ratio decreased in older men, but whole body composition was not changed, and the lipoprotein-lipid profile response was opposite in older women. Collectively, these data strongly support that the metabolic and physiologic responses to RT are greater in older men than older women. Future research in a larger cohort of older men and women is needed to more fully assess the effect of RT on whole body composition, muscle metabolism and size, and whole body energy metabolism and requirement.

The results from this study provide an opportunity to assess the metabolizable energy requirements of older men and women in relationship to the current RDA. The results show that the RDA energy requirement prediction of 1.5 times REE accurately estimated MEI for older women (1.53 ± 0.04), but underestimated MEI for older men (1.68 ± 0.05). The higher MEI/REE ratio of the men versus women would suggest that the men were more physically active. These findings are in general agreement with previous research in older men[4,29,30] and women,[29-31] in which TEE was measured using the doubly-labeled water technique. Research by Seale et al[32] indicated that for weight-stable people, an energy requirement may be accurately and comparably determined by either measured MEI or TEE assessed via the doubly-labeled water technique. It should be noted that while the present data suggest that free-living older men have a higher energy requirement than the current RDA, this conclusion might only be appropriate for men under the age of 75 years. Two studies that examined energy requirement in men over 75 years do not show differences from the RDA.[33,34]

The dietary protein intake of the men and women in this study was strictly controlled at the current RDA of 0.8 g protein · kg^{-1} · d^{-1}. We have questioned the adequacy of this protein intake for older people[35,36] and have documented a decrease in midthigh muscle area in the SED group.[37] The decrease in fat-free mass observed for all of the groups also suggest that the current RDA may not be adequate to maintain lean tissue mass in older people. Based on the finding that the subjects lost fat-free mass, one could view the decision to provide the RDA for protein as a limitation of the study. Previous research from our laboratory has shown that older people who consumed the RDA versus twice the RDA for protein did not experience differential body composition or energy requirement responses to RT.[11,38] We view the decision to feed all of the subjects the RDA for protein as a strength of the study and the finding that these people lost fat-free mass of potential major nutritional importance.

One may view the apparent initial underestimation of energy needs of these subjects and the need to increase energy intakes to achieve and maintain stable body weights, especially in the men, as limitations of the study. The accurate estimation of a person's true energy requirement is indeed difficult, and the need to increase energy intakes over time in these subjects probably reflects this difficulty. This 14-week study is the longest-term strictly controlled diet and exercise assessment of energy requirements completed in older people and provided sufficient time to identify and correct inaccuracies in the initial estimation of the energy needs of each individual subject. The body weights of the subjects were successfully stabilized during the study, especially during study weeks RT6 to RT12. For the men, the mean body weight was only 0.6 kg lower at week RT12 than at baseline. This amount of weight change over a 12-week period of time would theoretically represent an energy imbalance of 0.23 MJ/d, well within the limit of measurability of any known energy requirement assessment technique. A longer baseline period to fully achieve body weight stability in all of the subjects prior to starting the RT intervention would have potentially strengthened the study design, albeit with the use of considerably more resources. All of the subjects started out sedentary, and a change in energy requirement with RT would have been seen as a differential change in the amount of energy needed to achieve and maintain stable body weight. A difference in energy requirement between the groups, if one existed, would also have been apparent via a cross-sectional evaluation of the week RT12 data. We view the inclusion of the control group as a major strength of the study. Without the control group, an incorrect conclusion that RT increased the energy requirement of these older people might have been reached.

The inclusion of both men and women in the study groups could be viewed as another potential limitation of this study. The number of men and women in each of the groups was inadequate, and indeed, the study was not designed, to study sex-specific responses to RT. The finding that older men have a higher energy requirement than older women, independent of RT, is very important information to dietitians and other health-care professionals who work with and care for older people.

In conclusion, these results indicate that the energy requirement of older men is greater than that of older women. The issue of whether RT increases the energy requirement of older people remains controversial. However, the present results indicate that RT, whether performed using the lower body only or the whole body, does not greatly influence the total energy requirement of older people.

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REFERENCES

1. FAO/WHO/UNU. Energy and protein requirements. Geneva, Switzerland, World Health Organization, 1985

2. National Research Council, Recommended Dietary Allowances (ed 10). Food and Nutrition Board, Washington, DC, National Academy Press, 1989

3. Campbell WW, Cyr-Campbell D, Weaver JA, et al: Energy requirement for long-term body weight maintenance in older women. Metabolism 46:884-889, 1997

4. Roberts SB, Young VR, Fuss P, et al: What are the dietary energy needs of elderly adults? Int J Obes 16:969-976, 1992

5. Roberts SB: Energy requirements of older individuals. Eur J Clin Nutr 50: S112-S118, 1996 (suppl 1)

6. Evans WJ, Campbell WW: Sarcopenia and age-related changes in body composition and functional capacity. J Nutr 123:465-468, 1993

7. Fiatarone MA, Evans WJ: The etiology and reversibility of muscle dysfunction in the aged. J Gerontol 48:77-83, 1993

8. Treuth MS, Hunter GR, Weinsier RL, et al: Energy expenditure and substrate utilization in older women after strength training: 24-h calorimeter results. J Appl Physiol 78:2140-2146, 1995

9. Pratley R, Nicklas B, Rubin M, et al: Strength training increases resting metabolic rate and norepinephrine levels in healthy 50- to 65-yr-old men. J Appl Physiol 76:133-137, 1994

10. Ryan AS, Pratley RE, Elahi D, et al: Resistive training increases fat-free mass and maintains RMR despite weight loss in postmenopausal women. J Appl Physiol 79:818-823, 1995

11. Campbell WW, Crim MC, Young VR, et al: Increased energy requirements and body composition changes with resistance training in older adults. Am J Clin Nutr 60:167-175, 1994

12. Hunter GR, Wetzstein CJ, Fields DA, et al: Resistance training increases total energy expenditure and free-living physical activity in older adults. J Appl Physiol 89:977-984, 2000

13. Poehlman ET, Melby C: Resistance training and energy balance. Int J Sport Nutr 8:143-159, 1998

14. Harris JA, Benedict FG: A Biometric Study of Basal Metabolism in Man. Washington, DC, Carnegie Institute of Washington, 1919

15. Campbell WW, Joseph LJO, Davey SL, et al: Effects of resistance training and chromium picolinate on body composition and skeletal muscle in older men. J Appl Physiol 86:29-39, 1999

16. Akers R, Buskirk ER: An underwater weighing system utilizing "force cube" transducers. J Appl Physiol 26:649-652, 1969

17. Wilmore JH: A simplified method for determination of residual lung volumes. J Appl Physiol 27:96-100, 1969

18. Siri WE: Body composition from fluid spaces and density: Analysis of methods, in Techniques for Measuring Body Composition. Washington, Dc, National Academy of Sciences, 1961, pp 223-244

19. Heymsfield S, Ateaga C, McManus C, et al: Measurement of muscle mass in humans: Validity of the 24-hour urinary creatinine method. Am J Clin Nutr 37:478-494, 1983

20. Welle S, Thornton C, Totterman S, et al: Utility of creatinine excretion in body-composition studies of healthy men and women older than 60 y. Am J Clin Nutr 63:151-156, 1996

21. McArdle WD, Katch FI, Katch VL: Exercise Physiology Energy, Nutrition, and Human Performance (ed 3). Philadelphia, PA, Lea & Febiger, 1991

22. DiPietro L, Caspesen CJ, Ostfeld AM, et al: A survey for assessing physical activity among older adults. Med Sci Sports Exerc 25:628-642, 1993

23. Meijer EP, Westerterp KR, Verstappen FT: Effects of exercise training on total daily physical activity in older humans. Eur J Appl Physiol 80:16-21, 1999

24. Goran MI, Poehlman ET: Endurance training does not enhance total energy expenditure in healthy elderly persons. Am J Physiol 263:E950-E957, 1992

25. Bunyard LB, Katzel LI, Busby-Whitehead MJ, et al: Energy requirements of middle-aged men are modifiable by physical activity. Am J Clin Nutr 68:1136-1142, 1998

26. Tracy BL, Ivey FM, Hurlbut D, et al: Muscle quality. II. Effects of strength training in 65- to 75-yr-old men and women. J Appl Physiol 86:195-201, 1999

27. Jozsi AC, Campbell WW, Joseph LJO, et al: Changes in power with resistance training in older and younger men and women. J Gerontol A Biol Sci Med Sci 54A:M591-M596, 1999

28. Joseph LJO, Davey SL, Evans WJ, et al: Differential effect of resistance training on the body composition and lipoprotein-lipid profile of older men and women. Metabolism 48:1474-1480, 1999

29. Starling RD, Toth MJ, Matthews DE, et al: Energy requirements and physical activity in older free-living African-Americans: A doubly labeled water study. J Clin Endocrinol Metab 83:1529-1534, 1998

30. Starling RD, Toth MJ, Carpenter WH, et al: Energy requirements and physical activity in free-living older women and men: A doubly labeled water study. J Appl Physiol 85:1063-1069, 1998

31. Sawaya AL, Saltzman E, Fuss P, et al: Dietary energy requirements of young and older women determined by using the doubly labeled water method Am J Clin Nutr 62:338-344, 1995

32. Seale JL, Rumpler WV, Conway JM, et al: Comparison of doubly labeled water, intake-balance, and direct- and indirect-calorimetry methods for measuring energy expenditure in adult men. Am J Clin Nutr 52:66-71, 1990

33. Fuller NJ, Sawyer MB, Coward WA, et al: Components of total energy expenditure in free-living elderly men (over 75 years of age): Measurement, predictablility and relationship to quality-of-life indices. Br J Nutr 75:161-173, 1996

34. Black AE, Coward WA, Cole TJ, et al: Human energy expenditure in affluent societies: An analysis of 574 doubly-labelled water measurements. Eur J Clin Nutr 50:72-92, 1996

35. Campbell WW, Crim MC, Dallal GE, et al: Increased protein requirements in elderly people: New data and retrospective reassessments. Am J Clin Nutr 60:501-509, 1994

36. Campbell WW, Evans WJ: Protein requirements of elderly people. Eur J Clin Nutr 50:S180-S185, 1996 (suppl 1)

37. Campbell WW, Trappe TA, Wolfe RR, et al: The Recommended Dietary Allowance for protein may not be adequate for older people to maintain skeletal muscle. J Gerontol A Biol Sci Med Sci 56:M373-M380, 2001

38. Campbell WW, Crim MC, Young VR, et al: Effects of resistance training and dietary protein intake on protein metabolism in older adults. Am J Physiol 268:E1143-E1153, 1995