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Activity energy expenditure and change in body composition in late life[1–3]

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ABSTRACT

Background: Change in body composition, specifically loss of fat-free mass and gain in fat mass, in older adults is a major pathway leading to the onset of functional decline and physical disability.

Objective: The objective was to determine the association of activity-related energy expenditure with change in body mass and composition among older men and women.

Design: Total energy expenditure (TEE) was assessed over 2 wk by using the doubly labeled water method in 302 community-dwelling older adults aged 70–82 y. Resting metabolic rate (RMR) was measured by using indirect calorimetry, and the thermic effect of meals was estimated at 10% of TEE. Activity energy expenditure (AEE) was calculated as [TEE(0.9) − RMR]. Total body mass, fat-free mass (FFM), and fat mass (FM) were assessed by dual-energy X-ray absorptiometry annually over a mean (±SD) of 4.9 ± 1.3 y.

Results: In multivariate models adjusted for baseline age, smoking status, and race, men and women had a decline (in kg/y) in body mass (men: −0.34, 95% CI: −0.71, 0.02; women: −0.45, 95% CI: −0.71, −0.19) and FFM (men: −0.48, 95% CI: −0.67, −0.29; women: −0.14, 95% CI: −0.026, −0.03). No changes (in kg/y) were observed in FM (men: 0.14, 95% CI: −0.10, 0.38; women: −0.28, 95% CI: −0.49, −0.07). In men and women, higher AEE at baseline was associated with greater FFM. The average change in these outcomes (ie, slope), however, was similar across tertiles of AEE.

Conclusions: These data suggest that accumulated energy expenditure from all physical activities is associated with greater FFM, but the effect does not alter the trajectory of FFM change in late life. *Am J Clin Nutr* 2009;90:1336–42.

INTRODUCTION

Aging in late life is associated with a decrease in body mass and a disproportionate loss of fat-free mass (FFM) (1, 2) that is not influenced by weight stability (3). Several reports suggest that physical activity levels (PALs) may attenuate age-related declines in body mass and changes in body composition (4, 5). For example, previous studies have shown that higher levels of reported physical activity predict less of a decline in body mass and preservation of FFM in older adults (4, 5). However, these studies are limited by infrequent follow-up and populations that include a high proportion of nonelderly persons, which reduce the sensitivity of detecting severe losses in FFM known to occur in participants aged ≥70 y (4).

Previous studies documenting a positive effect of physical activity on body composition in older adults have assessed activity levels using valid and reliable self-report questionnaires (4, 5). Such instruments tend to focus on purposeful exercise-related activity and do not typically yield precise information on total activity expenditure. The doubly labeled water (DLW) technique, in contrast, captures any form of physical activity ranging from purposeful exercise to simple fidgeting (6). Thus, the DLW method can better address whether higher levels of free-living activity energy expenditure (AEE) provide protection from age-related changes in body composition in late life. On the basis of previous studies that used self-reported activity levels, it was hypothesized that older adults with higher levels of AEE would have an attenuated loss of total and fat-free body mass.

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SUBJECTS AND METHODS

Study sample

In 1997–1998, investigators from the University of Pittsburgh and University of Tennessee, Memphis, recruited 3075 participants aged 70–79 y from a random sample of white Medicare beneficiaries and all age eligible self-identified black community residents to participate in the Health, Aging and Body Composition (Health ABC) study. Eligibility criteria included self-report of no difficulty walking 0.25 miles (0.4 km), climbing 10 stairs, or performing activities of daily living; no plans to leave the area for the next 3 y; and no evidence of life-threatening illness. The sample was approximately balanced for sex (51% women), and 42% of participants were black.

An energy expenditure (EE) substudy was carried out between 1998 and 2000. A randomly selected list of 500 participants stratified by race and sex was generated from study-eligible individuals: those who did not have a recent blood transfusion, did not use supplemental oxygen or insulin, and did not plan overnight travel immediately before or during the EE substudy. A replacement list of ≈200 participants was also generated. Individuals of the same race and sex from this replacement list were contacted when a participant from the primary list was ineligible. Toward the end of recruitment, the EE cohort was unbalanced with regard to race, and the study was extended into the year 2000, when a new primary list that oversampled blacks was generated. Individuals who volunteered were paid a nominal sum ($20) for their efforts.

After recruitment, a total of 323 participants were enrolled (n = 92 in 1998, n = 125 in 1999, and n = 85 in 2000). Twenty-one participants were excluded from this analysis because of failure to complete the protocol, lack of adequate urine volume specimens, or failure of isotope or RMR data to meet a priori quality-control criteria, which left an analytic sample of 302 participants (n = 150 men and 152 women). Compared with the full Health ABC cohort, there were 8% more blacks in the EE substudy, but there were no differences in age, sex, body mass, FFM, FM, gait speed, self-reported walking ability, or self-reported physical activity (eg, walking, stair climbing, working, volunteering, and caregiving). Therefore, this substudy was considered to be representative of the entire Health ABC study cohort. Written informed consent, approved by the institutional review boards at the University of Pittsburgh and University of Tennessee, Memphis, was obtained from each participant.

General overview of the protocol

Participants completed the protocol over 2 visits to the clinic, each time arriving in a fasted stated. During visit 1, participants received a dose of DLW for measurement of total energy expenditure (TEE) according to a protocol previously described (7, 8). During this visit, body-composition measures were ascertained by using dual-energy X-ray absorptiometry (DXA). Participants returned to the clinic for a second visit, 14 ± 1 d (mean ± SD) after visit 1, at which time their body weight and RMR were measured. Additionally, 2 urine samples were collected for the endpoint DLW analysis. Participants were encouraged to maintain their normal activity levels between visits 1 and 2.

Total energy expenditure

TEE was measured by using the 2-point DLW technique, which was previously described in detail (7). Briefly, on the first visit, participants ingested 2 g/kg estimated total body water (TBW) of DLW, which was composed of 1.9 g/kg estimated TBW (10% $H_2{}^{18}O$) and 0.12 g/kg estimated TBW (99.9% ^2H_2O). After dosing, 3 urine samples were obtained at ≈2, 3, and 4 h. Two consecutive urine voids were collected during a second visit to the laboratory, ≈14 d after the first visit. Plasma from a 5-mL blood sample was obtained from everyone, but was only used for those who had evidence of delayed isotopic equilibration likely caused from urine retention in the bladder (n = 28) (7). Urine and plasma samples were stored at –20°C until analyzed by isotope ratio mass spectrometry.

Dilution spaces for ^2H and ^{18}O were calculated according to Coward (9). TBW was calculated as the average of the dilutions spaces of ^2H and ^{18}O after correction for isotopic exchange (1.041 for ^2H and 1.007 for ^{18}O). Carbon dioxide production was calculated by using the 2-point DLW method outlined by Schoeller et al (10, 11), and TEE was derived by using Weir's equation (12). A food quotient of 0.86 was used from the third National Health and Nutrition Examination Survey (13) and from Black et al (14). All EE values were converted to kilocalories per day, and the thermic effect of meals was assumed to be 10% of TEE (15). For measurement of TBW, the intrasubject repeatability (calculated as the average percentage difference between the 2 analyses) was −0.1 ± 1.2%. The intratester repeatability of TEE based on blinded, repeat, urine isotopic analysis was excellent (mean difference = 1.2 ± 5.4%; n = 16) and compared well with a recent review article (16).

Resting metabolic rate

Resting metabolic rate (RMR) was measured via indirect calorimetry on a Deltatrac II respiratory gas analyzer (Datex Ohmeda Inc, Helsinki, Finland); the detailed procedures were described elsewhere (8). While the patients were in a fasting state and after they had rested for 30 min, a respiratory gas exchange hood was placed over their heads, and RMR was measured minute-by-minute for 40 min. To avoid gas exchange created by the initial placement of the hood, only the final 30 min was used in subsequent calculations. Movement or sleeping during the test was noted, and those time periods were excluded from the RMR calculation. Methanol burn tests were performed in duplicate once or twice per month. Carbon dioxide recovery averaged 100.1 ± 1.4% at the Pittsburgh site and 100.5 ± 1.5% at the Memphis site. The gas exchange ratios for methanol differed by 2.5% between sites (Memphis: 0.66 ± 0.01; Pittsburgh: 0.68 ± 0.01; $P < 0.001$), and this difference did not demonstrate a trend over time. Therefore, a correction factor was used to equate the 2 study sites by dividing the respiratory ratios for participants enrolled at Pittsburgh by 1.025.

Activity energy expenditure

To calculate AEE, the thermic effect of food was assumed to be 10% of TEE in the equation AEE = (TEE × 0.9) − RMR (17, 18). AEE is defined as the calories an individual expends in any and all activities per day. For descriptive purposes, PAL was calculated as TEE/RMR.

Body mass and composition

Total body mass, fat mass (FM), and FFM were measured annually by using a Hologic 4500A Scanner (Hologic Inc, Waltham, MA). Body-composition analysis was performed by using HOLOGIC software (version 8.21; Hologic Inc). Calibration was performed 3 times/wk by using whole-body quality-control phantoms outlined in the Hologic manual. Absolute variation between the clinic sites was monitored by cross-calibrating the 2 scanners with the use of separate phantoms. Validation analyses on the scanners detected a systematic overestimation of FFM that was subsequently corrected by multiplying by a factor of 0.964 (*see* reference 19 for more details). FFM values were calculated after removing mass due to bone mineral content (BMC) by using the equation (FFM + BMC) − BMC = FFM.

Other measurements

Smoking status was evaluated by using a questionnaire administered at study baseline 2 or 3 y before DLW dosing. Responses were categorized as currently smoking or not smoking.

Data analysis

In our initial analysis, we evaluated whether sex or race change the trajectory of body composition over time. We found that blacks had similar trajectories of change in all outcomes. However, we found that men had a steeper decline in FFM and an opposite change in FM when compared with women. Both outcomes resulted in significant sex × time interactions ($P < 0.01$); therefore, all analyses were stratified by sex. Baseline participant characteristics were compared across sex by using analysis of variance for continuous variables and the chi-square statistic for categorical variables. To illustrate relations of interest, AEE was categorized into sex-specific tertiles; the lowest tertile served as the reference group. AEE was also converted into standardized values (per SD) and examined as a continuous variable.

Longitudinal analyses were undertaken to evaluate whether AEE was associated with different trajectories of change in total body mass, FFM, and FM. Changes in body mass and composition were examined by using linear mixed models, for which intercepts and slopes were permitted to differ between individuals and thus are often referred to as random effects (20). The model included a term for time, which was calculated, because of unequal spacing between follow-up, by using the clinic visit date subtracted from the date of the initial contact (baseline) and divided by 365.25. This term indicates the mean annual linear change in body mass or composition for an average participant. Body mass and composition were regressed on time and AEE with adjustment for baseline age (in y) alone and with the addition of race (black versus white) and smoking status (current versus not current smoker) according to the following equation:

$$Y_{ij} = (\beta_0 + b_{0i}) + (\beta_1 + b_{1i})t_{ij} + \beta_2\text{AEE}_2 + \beta_3\text{AEE}_3 + \beta_4(\text{AEE}_2 \times t_{ij}) + \beta_5(\text{AEE}_3 \times t_{ij}) + \beta_6\text{Race} + \beta_7\text{Smoke} + \beta_8\text{Age} + \varepsilon_{ij} \quad (1)$$

Where Y_{ij} is the outcome (body mass, FFM, or FM) for the *i*th subject at the *j*th clinic visit, AEE_2 and AEE_3 are dummy variables for the tertile of AEE (eg, $\text{AEE}_2 = 1$ if AEE is in the second tertile, $\text{AEE}_2 = 0$ otherwise), and t_{ij} is the time (in y) from initial contact (baseline visit) for the *i*th subject at the *j*th clinic visit. Thus, b_{0t} is the random intercept (ie, the deviation of the *i*th subject's intercept ($\beta_0 + b_{0t}$ from the mean population tertile, β_0. Similarly, b_{1t} is the random slope [ie, the deviation of the *i*th subject's slope ($\beta_1 + b_{1t}$) from the mean population slope, β_1. The parameters of interest for our primary research question were β_4 and β_5 , which tested whether the mean annual linear change in body mass or composition was different for participants in the second (β_4) and third (β_5) tertiles of AEE than for those in the first tertile (β_1, reference). Coefficients from this set of models were used to graphically illustrate changes in body mass and composition in men and women across AEE tertiles. Another model was fitted to test AEE as a continuous variable expressed in standardized units (per SD) as opposed to a dummy variable. This model contained the same covariates as the model described above.

Each model was estimated by using an unstructured error covariance matrix with STATA version 9.0 (StataCorp, College Station, TX) and the *xtmixed* command. Data were fitted using a *missing at random* assumption that was confirmed with sensitivity analyses. Goodness of fit for each model was examined with a plot of the residuals versus primary predictor value of AEE. Scatter plots showed no trends or correlations between the primary predictor and each outcome, and residuals were homoscedastic across the distribution of AEE values. Values are expressed as means ± SEMs unless otherwise noted.

RESULTS

Descriptive characteristics of the entire cohort stratified by sex and race are listed in **Table 1**. At baseline, sexes and races were of similar age and race and had similar PALs, and ≈45% were from Pittsburgh. Men had a higher TEE, higher RMR (lower after adjustment for FFM), higher AEE, and lower RMR adjusted for FFM and were more likely to be current smokers than were women. Additionally, men had a greater body mass and FFM, but lower FM than women. Blacks were more likely to smoke and had a lower RMR after adjustment for FFM. In this cohort, 289 of the 302 participants had more than one clinic follow-up evaluation (95% total follow-up rate; men: 97%; women: 94%). Forty-eight of the 51 individuals who died during the follow-up had more than one evaluation of body mass and composition before death and continued to contribute to the analysis. Individuals were followed for an average (±SD) of 4.9 ± 1.3 y (range: 1.0–6.3 y).

The association between AEE and rate of change in body mass and composition was tested by using linear mixed models with an interaction term for AEE × time and adjustment for the potentially confounding effects of baseline age, smoking, and race (**Table 2** for men; **Table 3** for women). Men in the third tertile had a greater body mass (4.5 ± 2.6 kg; $P = 0.084$) and FFM (2.9 ± 1.3 kg; $P = 0.033$) than did men in the first tertile of AEE. Changes over time in body mass, FFM, or FM were not significantly different for the second or third tertiles of AEE compared with the first tertile (*see* interaction effects in Table 2 and **Figure 1**). In models adjusted for age, smoking status, and race and across tertiles of AEE, men experienced an average decline in body mass of 0.34 kg/y ($P = 0.066$), in FFM of

TABLE 1
Baseline characteristics of the participants stratified by sex[1]

Characteristic	White men (n = 76)	White women (n = 80)	Black men (n = 74)	Black women (n = 72)	P for sex difference	P for race difference
Age (y)[2]	75.5 ± 3.1	75.5 ± 2.8	75.2 ± 2.9	5.5 ± 2.8	0.733	0.333
From Pittsburgh [n (%)]	39 (12.9)	35 (11.6)	31 (10.2)	34 (11.2)	0.557	0.179
Currently smoking [n (%)]	6 (1.9)	3 (0.9)	17 (5.6)	8 (2.6)	0.026	0.002
BMI (kg/m^2)[2]	27.5 ± 4.0	26.2 ± 5.2	27.2 ± 4.5	28.5 ± 5.6	0.944	0.074
TEE (kcal/d)[2]	2511 ± 390	1891 ± 286	2327 ± 431	1930 ± 395	<0.001	0.240
RMR (kcal/d)[2]	1455 ± 187	1360 ± 184	1153 ± 169	1131 ± 166	<0.001	0.039
RMR adjusted for FFM (kcal/d)[3,4]	1296 ± 6.3	1344 ± 6.7	1193 ± 7.1	1241 ± 6.33	<0.001	<0.001
AEE (kcal/d)[2]	804 ± 273	549 ± 192	733 ± 302	605 ± 302	<0.001	0.925
PAL[2]	1.73 ± 0.21	1.65 ± 0.20	1.71 ± 0.24	1.71 ± 0.30	0.132	0.412
Baseline body mass (kg)[2]	83.1 ± 12.0	67.5 ± 13.6	81.2 ± 14.2	72.9 ± 16.4	<0.001	0.251
Baseline FFM (kg)[2]	55.4 ± 12.0	38.6 ± 13.6	53.3 ± 14.2	41.7 ± 16.4	<0.001	0.050
Baseline fat mass (kg)[2]	25.0 ± 12.0	27.1 ± 13.6	22.0 ± 14.2	29.3 ± 16.3	<0.001	0.651

[1] TEE, total energy expenditure; AEE, activity energy expenditure; FFM, fat-free mass; RMR, resting metabolic rate; PAL, physical activity level (TEE/RMR).
[2] Values are means ± SDs.
[3] Values are means ± SEMs.
[4] Predicted values from general linear model of resting metabolic rate regressed on lean mass and sex.

0.48 kg/y (P < 0.001), and a nonsignificant increase in FM of 0.14 kg (P = 0.254). When AEE was entered as a continuous variable, the results were similar. These results show that AEE levels were not associated with the trajectory of body mass or composition change over time in men.

Women in the highest tertile exhibited similar overall body mass (3.2 ± 2.9 kg; P = 0.277) and FM (1.2 ± 1.9 kg; P = 0.531), but greater FFM (2.0 ± 1.2 kg; P = 0.012) than women in the lowest tertile of AEE (Table 3). In fully adjusted models, women showed a significant decline in body mass (−0.45 kg/y), FFM (−0.14 kg/y), and FM (−0.28 kg/y), but these changes were not significantly different across AEE tertiles (*see* Figure 1 and interaction effects in Table 3). AEE expressed in standardized units showed similar results. As a sensitivity analysis, each

TABLE 2
Association between activity energy expenditure (AEE) and longitudinal changes in body mass and composition in men (n = 150)[1]

	Body mass (kg)		Fat-free mass (kg)		Fat mass (kg)	
	b weight (SE)	P value	b weight (SE)	P value	b weight (SE)	P value
Adjusted for baseline age						
Time (y)	−0.34 (0.18)	0.068	−0.48 (0.10)	<0.001	0.14 (0.12)	0.250
AEE tertiles						
Tertile 1 (<624 kcal/d)	Reference		Reference		Reference	
Tertile 2 (624–866 kcal/d)	3.8 (2.6)	0.150	1.8 (1.3)	0.166	1.7 (1.6)	0.264
Tertile 3 (>866 kcal/d)	5.1 (2.6)	0.052	2.7 (1.3)	0.046	2.3 (16)	0.137
Interaction effects						
Tertile 1 × time	Reference		Reference		Reference	
Tertile 2 × time	0.20 (0.25)	0.425	0.12 (0.13)	0.360	0.09 (0.17)	0.576
Tertile 3 × time	−0.05 (0.25)	0.822	0.07 (0.13)	0.599	−0.12 (0.17)	0.464
AEE per SD[2]	2.6 (1.0)	0.006	1.7 (0.54)	0.002	0.86 (0.64)	0.180
AEE × time	−0.16 (0.10)	0.126	−0.05 (0.05)	0.366	−0.11 (0.07)	0.112
Fully adjusted model[3]						
Time (y)	−0.34 (0.18)	0.066	−0.48 (0.09)	<0.001	0.14 (0.12)	0.254
AEE tertiles						
Tertile 1 (<624 kcal/d)	Reference		Reference		Reference	
Tertile 2 (624–866 kcal/d)	2.6 (2.6)	0.311	1.6 (1.3)	0.219	0.77 (1.5)	0.620
Tertile 3 (>866 kcal/d)	4.5 (2.6)	0.084	2.9 (1.3)	0.033	1.5 (1.5)	0.333
Interaction effects						
Tertile 1 × time	Reference		Reference		Reference	
Tertile 2 × time	0.20 (0.25)	0.422	0.12 (0.12)	0.358	0.09 (0.16)	0.570
Tertile 3 × time	−0.05 (0.25)	0.836	0.07 (0.13)	0.576	−0.12 (0.16)	0.473
AEE per SD[2]	2.4 (1.0)	0.024	1.7 (0.54)	0.002	0.59 (0.63)	0.347
AEE × time	−0.15 (0.10)	0.133	−0.04 (0.05)	0.395	−0.11 (0.07)	0.116

[1] Values were predicted by using linear mixed models with Equation *1* (*see* Subjects and Methods). b weight, regression coefficient.
[2] This model used the same covariates as those tested with tertiles of AEE.
[3] Adjusted for baseline age, cigarette smoking, and race.

TABLE 3
Association between activity energy expenditure (AEE) and longitudinal changes in body mass and composition in women (n = 152)[1]

	Body mass (kg)		Fat-free mass (kg)		Fat mass (kg)	
	b weight (SE)	*P* value	b weight (SE)	*P* value	b weight (SE)	*P* value
Adjusted for baseline age						
Time (y)	−0.45 (0.13)	0.001	−0.14 (0.06)	0.012	−0.28 (0.11)	0.008
AEE tertiles						
Tertile 1 (<442 kcal/d)	Reference		Reference		Reference	
Tertile 2 (442–647 kcal/d)	0.31 (2.9)	0.917	0.26 (1.2)	0.828	0.13 (1.9)	0.948
Tertile 3 (>647 kcal/d)	4.2 (3.0)	0.166	2.6 (1.2)	0.032	1.5 (2.0)	0.436
Interaction effects						
Tertile 1 × time	Reference		Reference		Reference	
Tertile 2 × time	0.14 (0.19)	0.456	−0.03 (0.08)	0.667	0.15 (0.15)	0.301
Tertile 3 × time	0.11 (0.19)	0.572	−0.04 (0.08)	0.626	0.15 (0.15)	0.330
AEE per SD[2]	1.3 (1.2)	0.290	0.78 (0.47)	0.114	0.48 (0.81)	0.551
AEE × time	0.09 (0.08)	0.236	0.003 (0.03)	0.931	0.09 (0.06)	0.157
Fully adjusted model[3]						
Time (y)	−0.45 (0.13)	0.001	−0.14 (0.06)	0.012	−0.28 (0.11)	0.008
AEE tertiles						
Tertile 1 (<442 kcal/d)	Reference		Reference		Reference	
Tertile 2 (442–647 kcal/d)	0.68 (2.9)	0.813	0.31 (1.1)	0.786	0.43 (1.9)	0.824
Tertile 3 (>647 kcal/d)	3.2 (2.9)	0.277	2.0 (1.2)	0.012	1.2 (1.9)	0.531
Interaction effects						
Tertile 1 × time	Reference		Reference		Reference	
Tertile 2 × time	0.13 (0.19)	0.468	−0.03 (0.08)	0.663	0.15 (0.15)	0.308
Tertile 3 × time	0.11 (0.19)	0.574	−0.04 (0.08)	0.627	0.15 (0.15)	0.329
AEE per SD[2]	1.0 (1.2)	0.393	0.61 (0.47)	0.198	0.38 (0.79)	0.628
AEE × time	0.09 (0.08)	0.235	0.002 (0.03)	0.932	0.09 (0.06)	0.155

[1] Values were predicted by using linear mixed models with Equation *1* (*see* Subjects and Methods). b weight, regression coefficient.
[2] This model used the same covariates as those tested with tertiles of AEE.
[3] Adjusted for baseline age, cigarette smoking, and race.

model was reassessed after including only those individuals who had complete follow-up data (n = 215). The results did not differ from those reported above.

DISCUSSION

A commonly proposed strategy to avert change in body composition in late life is increased physical activity. We analyzed whether accumulated AEE, as determined by DLW, preserves body composition over ≈5 y in a large sample of black and white men and women between the ages of 70 and 82 y. Contrary to some previous reports, AEE did not predict changes in body composition in our sample. The cross-sectional results suggest that men and women with a higher AEE were more likely to have higher FFM, which may translate to a reduced risk of sarcopenia. It is unknown whether higher AEE is a cause or consequence of greater FFM, but our findings certainly suggest that accumulated AEE may not slow the age-related change in body mass and FFM.

Change in body mass and FFM observed in this study are consistent with those of previous longitudinal reports (1, 2) and those in the entire Health ABC cohort (21). For example, even in healthy community-dwelling older adults who remain weight stable over ≈5 y, loss of FFM continues to be evident with a compensatory increase in FM (1). Change in FM in adults older than 70 y is unclear because findings have been inconsistent across studies, with some reporting an increase (1, 22), decrease (22), or no change (3). Overall, the changes in body mass and composition found in this study seem to correspond well with those of previous reports in older adults.

The current work is consistent with that of Raguso et al (23), who observed that self-reported physical activity was not associated with 3-y changes in body mass, FFM, and FM in adults older than 75 y. However, 3 longitudinal studies support the idea that physical activity attenuates the loss in FFM and body mass with advancing age (4, 5, 24). First, Hughes et al (5) measured 10-y changes in self-reported PALs and anthropometric measures in 129 adults with an average age of 60 y at baseline, and individuals who increased their physical activity over the follow-up had a slower decline in thigh girth than did individuals who decreased their physical activity over the same period. Ekelund et al (24) showed that baseline physical activity assessed with 4 d of continuous heart rate monitoring predicted a slower decline in both FFM and FM over 5.6 y in adults older than 53 y, but not in adults younger than 53 y (median age studied: 53.8 y). Last, Dziura et al (4) reported 12-y changes in body mass in 2812 men aged ≥65 y enrolled in the Yale Health and Aging Study and found that greater frequency of performing physical activity was associated with an attenuated age-related loss of body mass.

There are some important differences between the current study and this previous work. First, we evaluated change in body composition in adults between 70 and 80 y of age—a population 10–20 y older than the samples used by Hughes et al (5) and Ekelund et al (24). Additionally, Hughes et al used anthropometric assessments to show that physical activity was associated with reduced decline in thigh girth. Last, the associations found

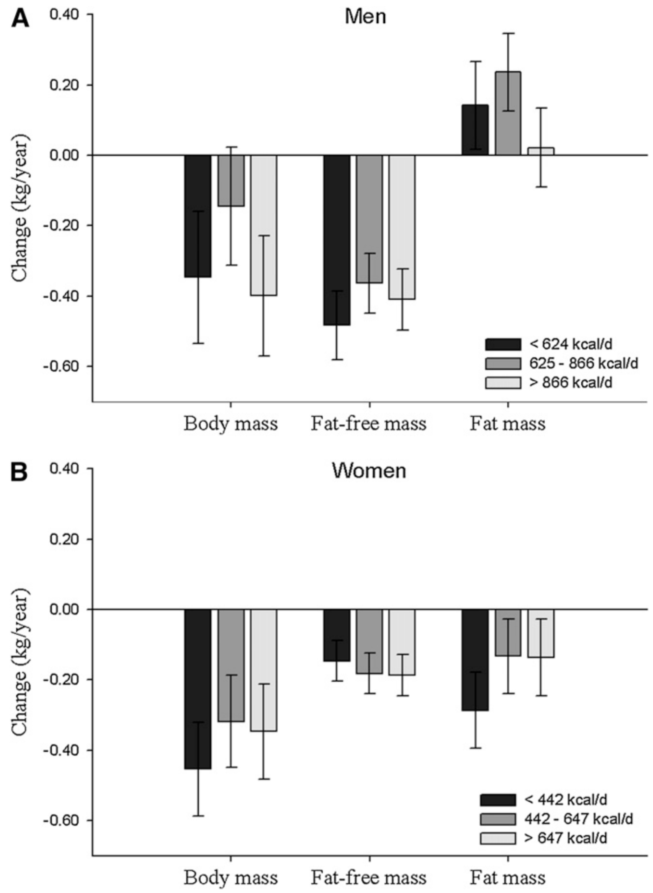

FIGURE 1. Mean (±SE) longitudinal changes in body composition over an average of 4.9 y of follow-up according to tertiles of activity energy expenditure (AEE) in men and women. Values are predicted from linear mixed models (described in Subjects and Methods) by using Equation *1* (*see* text). The results suggest that body mass and fat-free mass decline with age, but this change was not predicted by an individual's AEE.

with self-reported physical activity by Dziura et al could be explained by individuals who performed high-intensity physical activity, which may be important for minimizing age-related changes in body mass. Because we assessed accumulated physical activity with DLW in adults older than 70 y, comparisons with the previous literature are difficult.

AEE does not capture information about the intensity of physical activity, which may have an important role in preventing age-related declines in FFM. Our assessment captures all activities, including those of high and low intensity. We previously showed using self-reports of leisure time activity that AEE is likely being accumulated through everyday activities and not high-intensity exercise (25, 26). Therefore, it seems that simply staying active through low-intensity exercise may not alter the age-related changes in body composition in late life. Incorporation of high-intensity exercise and/or resistance-type exercises may be needed to prevent these changes. In particular, several studies have shown that resistance exercise has a potent dose-response effect on muscle size and lipid oxidation (27–31). Additionally, improved nutrition supplementation that promotes anabolism may be an alternative or additive to physical activity in helping reduce age-related changes in body composition. Withstanding the limitations of this study, an individuals' accumulated AEE may not prevent the impending change in body composition with aging.

AEE was assessed as baseline and used to predict changes in body composition over time. There are inherent limitations to this approach because an individuals' activity is influenced by both intrinsic and extrinsic factors. The ideal analysis would be to examine changes in body composition in parallel with changes in AEE, but these data were not available. In an attempt to address this concern, we evaluated whether AEE modified the change in FFM from baseline to the first year of follow-up. Such an analysis would provide evidence that the proximity of body-composition change to the measurement of AEE is important when evaluating whether baseline AEE predicts long-term effects. The results showed that individuals in the low-AEE group lost 0.54 kg FFM/y, and the high-AEE group lost 0.05 kg FFM/y. At first glance these values appear to be different, but the difference in the slopes was not statistically significant (P = 0.316). Additionally, the separation in these differences was diminished (0.39 compared with 0.27 kg/y in high- and-low AEE groups, respectively) by the second year. During the follow-up, 51 individuals had died and thus may have contributed disproportionally to the derived estimates. However, there was no difference in change in body mass or composition between those who lived and died (P for interaction term > 0.80), and it appears that deaths did not contribute disproportionally to our findings. Another limitation was that, theoretically, low AEE may reflect burdening disease conditions. We performed a simple correlation between AEE and scores on self-reported health questionnaires and found a poor association ($r < 0.15$, $P > 0.10$). Therefore, low AEE levels may not be reflective of disease burden in our sample of older adults. Another limitation was that AEE was only measured at baseline and, therefore, changes in physical activity could not be documented in parallel with changes in body composition. The next step in this line of research is to determine whether changes in AEE are associated with changes in body composition in old age. In conclusion, these results suggest that accumulated EE from all physical activities is associated with higher levels of FFM, but the effect may not be adequate to prevent deleterious age-related changes in body composition.

The authors' responsibilities were as follows—TMM: had full access to all of the data in the study, took responsibility for the integrity of the data and the accuracy of the data analysis, and had final responsibility for the decision to submit for publication; TMM, JEE, and TBH: study concept and design; DAS and FT: data acquisition; TMM, JEE, TBH, DAS, SRC, LHC, MJD, EMS, ABN, and SDA: analysis and interpretation of data; TMM, JEE, TBH, EMS, MJD, ABN, and SDA: draft of the manuscript; DAS, DCB, MV, LHC, and SDA: critical intellectual support; TMM, JEE, and DCM: statistical analysis; JEE and TBH: obtained funding; and DAS, TBH, and JEE: study supervision. None of the coauthors expressed any financial or personal relationships with other persons or organizations that could inappropriately influence this work.

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