# Activity energy expenditure and change in body composition in late life ${ }^{1-3}$ 

Todd M Manini, James E Everhart, Stephen D Anton, Dale A Schoeller, Steve R Cummings, Dawn C Mackey, Matthew J Delmonico, Douglas C Bauer, Eleanor M Simonsick, Lisa H Colbert, Marjolein Visser, Frances Tylavsky, Anne B Newman, and Tamara B Harris for the Health, Aging, and Body Composition Study


#### 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 activityrelated 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 communitydwelling older adults aged $70-82 \mathrm{y}$. 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 $( \pm \mathrm{SD})$ of $4.9 \pm 1.3 \mathrm{y}$. Results: In multivariate models adjusted for baseline age, smoking status, and race, men and women had a decline (in $\mathrm{kg} / \mathrm{y}$ ) in body mass (men: $-0.34,95 \% \mathrm{CI}:-0.71,0.02$; women: $-0.45,95 \% \mathrm{CI}$ : $-0.71,-0.19$ ) and FFM (men: $-0.48,95 \%$ CI: $-0.67,-0.29$; women: $-0.14,95 \%$ CI: $-0.026,-0.03$ ). No changes (in $\mathrm{kg} / \mathrm{y}$ ) were observed in FM (men: $0.14,95 \% \mathrm{CI}:-0.10,0.38$; women: $-0.28,95 \% \mathrm{CI}:-0.49,-0.07$ ). 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 $\geq 70$ 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.

[^0]
## 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 selfreport 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 $\approx 200$ 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 qualitycontrol 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, $14 \pm 1 \mathrm{~d}$ (mean $\pm \mathrm{SD}$ ) 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 $2 \mathrm{~g} / \mathrm{kg}$ estimated total body water (TBW) of DLW, which was composed of $1.9 \mathrm{~g} / \mathrm{kg}$ estimated TBW $\left(10 \% \mathrm{H}_{2}{ }^{18} \mathrm{O}\right)$ and $0.12 \mathrm{~g} / \mathrm{kg}$ estimated TBW $(99.9 \%$ ${ }^{2} \mathrm{H}_{2} \mathrm{O}$ ). After dosing, 3 urine samples were obtained at $\approx 2,3$, and 4 h . Two consecutive urine voids were collected during a second visit to the laboratory, $\approx 14 \mathrm{~d}$ after the first visit. Plasma from a $5-\mathrm{mL}$ 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 $-20^{\circ} \mathrm{C}$ until analyzed by isotope ratio mass spectrometry.

Dilution spaces for ${ }^{2} \mathrm{H}$ and ${ }^{18} \mathrm{O}$ were calculated according to Coward (9). TBW was calculated as the average of the dilutions spaces of ${ }^{2} \mathrm{H}$ and ${ }^{18} \mathrm{O}$ after correction for isotopic exchange ( 1.041 for ${ }^{2} \mathrm{H}$ and 1.007 for ${ }^{18} \mathrm{O}$ ). 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 $-0.1 \pm 1.2 \%$. The intratester repeatability of TEE based on blinded, repeat, urine isotopic analysis was excellent (mean difference $=1.2 \pm 5.4 \% ; n=16$ ) 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 $100.1 \pm 1.4 \%$ at the Pittsburgh site and $100.5 \pm 1.5 \%$ at the Memphis site. The gas exchange ratios for methanol differed by $2.5 \%$ between sites (Memphis: $0.66 \pm 0.01$; Pittsburgh: $0.68 \pm$ $0.01 ; P<0.001$ ), 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 $\mathrm{AEE}=(\mathrm{TEE} \times 0.9)-\operatorname{RMR}(17,18)$. 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 qualitycontrol phantoms outlined in the Hologic manual. Absolute variation between the clinic sites was monitored by crosscalibrating 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 + $\mathrm{BMC})-\mathrm{BMC}=\mathrm{FFM}$.

## 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 $\times$ 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:

$$
\begin{align*}
Y_{i j}= & \left(\beta_{0}+b_{0 i}\right)+\left(\beta_{1}+b_{1 i}\right) t_{i j}+\beta_{2} \mathrm{AEE}_{2}+\beta_{3} \mathrm{AEE}_{3} \\
& +\beta_{4}\left(\mathrm{AEE}_{2} \times t_{i j}\right)+\beta_{5}\left(\mathrm{AEE}_{3} \times t_{i j}\right)+\beta_{6} \text { Race } \\
& +\beta_{7} \text { Smoke }+\beta_{8} \mathrm{Age}+\varepsilon_{i j} \tag{1}
\end{align*}
$$

Where $Y_{i j}$ is the outcome (body mass, FFM, or FM) for the $i$ th subject at the $j$ th clinic visit, $\mathrm{AEE}_{2}$ and $\mathrm{AEE}_{3}$ are dummy var-
iables for the tertile of AEE (eg, $\mathrm{AEE}_{2}=1$ if AEE is in the second tertile, $\mathrm{AEE}_{2}=0$ otherwise), and $t_{i j}$ is the time (in y) from initial contact (baseline visit) for the $i$ th subject at the $j$ th clinic visit. Thus, $b_{0 t}$ is the random intercept (ie, the deviation of the $i$ th subject's intercept ( $\beta_{0}+b_{0 t}$ from the mean population tertile, $\beta_{0}$. Similarly, $b_{1 t}$ is the random slope [ie, the deviation of the $i$ th subject's slope $\left(\beta_{1}+b_{1 t}\right)$ from the mean population slope, $\beta_{1}$. The parameters of interest for our primary research question were $\beta_{4}$ and $\beta_{5}$, which tested whether the mean annual linear change in body mass or composition was different for participants in the second $\left(\beta_{4}\right)$ and third $\left(\beta_{5}\right)$ tertiles of AEE than for those in the first tertile ( $\beta_{1}$, 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 $\pm$ 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 $\approx 45 \%$ 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 ( $\pm$ SD) of $4.9 \pm 1.3$ y (range: $1.0-6.3 \mathrm{y}$ ).

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 $\times$ 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 $(4.5 \pm 2.6 \mathrm{~kg} ; P=0.084)$ and FFM $(2.9 \pm$ $1.3 \mathrm{~kg} ; P=0.033$ ) 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 $0.34 \mathrm{~kg} / \mathrm{y}(P=0.066)$, 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) ${ }^{2}$ | $75.5 \pm 3.1$ | $75.5 \pm 2.8$ | $75.2 \pm 2.9$ | $5.5 \pm 2.8$ | 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 ( $\left.\mathrm{kg} / \mathrm{m}^{2}\right)^{2}$ | $27.5 \pm 4.0$ | $26.2 \pm 5.2$ | $27.2 \pm 4.5$ | $28.5 \pm 5.6$ | 0.944 | 0.074 |
| TEE (kcal/d) ${ }^{2}$ | $2511 \pm 390$ | $1891 \pm 286$ | $2327 \pm 431$ | $1930 \pm 395$ | <0.001 | 0.240 |
| RMR (kcal/d) ${ }^{2}$ | $1455 \pm 187$ | $1360 \pm 184$ | $1153 \pm 169$ | $1131 \pm 166$ | $<0.001$ | 0.039 |
| RMR adjusted for FFM ( $\mathrm{kcal} / \mathrm{d}$ ) ${ }^{3,4}$ | $1296 \pm 6.3$ | $1344 \pm 6.7$ | $1193 \pm 7.1$ | $1241 \pm 6.33$ | <0.001 | <0.001 |
| AEE ( $\mathrm{kcal} / \mathrm{d})^{2}$ | $804 \pm 273$ | $549 \pm 192$ | $733 \pm 302$ | $605 \pm 302$ | <0.001 | 0.925 |
| PAL ${ }^{2}$ | $1.73 \pm 0.21$ | $1.65 \pm 0.20$ | $1.71 \pm 0.24$ | $1.71 \pm 0.30$ | 0.132 | 0.412 |
| Baseline body mass (kg) ${ }^{2}$ | $83.1 \pm 12.0$ | $67.5 \pm 13.6$ | $81.2 \pm 14.2$ | $72.9 \pm 16.4$ | <0.001 | 0.251 |
| Baseline FFM (kg) ${ }^{2}$ | $55.4 \pm 12.0$ | $38.6 \pm 13.6$ | $53.3 \pm 14.2$ | $41.7 \pm 16.4$ | <0.001 | 0.050 |
| Baseline fat mass (kg) ${ }^{2}$ | $25.0 \pm 12.0$ | $27.1 \pm 13.6$ | $22.0 \pm 14.2$ | $29.3 \pm 16.3$ | $<0.001$ | 0.651 |

[^1] RMR).
${ }^{2}$ Values are means $\pm$ SDs.
${ }^{3}$ Values are means $\pm$ SEMs.
${ }^{4}$ Predicted values from general linear model of resting metabolic rate regressed on lean mass and sex.
$0.48 \mathrm{~kg} / \mathrm{y}(P<0.001)$, and a nonsignificant increase in FM of $0.14 \mathrm{~kg}(P=0.254)$. 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 $(3.2 \pm 2.9 \mathrm{~kg} ; P=0.277)$ and $\mathrm{FM}(1.2 \pm 1.9 \mathrm{~kg} ; P=$
$0.531)$, but greater FFM $(2.0 \pm 1.2 \mathrm{~kg} ; P=0.012)$ than women in the lowest tertile of AEE (Table 3). In fully adjusted models, women showed a significant decline in body mass $(-0.45 \mathrm{~kg} / \mathrm{y})$, FFM ( $-0.14 \mathrm{~kg} / \mathrm{y}$ ), and FM ( $-0.28 \mathrm{~kg} / \mathrm{y}$ ), 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 ( $<624 \mathrm{kcal} / \mathrm{d}$ ) | Reference |  | Reference |  | Reference |  |
| Tertile 2 ( $624-866 \mathrm{kcal} / \mathrm{d}$ ) | 3.8 (2.6) | 0.150 | 1.8 (1.3) | 0.166 | 1.7 (1.6) | 0.264 |
| Tertile 3 ( $>866 \mathrm{kcal} / \mathrm{d}$ ) | 5.1 (2.6) | 0.052 | 2.7 (1.3) | 0.046 | 2.3 (16) | 0.137 |
| Interaction effects |  |  |  |  |  |  |
| Tertile $1 \times$ time | Reference |  | Reference |  | Reference |  |
| Tertile $2 \times$ time | 0.20 (0.25) | 0.425 | 0.12 (0.13) | 0.360 | 0.09 (0.17) | 0.576 |
| Tertile $3 \times$ 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 $\times$ 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 ( $<624 \mathrm{kcal} / \mathrm{d}$ ) | Reference |  | Reference |  | Reference |  |
| Tertile 2 ( $624-866 \mathrm{kcal} / \mathrm{d}$ ) | 2.6 (2.6) | 0.311 | 1.6 (1.3) | 0.219 | 0.77 (1.5) | 0.620 |
| Tertile 3 ( $>866 \mathrm{kcal} / \mathrm{d}$ ) | 4.5 (2.6) | 0.084 | 2.9 (1.3) | 0.033 | 1.5 (1.5) | 0.333 |
| Interaction effects |  |  |  |  |  |  |
| Tertile $1 \times$ time | Reference |  | Reference |  | Reference |  |
| Tertile $2 \times$ time | 0.20 (0.25) | 0.422 | 0.12 (0.12) | 0.358 | 0.09 (0.16) | 0.570 |
| Tertile $3 \times$ 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 $\times$ time | -0.15 (0.10) | 0.133 | -0.04 (0.05) | 0.395 | -0.11 (0.07) | 0.116 |

[^2]TABLE 3
Association between activity energy expenditure (AEE) and longitudinal changes in body mass and composition in women $(n=152)^{l}$

|  | 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 ( $<442 \mathrm{kcal} / \mathrm{d}$ ) | 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 ( $>647 \mathrm{kcal} / \mathrm{d}$ ) | 4.2 (3.0) | 0.166 | 2.6 (1.2) | 0.032 | 1.5 (2.0) | 0.436 |
| Interaction effects |  |  |  |  |  |  |
| Tertile $1 \times$ time | Reference |  | Reference |  | Reference |  |
| Tertile $2 \times$ time | 0.14 (0.19) | 0.456 | -0.03 (0.08) | 0.667 | 0.15 (0.15) | 0.301 |
| Tertile $3 \times$ 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 $\times$ 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 ( $<442 \mathrm{kcal} / \mathrm{d}$ ) | 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 ( $>647 \mathrm{kcal} / \mathrm{d}$ ) | 3.2 (2.9) | 0.277 | 2.0 (1.2) | 0.012 | 1.2 (1.9) | 0.531 |
| Interaction effects |  |  |  |  |  |  |
| Tertile $1 \times$ time | Reference |  | Reference |  | Reference |  |
| Tertile $2 \times$ time | 0.13 (0.19) | 0.468 | -0.03 (0.08) | 0.663 | 0.15 (0.15) | 0.308 |
| Tertile $3 \times$ time | 0.11 (0.19) | 0.574 | -0.04 (0.08) | 0.627 | 0.15 (0.15) | 0.329 |
| AEE per $\mathrm{SD}^{2}$ | 1.0 (1.2) | 0.393 | 0.61 (0.47) | 0.198 | 0.38 (0.79) | 0.628 |
| AEE $\times$ time | 0.09 (0.08) | 0.235 | 0.002 (0.03) | 0.932 | 0.09 (0.06) | 0.155 |

[^3]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 $\approx 5 \mathrm{y}$ 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 $\approx 5 \mathrm{y}$, 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 followup 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 $\geq 65$ 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 ( $\pm$ 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' ac-
cumulated 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 $0.54 \mathrm{~kg} \mathrm{FFM} / \mathrm{y}$, 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 $0.27 \mathrm{~kg} / \mathrm{y}$ 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.

## REFERENCES

1. Gallagher D, Ruts E, Visser M, et al. Weight stability masks sarcopenia in elderly men and women. Am J Physiol Endocrinol Metab 2000;279: E366-75.
2. Newman AB, Lee JS, Visser M, et al. Weight change and the conservation of lean mass in old age: the Health, Aging and Body Composition Study. Am J Clin Nutr 2005;82:872-8.
3. Fantin F, Francesco VD, Fontana G, et al. Longitudinal body composition changes in old men and women: interrelationships with worsening disability. J Gerontol A Biol Sci Med Sci 2007;62:1375-81.
4. Dziura J, Mendes de Leon C, Kasl S, DiPietro L. Can physical activity attenuate aging-related weight loss in older people? The Yale Health and Aging Study, 1982-1994. Am J Epidemiol 2004;159:759-67.
5. Hughes VA, Frontera WR, Roubenoff R, Evans WJ, Singh MA. Longitudinal changes in body composition in older men and women: role of body weight change and physical activity. Am J Clin Nutr 2002;76: 473-81.
6. Ravussin E, Lillioja S, Anderson TE, Christin L, Bogardus C. Determinants of 24-hour energy expenditure in man. Methods and results using a respiratory chamber. J Clin Invest 1986;78:1568-78.
7. Blanc S, Colligan AS, Trabulsi J, et al. Influence of delayed isotopic equilibration in urine on the accuracy of the (2)H(2)(18)O method in the elderly. J Appl Physiol 2002;92:1036-44.
8. Blanc S, Schoeller DA, Bauer D, et al. Energy requirements in the eighth decade of life. Am J Clin Nutr 2004;79:303-10.
9. Coward WA. Calculation of pool sizes and flux rates. In: the doubly labeled water method: technical recommendations for use in humans. In: Prentice AM, ed. Report of an IDECG Expert Working Group. Vienna, Austria: AERA, 1990:48-68.
10. Schoeller DA, Ravussin E, Schutz Y, Acheson KJ, Baertschi P, Jequier E. Energy expenditure by doubly labeled water: validation in humans and proposed calculation. Am J Physiol 1986;250:R823-30.
11. Schoeller DA, van Santen E. Measurement of energy expenditure in humans by doubly labeled water method. J Appl Physiol 1982;53: 955-9.
12. Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. J Physiol 1949;109:1-9.
13. Kant AK. Nature of dietary reporting by adults in the third National Health and Nutrition Examination Survey, 1988-1994. J Am Coll Nutr 2002;21:315-27.
14. Black AE, Prentice AM, Coward WA. Use of food quotients to predict respiratory quotients for the doubly-labelled water method of measuring energy expenditure. Hum Nutr Clin Nutr 1986;40:381-91.
15. Bloesch D, Schutz Y, Breitenstein E, Jequier E, Felber JP. Thermogenic response to an oral glucose load in man: comparison between young and elderly subjects. J Am Coll Nutr 1988;7:471-83.
16. Elia M, Ritz P, Stubbs RJ. Total energy expenditure in the elderly. Eur J Clin Nutr 2000;54(suppl 3):S92-103.
17. Tataranni PA, Larson DE, Snitker S, Ravussin E. Thermic effect of food in humans: methods and results from use of a respiratory chamber. Am J Clin Nutr 1995;61:1013-9.
18. Harris AM, Lanningham-Foster LM, McCrady SK, Levine JA. Nonexercise movement in elderly compared with young people. Am J Physiol Endocrinol Metab 2007;292:E1207-12.
19. Tylavsky F, Lohman T, Blunt BA, et al. QDR 4500A DXA overestimates fat-free mass compared with criterion methods. J Appl Physiol 2003;94: 959-65.
20. Laird NM, Ware JH. Random-effects models for longitudinal data. Biometrics 1982;38:963-74.
21. Ding J, Kritchevsky SB, Newman AB, et al. Effects of birth cohort and age on body composition in a sample of community-based elderly. Am J Clin Nutr 2007;85:405-10.
22. Hughes VA, Roubenoff R, Wood M, Frontera WR, Evans WJ, Fiatarone Singh MA. Anthropometric assessment of 10-y changes in body composition in the elderly. Am J Clin Nutr 2004;80:475-82.
23. Raguso CA, Kyle U, Kossovsky MP, et al. A 3-year longitudinal study on body composition changes in the elderly: role of physical exercise. Clin Nutr 2006;25:573-80.
24. Ekelund U, Brage S, Franks PW, et al. Physical activity energy expenditure predicts changes in body composition in middle-aged healthy whites: effect modification by age. Am J Clin Nutr 2005;81:964-9.
25. Manini TM, Everhart JE, Patel KV, et al. Daily activity energy expenditure and mortality among older adults. JAMA 2006;296:171-9.
26. Westerterp KR. Pattern and intensity of physical activity. Nature 2001; 410:539.
27. Fiatarone M, O'Neill E, Ryan ND, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med 1994;330:1769-75.
28. Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ. High-intensity strength training in nonagenarians. Effects on skeletal muscle. JAMA 1990;263:3029-34.
29. Frontera WR, Meredith CN. O'Reilly KP ea. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. J Appl Physiol 1988;64:1038-44.
30. Koopman R, Manders RJ, Jonkers RA, Hul GB, Kuipers H, van Loon LJ. Intramyocellular lipid and glycogen content are reduced following resistance exercise in untrained healthy males. Eur J Appl Physiol 2006; 96:525-34.
31. Misra A, Alappan NK, Vikram NK, et al. Effect of supervised progressive resistance-exercise training protocol on insulin sensitivity, glycemia, lipids and body composition in Asian Indians with type 2 diabetes. Diabetes Care 2008;31:1282-7.

[^0]:    ${ }^{1}$ From the University of Florida, Department of Aging and Geriatric Research, Gainesville, FL (TMM and SDA); the National Institute on Aging, Laboratory of Epidemiology, Demography and Biometry, Bethesda, MD (TBH); the National Institute of Diabetes and Digestive and Kidney Diseases, Bethesda, MD (JEE); the Departments of Nutritional Sciences (DAS) and Kinesiology (LHC), University of Wisconsin-Madison, Madison, WI; the Department of Kinesiology, University of Rhode Island, Kingston, RI (MJD); the Institute of Health Sciences, Faculty of Earth and Life Sciences, VU University and EMGO, VU University Medical Center, Amsterdam, Netherlands (MV); the Department of Biostatistics and Epidemiology, University of Tennessee, Memphis, TN (FT); the San Francisco Coordinating Center, California Pacific Medical Center, San Francisco, CA (SRC and DCM); the Department of Epidemiology, University of Pittsburgh, Pittsburgh, PA (ABN); the National Institute on Aging, Clinical Research Branch, Baltimore, MD (EMS); and the Departments of Medicine and Epidemiology and Statistics, University of California, San Francisco, San Francisco, CA (DCB).
    ${ }^{2}$ Supported by the NIA Claude D. Pepper Center (P30AG028740) and a grant from the Institute on Aging at the University of Florida. The Health, Aging and Body Composition Study was supported by the Intramural Research Program of the NIH, National Institute on Aging (contracts N01-AG-6-2106, N01-AG-6-2101, and N01-AG-6-2103) with additional support from the National Institute of Diabetes and Digestive and Kidney Diseases.
    ${ }^{3}$ Address correspondence to TM Manini, Department of Aging and Geriatric Research, University of Florida, PO Box 112610, Gainesville, FL 32611-0107. E-mail: tmanini@aging.ufl.edu.

    Received February 19, 2009. Accepted for publication July 28, 2009.
    First published online September 9, 2009; doi: 10.3945/ajen.2009.27659.

[^1]:    ${ }^{1}$ TEE, total energy expenditure; AEE, activity energy expenditure; FFM, fat-free mass; RMR, resting metabolic rate; PAL, physical activity level (TEE/

[^2]:    ${ }^{1}$ 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.

[^3]:    ${ }^{I}$ 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.

