Physical activity energy expenditure predicts changes in body composition in middle-aged healthy whites: effect modification by age \(^1\text{–}^3\)

Ulf Ekelund, Søren Brage, Paul W Franks, Susie Hennings, Sue Emms, Man-Yu Wong, and Nicholas J Wareham

ABSTRACT

**Background:** It is unclear whether physical activity energy expenditure (PAEE) predicts changes in body composition.

**Objective:** The objective was to describe the independent associations between PAEE and changes in body composition in a population-based cohort.

**Design:** This was a prospective population-based study conducted in 739 (311 men and 428 women) healthy middle-aged (median age: 53.8 y) whites. The median follow-up was 5.6 y. PAEE (MJ/d) was assessed by heart rate monitoring, individually calibrated by using the FLEX heart rate method. Fat mass (FM) and fat-free mass (FFM) were assessed by bioimpedance.

**Results:** Body weight (BW) at follow-up was significantly related to baseline PAEE (\(P < 0.05\)) after adjustment for sex, baseline age, FM, FFM, and follow-up time. A significant interaction between PAEE and age was observed. After the subjects were stratified (above and below the median for age), BW increased by a mean (\(±\)SD) of 1.7 (\(±\)5.9) kg (\(P < 0.0001\)) in the younger cohort. In this group, follow-up FM was significantly associated with baseline PAEE (\(P = 0.036\)) after adjustment for confounders. In the older cohort, BW did not change between baseline and follow-up. In this group, in contrast with the younger population, follow-up BW, FM, and FFM were all significantly and positively associated with baseline PAEE (\(P < 0.01\) for all).

**Conclusions:** Baseline PAEE predicts a change in FM in younger adults, who as a group gained weight in this study. In contrast, baseline PAEE in older adults—who were on average weight stable—is associated with a gain in BW, which was explained by an increase in FM and FFM. 

**KEY WORDS** Energy expenditure, fat mass, fat-free mass, physical activity

INTRODUCTION

Obesity is multifactorial, involving genetic (1), social, cultural, and environmental (2) components. Gains in body weight (BW) and fat mass (FM) are the consequence of a positive energy balance over time. Thus, it has been suggested that the exponential rise in the prevalence of excess BW and body fat during past decades is most likely due to environmental changes, such as easy access to large portion sizes of energy-dense foods and reduced levels of physical activity energy expenditure (PAEE) or a combination of the 2 (2–4).

Previous population-based prospective studies that examined the association between physical activity and BW gain typically used subjective assessments of physical activity through self-report (5–11) and often also included self-reported height and weight (7, 9, 11). However, the measurement of physical activity in epidemiologic studies is difficult because of the complex nature of the exposure. Self-reported data on physical activity provides a relatively imprecise estimate of energy expenditure (EE) associated with physical activity (12). Many have argued that objective assessment methods of PAEE are needed to define the quantitative relation between activity and specific health outcomes, such as change in BW, and to characterize dose-response relations (12, 13).

Although BMI is widely used as a marker of overweight and obesity in epidemiologic studies (4), it does not allow separation of the components of FM and fat-free mass (FFM). Indeed neither the change in BMI nor in BW over time alone indicates whether change is due to an increase or decrease in FM or FFM or a change in both.

Therefore, the purpose of the present study was to describe whether objectively measured baseline PAEE predicts a change in BW after adjustment for potential confounders, including baseline FM and FFM. As a secondary aim, we examined whether baseline PAEE predicted change in body-composition variables (FM and FFM) after adjustment for confounding factors. This study was conducted over a 5-y period of follow-up in a randomly selected population-based cohort from the United Kingdom.

SUBJECTS AND METHODS

Study population

Participants were selected from the Medical Research Council Ely Study (14, 15), a prospective population-based cohort study...
of the etiology and pathogenesis of type 2 diabetes and related metabolic disorders. The volunteers were examined between 1994 and 1996 (baseline) and subsequently between 2001 and 2003 (follow-up). The median follow-up was 5.6 y. At baseline, 1120 healthy, middle-aged, white participants from the United Kingdom were assessed. Of these, 902 participants attended follow-up exams. A cohort of 739 participants (311 men and 428 women), in whom complete anthropometric and PAEE data were available, constitutes the sample for this report. All participants provided written informed consent. Ethical permission for the study was granted by the Cambridge Local Research Ethics Committee.

Repeate-measures substudy

During the year after the first assessment, a random subsample of 170 persons from the main cohort reattended our laboratories at 3 monthly intervals on 3 additional occasions for the reassessment of PAEE, REE, and body composition. The characteristics of the subsample and the methods used at reattendance, which did not differ significantly from those of the main study, were described in detail previously (15).

Body weight and body composition

Participants attended the laboratory after a 10-h overnight fast at baseline and follow-up. Height and BW were measured while the subjects were wearing indoor clothing with a rigid stadiometer and a calibrated scale. Resistance (Ω) was assessed by using a standard bioimpedance technique (Bodystat, Isle of Man, United Kingdom). This device was previously shown to be valid (16) and reliable (17) measure of percentage body fat. Total body water and FFM were calculated by using the impedance index (height²/resistance), BW, and resistance according to the equations published by Sun et al (18). FM was calculated as BW minus FFM. Exactly the same procedures and equipment were used at baseline and at the follow-up visits.

Assessment of baseline PAEE

After the measurement of anthropometric factors, a standard protocol for individually calibrating HR and EE was undertaken. This method was described in detail elsewhere (15). The relation between EE (ie, oxygen consumption) and HR was assessed at rest, while the participants were lying and then sitting, with an oxygen analyzer calibrated daily by using 100% nitrogen and fresh air as standard gases (PK Morgan, Kent, United Kingdom). The participants then bicycled on a cycle ergometer at several different workloads to provide the slope and the intercept of the line relating EE to HR. Each subject cycled at 50 revolutions per minute, and the workload was progressively increased from 0 W to 37.5 W, 75 W, and 125 W in stages lasting 5 min each. At each workload, 3 separate readings were recorded of HR, minute volume, and expired air oxygen concentration. The 125-W level was only undertaken if the HR had not reached 120 beats per minute by the end of the 75-W level. The oxygen concentration in the expired air and minute volume data were used to calculate oxygen consumption after correction for standard temperature and pressure. EE (kJ/min) was calculated at each time point as oxygen consumption (L/min) × 20.35 (19). Mean REE was the average of the lying and sitting values. The slope and intercept of the least-squares regression line of the exercise points were calculated. Flex HR was calculated as the mean of the highest resting HR and the lowest HR while exercising. This point was used in the analysis of free-living minute-by-minute HR data to discriminate between rest and exercise. Below this point, EE was assumed to be equivalent to REE. EE above the flex point was predicted from the slope and intercept of the regression line calculated during the exercise test. Participants wore HR monitors (Polar Electro Ltd, Kemple, Finland) continuously during the waking hours over the following 4 d. HR readings were directly downloaded into a computer via a serial interface, and the individual calibration data were used to predict minute-by-minute EE for each person. PAEE (MJ/d) was calculated by subtracting REE from the minute-by-minute EE and thereafter averaged over the 4-d period and expressed in MJ/d.

Statistical analyses

The unadjusted means and SD of the means of anthropometric data and EE data were calculated. All data were analyzed in their continuous form, unless otherwise indicated. Nonnormally distributed variables were log transformed (ln) before analysis. Associations between PAEE and BW and FM at baseline and follow-up were assessed by correlation analyses. Using generalized linear modeling, the independent associations of PAEE with BW at follow-up were assessed, adjusting for sex, age, duration of follow-up, and baseline FM and FFM, and the regression coefficients for the exposure variables were presented. Because age was highly significant in this model, the interaction term PAEE × age was included in the model to test whether age modified the relation between PAEE and BW at follow-up. The purpose of doing this was to test whether age modified the relation between baseline PAEE and change in BW. A significant interaction effect was observed; therefore, we stratified the analyses above and below the median for age. To test whether change in BW is a function of change in FFM, FM, or both, we substituted BW with FM and FFM in subsequent models. In preliminary analyses, adjustments were also made for smoking and dietary fat intake at baseline, but, because these factors were not significant covariates and did not affect the relation between PAEE and body composition at follow-up, they were removed from the final models. All data were analyzed in their continuous form in the generalized linear models and corrected for error by using the method described below. PAEE was expressed by quartiles for illustrative purposes.

Statistical correction for measurement error

The within-individual and between-individual mean squares and the reliability coefficients for PAEE and body-composition variables were estimated by using the formulas described by Armstrong et al (20). We subsequently applied these error correction coefficients to the linear regression models constructed to test the association of PAEE with body-composition variables. The purpose of applying these error correction coefficients was to control statistically for measurement bias that occurs for exposure variables that are inherent highly variability, such as PAEE. Error correction coefficients were calculated under the assumption that the errors associated with repeated measures on the same individual were independent. The β coefficients are standardized to the variance in the exposure variable. Therefore, the magnitude of change in the outcome that is attributable to a 1-SD change in the exposure can be easily determined. We previously showed the utility of the method described by Armstrong.
et al (20) in models designed to test the relative associations of physical activity with other metabolic phenotypes (15, 21).

RESULTS

The descriptive characteristics of participants at baseline and follow-up are displayed in Table 1. The median follow-up time was 5.6 y. BW was significantly higher in men than in women ($P < 0.001$) but did not change between baseline and follow-up. FM was significantly higher in women than in men ($P < 0.001$) and increased significantly between baseline and follow-up ($P < 0.01$). FFM was significantly higher in men than in women ($P < 0.001$) but did not change significantly between baseline and follow-up.

Baseline PAEE was significantly and inversely associated with age ($r = -0.20, P < 0.001$) at baseline. It was also inversely related to FM both at baseline ($r = -0.14, P < 0.001$) and at follow-up ($r = -0.11, P < 0.001$). Conversely, it was significantly and positively associated with BW ($r = 0.31, P < 0.001$; $r = 0.30, P < 0.001$) and FFM ($r = 0.48, P < 0.001$; $r = 0.48, P < 0.001$) at baseline and at follow-up, respectively.

The results of the generalized linear model for BW at follow-up, with baseline PAEE as the main exposure and with adjustment for sex, age, duration of follow-up, and baseline FM and FFM, are shown in Table 2. Age ($P < 0.001$) and baseline PAEE ($P = 0.037$) were significantly and negatively associated with BW at follow-up, whereas baseline FM and FFM ($P < 0.0001$) were positively associated with BW at follow-up. A significant interaction baseline PAEE and age ($P = 0.023$) was also observed.

We thereafter explored the association between baseline PAEE and FM at follow-up, with adjustment for sex, age, duration of follow-up, and baseline FM and FFM (Table 3). Baseline age ($P < 0.0001$) and baseline PAEE ($P = 0.041$) were significantly and negatively associated with FM at follow-up, whereas baseline FM was significantly and positively associated with FM at follow-up ($P < 0.0001$).

Because age modified the relation between baseline PAEE and BW at follow-up, we repeated our analyses in 2 age strata, above and below median baseline age (53.8 y). BW increased by 1.7 ± 5.9 kg ($P < 0.001$) in the younger cohort, in which BW at follow-up was significantly associated with baseline FM ($\beta = 1.131, P < 0.0001$), baseline FFM ($\beta = 1.023, P < 0.0001$), and baseline age ($\beta = -0.185, P = 0.002$) but not with baseline PAEE. FM at follow-up was significantly associated with baseline FM ($\beta = 1.04, P < 0.0001$), baseline FFM ($\beta = 0.119, P = 0.023$), and baseline PAEE ($\beta = -0.001, P = 0.036$). In the older cohort, there was no significant change in BW (0.05 ± 4.9 kg) between baseline and follow-up. BW, FM, and FFM at follow-up were all significantly and positively associated with baseline PAEE ($\beta = 0.0018, P = 0.001; \beta = 0.00053, P = 0.007$; and $\beta = 0.0013, P = 0.001$, respectively) after adjustment for sex, baseline age, duration of follow-up, and baseline FM and FFM.

The relation between change in FM and quartiles of baseline

### Table 1

Descriptive characteristics of participants at baseline and follow-up in the Medical Research Council Ely Study, 1996–2003

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>Follow-up</th>
<th>Baseline</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)$^a$</td>
<td>54.1 ± 10.3</td>
<td>59.7 ± 10.5</td>
<td>53.3 ± 10.1</td>
<td>59.0 ± 10.2</td>
</tr>
<tr>
<td>Weight (kg)$^b$</td>
<td>81.6 ± 11.3</td>
<td>82.2 ± 12.8</td>
<td>69.0 ± 13.0</td>
<td>70.1 ± 14.8</td>
</tr>
<tr>
<td>Height (cm)$^c$</td>
<td>174.9 ± 6.7</td>
<td>174.5 ± 6.7</td>
<td>162.3 ± 6.1</td>
<td>161.9 ± 6.2</td>
</tr>
<tr>
<td>Fat mass (kg)$^d$</td>
<td>19.6 ± 5.7</td>
<td>20.8 ± 6.2</td>
<td>26.0 ± 8.9</td>
<td>27.5 ± 10.3</td>
</tr>
<tr>
<td>Fat-free mass (kg)$^e$</td>
<td>62.0 ± 7.5</td>
<td>61.4 ± 8.4</td>
<td>43.0 ± 5.9</td>
<td>42.6 ± 6.1</td>
</tr>
</tbody>
</table>

$^a$ All values are $\bar{x} ± SD$. No significant time-by-sex interactions were observed.
$^b$ ANOVA for between-time differences: $P < 0.001$.
$^c$ ANOVA for between-time differences, $P < 0.001$.

### Table 2

$\beta$ Coefficients (and 95% CIs) for the association between baseline physical activity energy expenditure (PAEE) and change in body weight (kg) during a 5.6-y period in healthy middle-aged white men and women ($n = 739$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>0.292</td>
<td>(-1.677, 2.26)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>-0.206$^a$</td>
<td>(-0.287, -0.126)</td>
</tr>
<tr>
<td>Follow-up time</td>
<td>0.00171</td>
<td>(-0.0013, 0.00455)</td>
</tr>
<tr>
<td>Baseline FM (kg)</td>
<td>1.082$^c$</td>
<td>(1.018, 1.145)</td>
</tr>
<tr>
<td>Baseline FFM (kg)</td>
<td>0.978$^c$</td>
<td>(0.898, 1.058)</td>
</tr>
<tr>
<td>PAEE (MJ/d)</td>
<td>-0.00375$^d$</td>
<td>(-0.0072, -0.00024)</td>
</tr>
<tr>
<td>PAEE × age</td>
<td>0.000078$^d$</td>
<td>(0.000013, 0.00014)</td>
</tr>
</tbody>
</table>

$^a$ Data were obtained with the use of a general linear model (analysis of covariance). FM, fat mass; FFM, fat-free mass.
$^c$ $P < 0.001$.
$^d$ $P < 0.05$.

### Table 3

$\beta$ Coefficients (and 95% CIs) for the association between baseline physical activity energy expenditure (PAEE) and change in fat mass (FM) during a 5.6-y period in healthy middle-aged white men and women ($n = 739$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>-0.759</td>
<td>(-2.093, 0.574)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>-0.171$^a$</td>
<td>(-0.226, -0.117)</td>
</tr>
<tr>
<td>Follow-up time</td>
<td>0.00183</td>
<td>(-0.00091, 0.0038)</td>
</tr>
<tr>
<td>Baseline FM (kg)</td>
<td>1.034$^a$</td>
<td>(0.991, 1.077)</td>
</tr>
<tr>
<td>Baseline FFM (kg)</td>
<td>0.046</td>
<td>(-0.00024, 0.1)</td>
</tr>
<tr>
<td>PAEE (MJ/d)</td>
<td>-0.00245$^d$</td>
<td>(-0.00475, -0.00061)</td>
</tr>
<tr>
<td>PAEE × age</td>
<td>0.00004</td>
<td>(-0.000037, 0.000084)</td>
</tr>
</tbody>
</table>

$^a$ Data were obtained with the use of a general linear model (analysis of covariance). FM, fat mass.
$^c$ $P < 0.001$.
$^d$ $P < 0.05$. 

---

Downloaded from https://academic.oup.com/ajcn/article-abstract/81/5/964/4649906 by guest on 18 April 2018
PAEE and the relation between change in FFM and quartiles of baseline PAEE are shown in Figure 1.

Subsequently, we applied bivariate error correction coefficients derived from the repeated-measures substudy to the models that included PAEE. In the younger cohort, baseline PAEE was significantly and inversely related to FM at follow-up (uncorrected standardized $\beta = -0.0205$, $P = 0.03$) and after multivariate error correction (standardized $\beta = -0.0358$, $P = 0.03$) and adjustment for the same confounding variables as above. In the older cohort, baseline PAEE (MJ/d) was significantly and positively associated with BW (uncorrected standardized $\beta = 0.0130$), FM (uncorrected standardized $\beta = 0.0128$), and FFM (uncorrected standardized $\beta = 0.0130$) and after multivariate error correction ($\beta = 0.02580$, $\beta = 0.02589$, and $\beta = 0.02622$ for BW, FM and FFM, respectively) at follow-up ($P < 0.001$ for all in the older cohort).

**DISCUSSION**

The nature of the longitudinal relation between physical activity and change in body composition is uncertain. This may be because attempts to assess this relation have used relatively imprecise self-reported measures of exposure and outcome variables. In this study we quantified the outcome and exposure variables objectively and observed independent inverse associations between PAEE and change in BW and FM over a 5.6-y period, after adjustment for confounding factors. However, the prospective relation between PAEE and BW was modified by age. In younger middle-aged adults, who on average gained weight during the follow-up period, baseline PAEE was inversely associated with change in FM but was not associated with the change in BW and FFM. In contrast, older middle-aged adults, who on average were weight stable over the follow-up period, baseline PAEE was positively associated with an increase in BW, FM, and FFM. Adjustment for the effect of measurement error substantially strengthened these associations.

Prospective analyses have suggested that physical activity, assessed through self-report, prevents weight gain (8-10). Other studies have only observed a significant association between weight gain and self-reported physical activity at follow-up (5-7), whereas others have observed no significant association between activity and change in BW (22, 23). Furthermore, sex differences for the longitudinal association between self-reported physical activity and change in BW and composition have been observed (8, 11). It was recently suggested that physical inactivity was not associated with the development of obesity, whereas obesity may lead to inactivity (24).

Prospective studies (25-27) using objective measurements of EE with the doubly labeled water method have failed to show a longitudinal association between baseline PAEE and change in FM. However, these studies were performed in relatively small and select samples, and 2 of these studies were conducted in children (26, 27). A decrease in REE over the follow-up period, without a subsequent change in PAEE, may explain our observation that PAEE predicted FM gain in the younger cohort. However, we did not observe a significant difference in REE between periods (data not shown), which indicated that this cannot explain our findings.

Although we observed a statistically significant association between baseline PAEE and FM in the younger adult cohort, the clinical significance of this finding may be questionable given the weak associations and the small amount of variance explained in the outcome attributable to PAEE (<1%). Because even the most active quartile in the younger cohort gained FM over the measurement period, it is tempting to speculate that energy intake may play a greater role than PAEE in the gain in FM and the pathogenesis of obesity. In support of this hypothesis, a recent prospective study showed that energy intake but not EE attributable to physical activity was related to BW gain in adult Pima Indians (25). The gain in BW in younger middle-aged adults of $\approx 1.7$ kg over the follow-up period equates to a positive energy balance of $<30$ kJ/d, or a value equivalent to the energy cost of $\approx 2$ min of brisk walking per day. Such a small energy imbalance cannot be quantified with current methods, and it seems unlikely that the issue regarding energy intake compared with EE in the development of obesity can be resolved at this time.

In contrast with our observation in the younger adult cohort, the older group remained weight stable over the follow-up period. In this group, we observed a statistically significant positive association between baseline PAEE and gain in BW, which was explained by an increase in FM and FFM. Aging is associated with weight loss and sarcopenia, and it was recently suggested that physical activity attenuated weight loss in subjects older than 65 y of age (28). Furthermore, it was shown that low FFM can be increased by physical activity in the elderly (8). Our findings partly support this and also suggest that high levels of physical activity are associated with an increase in BW. The ideal BW for
older people is controversial (29, 30). However a relatively high BMI (\(\geq 27\)) is associated with minimum health hazards in the elderly (30). Furthermore, because weight loss is strongly associated with deleterious health in older people (31, 32), our data support the role of physical activity for the prevention of weight loss and improved health at older ages.

As in all observational studies, our data only suggest a causal association between baseline PAEE and body composition. However, it is unlikely that these associations are due to chance. First, the ability to detect the association between PAEE and change in body-composition components that we report in the present study is dependent on several factors. These factors include the precision of both exposure and outcome measurements, the sample size, and the difference in the magnitude of the association between exposure and outcome. The present study was undertaken in a large randomly selected population-based cohort in whom objective assessments of EE are available. PAEE was assessed through individually calibrated heart rate against REE and exercising EE. Our measure of PAEE has been shown to correlate well with PAEE measured with the doubly labeled water method (33), which is considered by many to be the gold standard method for assessing free-living EE. Moreover, the heart rate flex method is considerably more reliable and valid than subjective techniques such as questionnaire and interview (34). Furthermore, when we repeated our analyses with adjustment for exposure measurement error (35), the observed associations were considerably strengthened, which provides additional evidence that our measure of PAEE is valid and reliable. Our measure of body composition was obtained by bioimpedance, a method less precise than underwater weighting or dual-energy X-ray absorptiometry. However, because the same method was used at baseline and follow-up, it is unlikely that the measure of body composition was differentially biased between exams. Additionally, the direction of the associations between baseline PAEE and change in BW (which is measured with high precision) in the 2 age groups was similar to the associations between baseline PAEE and change in body fat.

In summary, PAEE predicts change in FM in younger adults, who on average gain weight over 5 years. In contrast, in older adults, who remain relatively weight stable, PAEE is associated with a gain in BW that is attributable to an increase in FM and FFM. Our results underscore the importance of developing physical activity programs designed to prevent obesity in younger middle-aged adults who are likely to gain weight. In contrast, such programs may prevent weight loss and preserve FFM in older adults who are weight stable.

UE conceived the hypothesis for this manuscript, performed the data analyses, and drafted the manuscript. SB and PWF provided critical input for the conception of this manuscript and assisted with the editing of the manuscript. SE and SH were the lead field epidemiologists on the project and were primarily responsible for the data collection and helped with the editing of the manuscript. SB, PWF, and NJW provided critical input on the data analyses and on the previous versions of the manuscript. NJW was the principal investigator of the Medical Research Council Ely Study and was responsible for the overall study design. All authors took part in the discussion of the results and approved the final version of the manuscript. None of the authors had any conflicts of interest.

REFERENCES


