



# Physical activity and body weight: associations over ten years in the CARDIA study

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**BACKGROUND:** Hypothesis 1—sustained changes in physical activity are inversely related to changes in body weight. Hypothesis 2—those who attenuate weight gain because of a temporary increase in physical activity (PA) may maintain a lower body weight over time.

**METHODS:** Data were from the Coronary Artery Risk Development in Young Adults (CARDIA) Study, a cohort of black and white men and women, aged 18–30 y at baseline, who attended up to five examinations over a 10 y period ( $n=5115$  at baseline). Longitudinal associations between physical activity and body weight changes were assessed, adjusting for secular trend, age, clinic site, education, smoking, alcohol intake, parity, percentage energy intake from fat, and changes in these variables over time. For hypothesis 1, concurrent associations of physical activity and body weight changes were examined. For hypothesis 2, we explored whether weight gain attenuation associated with increased PA during the initial 2–3 y of follow-up was sustained over 5 y. The study 2 analyses were conducted with three separate 5 y intervals: baseline to year 5 ( $n=3641$ ), years 2–7 ( $n=3160$ ), and years 5–10 ( $n=2617$ ).

**RESULTS:** Hypothesis 1—change in physical activity was inversely associated with change in body weight within all four race and sex sub-groups ( $P<0.005$ ). The predicted weight change associated with change in physical activity was four to five times larger in participants who were overweight compared with those who were not overweight at baseline. Hypothesis 2—an increase in physical activity during 2–3 y of follow-up was associated with an attenuation of weight gain that was sustained through 5 y of follow-up whether or not the physical activity increase was maintained during the later years. This finding persisted whether the starting point for the 5 y follow-up was year 2, year 5 or baseline (women only). Comparing participants who increased physical activity with those who decreased physical activity in the first 2–3 y of follow-up (eg by at least 2 h per week of stationary cycling for at least 6 months per year), the mean 5 y weight gain attenuation ranged from 0.8 to 2.8 kg.

**CONCLUSIONS:** The results of these analyses support the need for public health messages for promoting increased physical activity for weight maintenance and attenuation of age-related weight gain, especially for higher weight sub-populations.

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**Keywords:** exercise; body weight

## Introduction

The prevalence of obesity is increasing in the US and is linked to many adverse health outcomes.<sup>1–3</sup> Thus, reduction of the prevalence and incidence of obesity are important public health goals. Metabolic ward- and laboratory-based studies help clarify genetic and other physiological influences which help explain individual differences in the development and maintenance of obesity as well as body weight responses to negative energy balance and exercise training. Observational studies of physical activity (PA) associations with body weight in free-living populations also are important because weight responses outside the metabolic ward may not be the same as those observed in

controlled environments. Observational studies contribute information about long-term changes, which is important for the study of diseases associated with obesity and sedentary lifestyle. These prevalent chronic diseases, such as cardiovascular disease, have a long latency period. Therefore, even though population-based studies lack precision in measuring PA energy expenditure, they allow investigation of the population experience of body weight changes associated with PA changes. Through a combination of tightly controlled laboratory studies of mechanisms and population-based observational studies, more efficacious population-based strategies for reducing the prevalence and incidence of obesity may be achieved.

In free-living populations, an inverse association between reported PA and body weight has been fairly consistently reported from both cross-sectional and longitudinal studies.<sup>4–14</sup> However, previous longitudinal studies have included only two measurements of PA and body weight (at baseline and at a single follow-up some years later), and have primarily involved middle-aged men<sup>7–14</sup> Further, the effect of

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PA on body weight may differ according to initial relative body weight. For example, if an individual is obese, an increase in PA might produce a disproportionately larger body weight change than for a normal-weight individual, since physiological adaptations to the negative energy challenge would be expected to help maintain weight in the lean individual.<sup>15,16</sup>

In weight reduction programs, increases in physical activity (PA) are generally temporary and any weight lost is generally regained.<sup>17</sup> However, maintenance of weight gain attenuation after a period of PA increase may be more feasible than maintenance of weight loss. Previous observational studies which have come closest to examining whether long-term weight gain attenuation exists from past PA investigated the association of baseline PA with a single follow-up body weight. Williamson<sup>12</sup> found no prospective association between baseline PA tertiles and body weight at a 9 y follow-up in a representative US national cohort. In contrast, Owens *et al*<sup>14</sup> found that leisure-time energy expenditure at baseline was associated with a modest attenuation of weight gain at follow-up 3 y later, in a study of 500 peri-menopausal women. However, at least three clinic visits are needed to confirm that weight gain was attenuated by a concurrent change in PA before follow-up began. Determination that an attenuation of weight gain associated with an increase in PA in the early portion of follow-up is sustained, independent of PA in the latter portion of the follow-up, would provide further evidence that the effects of PA on body weight may be maintained beyond the period of PA increase.

The goals of this investigation were to address these issues concerning the association of PA and body weight changes in free-living populations. The CARDIA data offer several advantages over previous data sets, including the extended period of follow-up (10 y), the repeated number of follow-up evaluations (five), and a young bi-racial cohort of both men and women. Two sets of analyses were conducted to address the two specific hypotheses. For both sets of analyses, we also sought to determine whether any of the observed associations differed by race and/or gender.

*Hypothesis 1:* longitudinal physical activity and body weight changes are inversely associated. Further, these associations will differ according to baseline body mass index (BMI).

*Hypothesis 2:* an attenuation of age-related weight gain associated with PA will be maintained over time, even if increased PA levels are not maintained.

## Methods

### Description of study, subjects and recruitment

CARDIA is a multi-center, longitudinal study of the influence of behavioral, demographic and physiologic factors on the presence and development of cardio-

vascular disease risk factors in young adults. The initial study cohort consisted of 5115 young adult participants, balanced as to age (18–24, 25–30), sex, race (black and white), and educational status (high school graduate or less or more than a high school education). In addition, eligibility criteria included long-term residence in the target area, and freedom from chronic disease or disability that would interfere with any part of the examination. Further details of the CARDIA eligibility criteria and baseline demographic characteristics of the cohort have been published elsewhere.<sup>18</sup> There were five assessments of the cohort at baseline (1985–1986) and 2, 5, 7 and 10 y later. Retention of the cohort was 90% at year 2, 85% at year 5, 80% at year 7 and 77% at year 10.<sup>19</sup>

### Exclusions and inclusions

In this young, healthy cohort at baseline, no consistent associations were found between chronic or acute self-reported illnesses and body weight or PA changes over time (results not shown). Therefore, no participants were excluded from the current analyses on the basis of medical conditions, with the exception of pregnancy. Women who were pregnant at any examination ( $n = 215$ ) or who were less than 180 days postpartum ( $n = 510$ ) at any examination were excluded from these analyses. Of the excluded women, 49% were black and the differences between included and excluded women were similar for black and white women. The excluded women weighed less at baseline ( $66.9 \pm 0.37$  and  $64.60 \pm 0.56$  kg for the included and excluded women, respectively,  $P = 0.001$ ) and decreased PA more over 10 y ( $-60.43 \pm 5.32$  and  $-88.43 \pm 8.82$  exercise units for included and excluded women, respectively,  $P = 0.007$ ) than the women included in these analyses. However, the change in weight over 10 y did not differ across included and excluded women ( $9.40 \pm 0.27$  and  $9.77 \pm 0.47$ , respectively,  $P = 0.49$ ), suggesting that the association of PA and body weight in the excluded and included women may have differed. In addition, only those subjects with both PA and body weight data at all five examinations were included in analyses of hypothesis 1, leaving a total of 2770 participants in the current analyses. Baseline demographic and other characteristics of these 2770 participants are presented in Table 1.

For hypothesis 2, an analysis was conducted using those with complete PA and body weight data from three assessments: years 2, 5 and 7 ( $n = 3160$ ). We repeated the study 2 analyses two more times in different age ranges, once with the year 5 assessment as the starting point and comparing those with complete PA and body weight data from the assessments at years 5, 7 and 10 ( $n = 2607$ ); and again with the baseline assessment as the starting point and comparing those with complete PA and body weight data from the assessments at baseline, year 2 and year 5 ( $n = 3641$ ). Baseline demographic and other

**Table 1** CARDIA participants: baseline demographic and other characteristics (mean  $\pm$  s.e.)

	Black women (n = 648)	White women (n = 675)	Black men (n = 601)	White men (n = 846)
Body weight (kg)	69.9 $\pm$ 0.73	63.9 $\pm$ 0.52	77.5 $\pm$ 0.61	76.9 $\pm$ 0.42
Height (cm)	163.7 $\pm$ 0.27	165.1 $\pm$ 0.25	177.1 $\pm$ 0.29	178.1 $\pm$ 0.23
Heavy intensity physical activity (exercise units)	167.2 $\pm$ 6.7	267.5 $\pm$ 8.2	369.5 $\pm$ 11.0	346.7 $\pm$ 8.1
Age (y)	25.0 $\pm$ 0.2	26.0 $\pm$ 0.1	24.5 $\pm$ 0.2	26.0 $\pm$ 0.1
Education (y)	13.2 $\pm$ 0.1	14.6 $\pm$ 0.1	13.1 $\pm$ 0.1	14.7 $\pm$ 0.1
Energy intake (kcal)	2493.1 $\pm$ 51.8	2141.6 $\pm$ 33.7	3937.5 $\pm$ 98.2	3234.0 $\pm$ 45.1
Alcohol intake (ml/day)	5.4 $\pm$ 0.5	8.9 $\pm$ 0.6	17.4 $\pm$ 1.3	17.5 $\pm$ 0.8
Smokers (%)	29.7%	24.2%	35.0%	22.4%
Have given birth between exams (%)	27.3%	25.2%	N/A	N/A

characteristics of these three sets of participants were similar to those presented in Table 1.

### Assessment of PA

PA was assessed at each of the five examinations using the CARDIA PA history questionnaire, an interviewer-based self-report of frequency of participation in each of 13 categories of sports and exercise over the previous 12 months.<sup>20,23</sup> Eight vigorous intensity (>6 METS<sup>†</sup>) activities surveyed by this questionnaire are: jogging, racket sports, bicycling, swimming, vigorous exercise/dancing, weight-lifting, vigorous job activity, and other strenuous sports. Five moderate intensity (3–6 METS) activities surveyed were: non-strenuous sports, walks/hikes, bowling/golf, home exercise, and home maintenance. Activities were scored according to the frequency of participation, including whether the activity was ever performed in the past year, consistency of performance, and the number of months during which the activity was frequently performed. Because duration is not assessed by the CARDIA PA history questionnaire, the resulting sum of frequency and intensity scores is expressed in 'exercise units', with separate scores for moderate and heavy intensity activity, and for total activity. For the present analysis, the focus was on the heavy intensity score, since high intensity activities generally are recalled with greater accuracy than moderate and low intensity activities,<sup>21</sup> and since a high correlation was observed between the heavy intensity score and the total activity score ( $r=0.94$ ,  $P=0.0001$ ). As a useful reference, 200 exercise units (EU) are roughly equivalent to regularly engaging in exercise at 6 METS, such as stationary bicycling or swimming, 2 h a week for 11 months per year. With such an exercise program, a 70 kg man would expend about 300 kcal per 50 min session, three times a week, which is the threshold amount of exercise recommended by the American College of Sports Medicine as appropriate for a weight loss program.<sup>22</sup> Details of the questionnaire administration and scoring are reported elsewhere.<sup>20,23</sup> The questionnaire is reported

to have good validity when compared with maximal aerobic fitness (heavy intensity score:  $r=0.63$ ), as assessed by a graded treadmill exercise test.<sup>21</sup> It also has been found to be a reliable instrument for assessing PA with test–retest correlation coefficients in the range of 0.77–0.84.<sup>21,24</sup> The heavy intensity score is reported to have a correlation of  $r=0.54$  with total daily energy expenditure from a detailed 4 week history of PA, and a correlation of  $r=0.83$  with heavy energy expenditure from the same 4 week PA history.<sup>21</sup> For hypothesis 2, change in PA was classified into one of the three following categories established *a priori* and based on reported high intensity PA: decreases in high intensity PA of 100 EU or more; maintenance within 100 EU; and increases in PA of 100 EU or more.

### Anthropometry

Body weight and height were measured at each examination. Body weight was measured on a calibrated balance scale with participants dressed in light clothing and without shoes to the nearest half pound (0.2 kg). Height (without shoes) was assessed using a vertical ruler, and was recorded to the nearest 0.5 cm. The average of two measurements was used for analysis. Body mass index (BMI) was calculated as the mass in kilograms divided by height in meters squared ( $\text{kg}/\text{m}^2$ ).

### Covariates

All of the following covariates were measured at each of the five examinations, unless otherwise noted. Age was assessed at baseline by self-reported birth date and calculated thereafter. Education status was based on the self-reported number of years of schooling completed. Self-reported number of alcoholic beverages (beer, wine and liquor) consumed per day was used to calculate average milliliters of alcohol consumed per day.<sup>25</sup> Parity was established by self-report of number of pregnancies and the outcome of each pregnancy. Cigarette smoking status was assessed by self-report at each examination and was verified by serum cotinine measurements at baseline. Excellent agreement between self-reported cigarette smoking and cotinine measurements in this cohort

<sup>†</sup>METS are defined as multiples of  $1 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ , which is commonly used as the amount of energy expenditure in adults at rest.

was previously reported.<sup>26</sup> Dietary energy intake was assessed at baseline and year 7 only, using a detailed quantitative dietary history, by centrally trained and certified interviewers with results reported as 'usual' intake during the previous month.<sup>27</sup> Percentage of total calories from dietary fat from these surveys was used in the present analysis.

### Statistical methods

All analyses were carried out using SAS version 6.12, (Cary, NC) with results stratified by race and sex. Although PA data were skewed, log transformation of the data failed to improve the normality of the distribution, so analyses reported here were performed on the non-transformed PA data. Since log transformation of data also affects how extreme scores are handled, models were tested both including and excluding extreme values to determine whether outcomes were influenced. Based on the findings of these assessments, no extreme values were excluded.

### Statistical analysis—hypothesis 1

*Variable definition—hypothesis 1.* Variables were defined for each examination and for comparisons between all 10 possible exam year intervals (eg baseline to year 2, baseline to year 5, baseline to year 7, baseline to year 10, year 2 to year 5, year 2 to year 7, etc). Parity was defined as an indicator: nulliparous (not having given birth) or parous (having carried one or more pregnancies to term, resulting in a live birth). Four cigarette smoking status groups were formed using criteria similar to previous analyses of CARDIA data.<sup>26</sup> Nonsmokers (the reference group) were those who reported not having smoked at any assessments, including ex-smokers at baseline. Quitters were those who reported smoking at the first and/or second exams and quitting at all subsequent assessments, with no report of re-starting after the assessment at which quitting was reported. Smokers were those who reported smoking cigarettes at each assessment. The fourth and final smoking status included all other potential patterns of smoking habits across time. Change in education, alcohol consumption, and percentage of total energy intake from fat was defined as the actual difference between the earlier and subsequent assessments. To examine the interaction of initial body weight with PA on body weight changes, sub-groups were established by splitting the cohort into two groups according to the sex-specific 75th percentile for BMI for 20–29-y-olds from NHANES II: BMI  $\geq$  26.3 for men, BMI  $\geq$  24.9 for women.

*Statistical models—hypothesis 1.* Repeated measures regression, using the SAS procedure Mixed, was used to assess simultaneously the association of the average PA level and body weight (between person or cross-sectional effect) and the association

of change in PA and body weight (within person or age matched time trend effect). The between person effect was modeled as the average PA level over 10 y, and the within-person effect was modeled as the difference between the reported PA at any specific examination and the 10 y average PA level. In those participants missing covariate information, the examinations at which covariate information was missing were excluded from the repeated measures analysis. The compound symmetry covariance matrix was applied, which assumes consistent variance across visits and equal correlations of the outcome variable across each potential pair of assessments. Restricted maximum likelihood estimates were used to estimate between- and within-person variances. Between- (cross-sectional) and within-person (time varying) components of the following independent variables were included in the repeated measures models: alcohol consumption; percentage of energy intake from fat; and educational level. Time varying components of these covariates were defined similarly to the within-person effect for PA. Clinical center, smoking status and parity also were included as nontime-varying covariates. Further, current age at each examination and time since the baseline assessment also were included in the model. The model allows aging and secular trend in body weight changes to be separated from the effect of PA on body weight, increasing the likelihood that an observed effect is not due to aging or secular trend.<sup>28</sup> Minimally adjusted models included the between and within components of PA, as well as age and follow-up time. Models to test the interaction of baseline BMI status and PA also included the product of baseline BMI status and average PA as well as the product of baseline BMI and change in PA. Repeated measures regression was also used to estimate the average weight change per year, adjusted for the same covariates, but not including PA in the models.

To illustrate the stability of estimation achieved in the repeated measures model by averaging in all available data at each examination (and all differences between pairs of examinations) we also estimated the associations between PA change and body weight change for each of the 10 possible pairs of assessments using nonrepeated regression analysis (SAS, PROC GLM). These regression models were adjusted for clinical center, age, body weight, education and alcohol intake at the first of the pair of assessments, as well as for changes in education, alcohol, parity and smoking. Percentage of total dietary energy intake from fat and change in percentage of total energy from fat also were included as covariates for those assessments in which dietary data were collected.

### Statistical models—hypothesis 2

Repeated measures regression analysis could not be used in hypothesis 2, because only those changes at specific examinations were to be involved. Therefore,

nonrepeated measures regression models were used, but the procedure was repeated for three starting points to check for consistency. Sex-specific nonrepeated regression models (SAS, PROC GLM) estimated the body weight change from year 2 to year 7 according to nine categories of PA change during years 2–5 and years 5–7 (ie decrease from year 2 to year 5 and decrease from year 5 to year 7, decrease from year 2 to year 5 and maintenance from year 5 to year 7, decrease from year 2 to year 5 and increase from year 5 to year 7, maintenance from year 2 to year 5 and decrease from year 5 to year 7, etc) using the LSMEANS option within Proc GLM. In addition, body weight change from year 2 to year 7 was estimated according to three categories of PA change during years 2–5, holding constant PA change category during years 5–7. This set of models was then repeated twice, using year 5 and baseline as starting points for a 5 y follow-up interval. For example, in the analysis which used year 5 as the starting point, the body weight change from years 5 to year 10 was predicted according to nine categories of PA change from year 5 to year 7, as well as year 7 to year 10. The regression models predicting body weight change were also adjusted for clinical center, age, race, starting education and alcohol intake, as well as changes in education, alcohol, parity and smoking over 5 y, and starting body weight.

In addition, to better visualize the weight patterns during 5 y according to PA change during the first 2–3 y, body weight at each exam was predicted by physical activity change and models were developed in which body weight at a specific exam was predicted by physical activity change during the first 2–3 y of the 5 y follow-up, holding constant PA change category for the latter 2–3 y of follow-up. For example, body weight at years 2, 5 and 7 was predicted by physical activity change during years 2–5, adjusting for physical activity change during years 5–7. Adjustments for these models were similar to adjustments for the above-described models, with the exception of body weight. Body weight at baseline was included in the models predicting body weight at years 2, 5 and 7. Similar models were developed to predict body weight at years 5, 7 and 10 from physical activity

during years 5–7. For models developed to predict body weight at baseline and years 2 and 5, baseline body weight was included in models that predicted years 2 and 5.

## Results

### PA and body weight at each assessment

Table 2 shows the body weight in kg and PA in exercise units (EU), at each of the five assessment visits, by race and sex sub-groups. The cohort, over 10 y, experienced an overall mean decrease in PA (about –55 EU for black participants and –79 EU for white participants) and an increase in weight (about 11 and 7 kg for black and white participants, respectively, unadjusted for age or any other covariates).

### Hypothesis 1

*Cross sectional analysis: the association of average PA level over 10 years with average body weight.* Table 3, line 1 shows regression coefficients from repeated measures regression for the relationship of average PA level to body weight over 10 y by race and sex sub-groups from fully adjusted models; an association was seen only in white women. In the second and third lines of Table 3, the contribution of average PA level to body weight over 10 y is shown separately for individuals who were, at baseline, above and below the sex-specific 75th percentile for BMI from NHANES II. The associations were inverse or more strongly inverse in the heavier participants (lines 2 and 3 of Table 3) and differed significantly ( $P < 0.005$ ) between the two baseline BMI subgroups, with the exception of black women.

*Longitudinal analysis: relationship of changes in body weight and PA over 10 y.* Figure 1 shows the body weight change expected from a 200 EU change in PA by race and sex sub-group from fully adjusted models (dark bars) as well as the observed yearly weight gain

**Table 2** Heavy intensity physical activity and body weight at each CARDIA assessment (mean  $\pm$  s.e.)

	Black women	White women	Black men	White men
<i>Heavy intensity physical activity (exercise units)</i>				
Baseline	167.2 $\pm$ 6.7	267.5 $\pm$ 8.2	369.5 $\pm$ 11.0	346.7 $\pm$ 8.1
Year 2	156.3 $\pm$ 6.3	217.5 $\pm$ 7.0	344.5 $\pm$ 10.6	314.9 $\pm$ 7.8
Year 5	167.4 $\pm$ 7.0	225.4 $\pm$ 7.9	348.6 $\pm$ 11.2	304.2 $\pm$ 7.7
Year 7	136.2 $\pm$ 6.2	188.9 $\pm$ 6.7	327.9 $\pm$ 11.2	263.4 $\pm$ 7.1
Year 10	124.2 $\pm$ 6.0	188.6 $\pm$ 7.6	301.7 $\pm$ 10.4	267.7 $\pm$ 7.3
<i>Body weight (kg)</i>				
Baseline	69.9 $\pm$ 0.73	63.9 $\pm$ 0.52	77.5 $\pm$ 0.61	76.9 $\pm$ 0.42
Year 2	72.1 $\pm$ 0.78	65.0 $\pm$ 0.54	80.0 $\pm$ 0.66	78.7 $\pm$ 0.44
Year 5	75.8 $\pm$ 0.82	66.8 $\pm$ 0.61	83.3 $\pm$ 0.70	81.2 $\pm$ 0.50
Year 7	78.4 $\pm$ 0.86	68.7 $\pm$ 0.65	85.7 $\pm$ 0.74	82.9 $\pm$ 0.50
Year 10	81.4 $\pm$ 0.87	70.7 $\pm$ 0.70	88.0 $\pm$ 0.80	84.6 $\pm$ 0.52

**Table 3** Association of average body weight (in kg) with Average heavy intensity physical activity level over 10y: regression coefficients<sup>a</sup> from adjusted models<sup>b</sup> (mean ± s.e.)

	Black women			White women			Black men			White men		
	n	$\beta \pm s.e.$	P	n	$\beta \pm s.e.$	P	n	$\beta \pm s.e.$	P	n	$\beta \pm s.e.$	P
Weight difference per 200 EU of PA <sup>c</sup>	648	+0.55 ± 1.36	0.69	675	-2.98 ± 0.80	0.0002	601	-0.19 ± 0.65	0.77	846	-0.41 ± 0.54	0.44
<i>Effect of average PA level on weight when BMI at baseline was:</i>												
<26.3 for men, <24.9 for women <sup>d</sup>	340	+1.02 ± 0.90	0.26	506	-0.26 ± 0.52	0.62	431	+1.66 ± 0.47	0.0005	671	+0.37 ± 0.41	0.37
≥ 26.3 for men, ≥ 24.9 for women	308	-0.09 ± 1.84	0.96	169	-3.39 ± 2.07	0.10	170	-2.17 ± 1.32	0.10	175	-2.70 ± 1.25	0.03

<sup>a</sup>All coefficients reflect the difference in body weight between individual participants who differed in average PA by 200EU, or the approximate equivalent of bicycling 2h weekly for 11 out of 12 months.

<sup>b</sup>Adjustments included: age, time, clinical center, cigarette smoking habits, alcohol consumption, education, parity, and percentage of total energy intake from fat.

<sup>c</sup>EU: exercise units; PA: physical activity.

<sup>d</sup>75th percentile for BMI (sex-specific) from NHANES II for 20–29-y-old adults.

regardless of PA change (light bars). In Figure 1A, all participants are included, regardless of baseline BMI status. The association between PA change and weight change is significant and inverse in all race and sex sub-groups ( $P < 0.005$ ). The amount of weight gain attenuation associated with a 200EU increase in PA exceeded the observed weight gain in three of the race and sex sub-groups, except for black men. Regression coefficients for the effect of a 200 EU change in PA on body weight from an unadjusted model were similar to those presented in Figure 1A (black women:  $\beta = -1.16 \pm 0.17$ ,  $P = 0.0001$ ; white women:  $\beta = -0.70 \pm 0.14$ ,  $P = 0.0001$ ; black men:  $\beta = -0.38 \pm 0.11$ ,  $P = 0.0007$ , and white men:  $\beta = -0.49 \pm 0.10$ ,  $P = 0.0001$ ).

In Figure 1B and C, the weight gain attenuation associated with a 200EU change in PA was about 4–7 times larger in participants who were above vs those below the baseline BMI cutpoints ( $P < 0.0001$ ). In Figure 1B (participants below the baseline BMI cut-point), the weight gain attenuation from a 200EU increase in PA did not match average yearly weight gain in any of the race and sex sub-groups. However, in Figure 1C (participants above the baseline BMI cut-off point), with the same amount of PA increase (200 EU) the weight gain attenuation exceeded the average yearly weight gain in the women and the white men, and came close to matching the average yearly weight gain in black men. Mean baseline body weight (in kg, ± s.e.) for the participants below and above the BMI cut-off point was  $57.58 \pm 0.41$  and  $83.41 \pm 1.00$  in black women;  $58.15 \pm 0.31$  and  $80.99 \pm 1.04$  in white women;  $70.87 \pm 0.42$  and  $94.38 \pm 1.07$  in black men, and  $72.74 \pm 0.32$  and  $92.80 \pm 0.92$  in white men.

The impact of a 200EU PA change on body weight was consistently negative and 4–7 times larger for the participants above than below the BMI cut-off point in all race and sex sub-groups. When the regression coefficients are expressed as a percentage change from baseline body weight, the impact of a 200EU PA change on body weight was 3.7–5.4 times larger

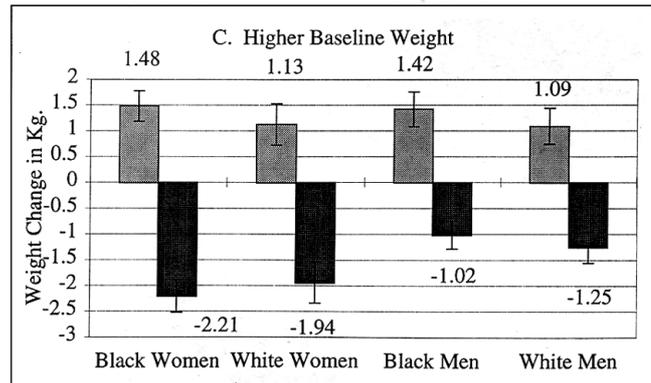
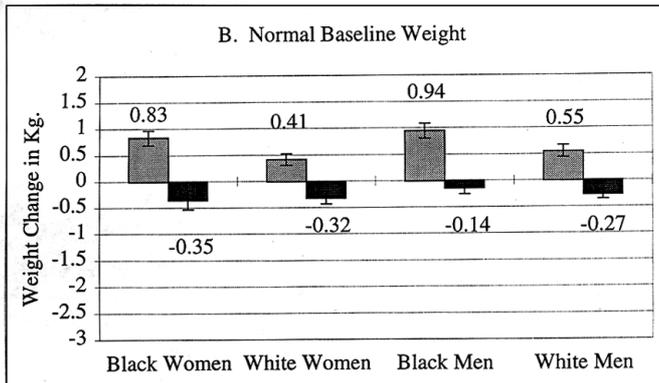
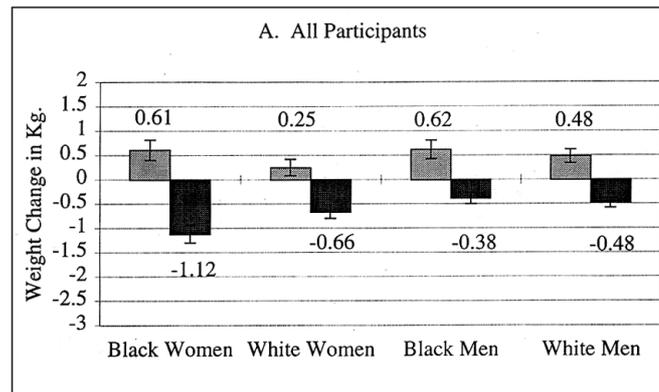
in those participants above than below the BMI cut-off point.

The interaction of change in PA on change in body weight according to baseline BMI was also modeled with baseline BMI continuous and linear. For every unit increase in BMI at baseline, the decrease in body weight associated with a 200EU change in PA on body weight was greater by  $0.16 \pm 0.03$ ,  $0.30 \pm 0.03$ ,  $0.15 \pm 0.03$ ,  $0.20 \pm 0.03$  kg in black women, white women, black men and white men, respectively ( $P = 0.0001$  in all race and sex sub-groups).

*Variability in association of PA change and body weight change across time intervals.* The results presented in Figure 1 represent a pooling of information across all concurrent pairs of examinations. Data from specific pairs of examinations were less consistent. Table 4 presents the lowest and highest regression coefficients for the association of PA change and body weight change for all 10 pairs of assessments to reveal the large range of the association and possibly misleading findings that might result if only two CARDIA examinations were used in the analysis. The regression coefficients from the repeated measures regression are also presented in Table 4.

**Hypothesis 2**

Table 5 shows the body weight changes over 5y follow-up (years 2–7) for men and women according to PA change categories. The upper portion of the table shows body weight changes according to the PA change category during years 2–5 as well as PA change category during years 5–7. The lower section shows 5y body weight changes according to PA change category for years 2–5, holding constant PA change category for years 5–7. Figure 2 graphically represents the data from the lower portion of Table 5, using data from models predicting body weight at years 2, 5 and 7 (see Methods section). The number of participants in each of the nine PA



**Figure 1** Attenuation of weight gain associated with physical activity increases. Mean weight change in kg per year: (light bars), average yearly weight gain, regardless of PA change; (dark bars), weight gain attenuation from 200 EU reported increase in PA. All values are adjusted for age, time, clinical center, cigarette smoking habits, alcohol consumption, education, parity, and percentage of total energy from fat. Cut-off points for normal vs higher baseline weight were 75th percentile for BMI (sex-specific) from NHANES II for 20–29 y olds. EU = exercise units; PA = physical activity.

**Table 4** Minimum and maximum body weight change (kg) predicted by a 200 EU<sup>a</sup> change in heavy intensity physical activity for specific pairs of exams and from repeated measures regression: regression coefficients ± s.e. from adjusted models<sup>b</sup>

	Black women		White women		Black men		White men	
	$\beta \pm s.e.$	Exam years <sup>c</sup>	$\beta \pm s.e.$	Exam years	$\beta \pm s.e.$	Exam years	$\beta \pm s.e.$	Exam years
Minimum	-0.47 ± 0.29	0–2	-0.42 ± 0.23	0–2	-0.21 ± 0.19	0–2	0.04 ± 0.16	0–2
Maximum	-1.68 ± 0.44**	2–10	-1.51 ± 0.30**	7–10	-0.62 ± 0.28*	0–10	-0.85 ± 0.19**	5–10
Repeated measures regression	-1.12 ± 0.18**		-0.66 ± 0.14**		-0.38 ± 0.12**		-0.48 ± 0.10**	

\* $P \leq 0.05$ ; \*\* $P \leq 0.001$ .

<sup>a</sup>200 exercise units (EU) is the approximate equivalent of bicycling 2 h weekly for 11 out of 12 months.

<sup>b</sup>Models were adjusted for body weight at the earlier exam, clinical center, parity, smoking, age at prior exam, and education, alcohol intake, and percentage of calories from fat, as well as their changes, where possible.

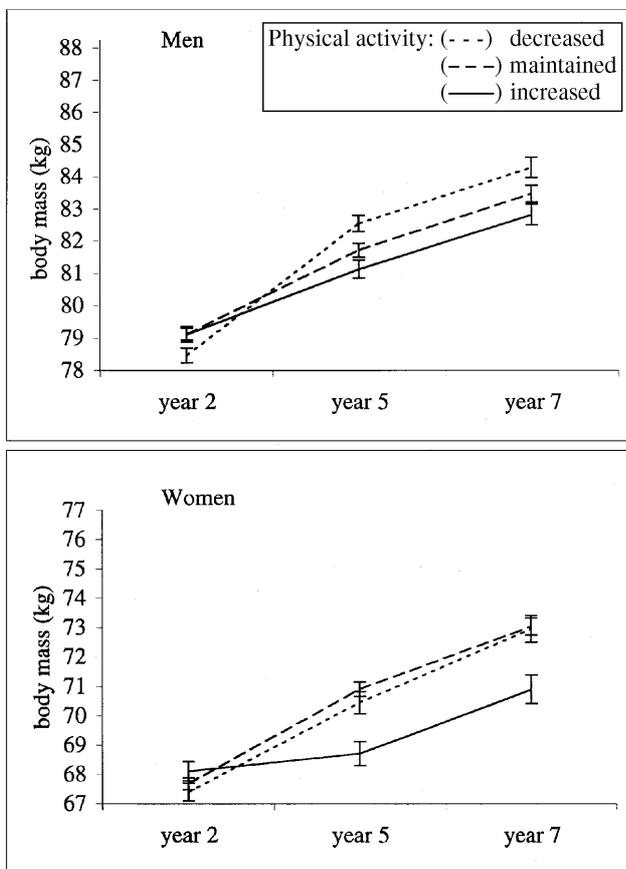
<sup>c</sup>Time interval, in years, for which the regression coefficient was estimated.

change categories represented by the upper portion of Table 5 shows that there were sufficient numbers in each category to assess the association of body weight change from year 2 to year 7 with PA change during years 2–5 as well as PA change during years 5–7. For men and women, the pattern of weight gain shows that physical activity change category during years 2–5 and years 5–7 were important in determining weight change from year 2 to year 7. The lower portion of Table 5 shows that the attenuation of weight gain associated with PA change during years 2–5 was maintained to year 7, holding constant PA change category during years 5–7 ( $P = 0.004$  and

$P = 0.0003$  comparing 5 y weight change across increased vs decreased PA during years 2–5, in men and women, respectively). The analysis was repeated two more times. In analyses with a starting point of year 5 (Table 6, Figure 3) the maintenance of weight gain attenuation associated with PA change category for the first 2 y of follow-up, holding constant PA change category in the latter 3 y of follow-up, was again observed in both men and women. Findings for the analyses with a starting point of baseline (results not shown) showed similar results for women but not men. Findings were similar for blacks as for whites with one exception: there was no

**Table 5** Body weight change from year 2 to year 7 according to physical activity change category during years 2–5 and years 5–7

PA change, years 2–5	PA change, years 5–7	Men		Women	
		n	Weight change	n	Weight change
Decrease	Decrease	86	6.70 ± 0.72	43	6.21 ± 1.23
	Maintain	243	4.72 ± 0.42	209	5.42 ± 0.57
	Increase	148	4.91 ± 0.55	84	3.88 ± 0.86
Maintain	Decrease	168	5.24 ± 0.51	138	4.64 ± 0.67
	Maintain	371	4.94 ± 0.35	567	5.52 ± 0.36
	Increase	144	2.44 ± 0.56	141	5.01 ± 0.71
Increase	Decrease	267	4.46 ± 0.41	238	4.01 ± 0.54
	Maintain	147	3.89 ± 0.57	95	1.85 ± 0.87
	Increase	45	3.80 ± 1.05	26	2.72 ± 1.58
Decrease	Held constant	477	5.35 ± 0.31	336	5.23 ± 0.45
Maintain	Held constant	683	4.55 ± 0.26	846	5.31 ± 0.29
Increase	Held constant	459	3.89 ± 0.33	359	3.18 ± 0.49



**Figure 2** Weight gain during years 2–7, according to physical activity during years 2–5.

maintenance of the effect of PA on body weight for the black men for the years 5–10 exam year interval (results not shown).

To determine whether the results shown in Tables 5 and 6, as well as Figures 2 and 3 could have been due to acute illnesses that could have reduced physical activity and or body weight, the analyses predicting body weight at year 10 (as shown in Figure 3) were repeated after excluding participants who reported having developed a medical condition that would

have interfered with PA participation during years 7–10. The pattern of findings did not change, but differences in body weight at year 10 according to PA change categories from years 5–7 were no longer statistically significant in women (results not shown). Similar exclusions from the analysis predicting year 7 body weight also showed no change in the pattern of findings and no change in statistical significance for differences in body weight at year 7 for men or women (results not shown).

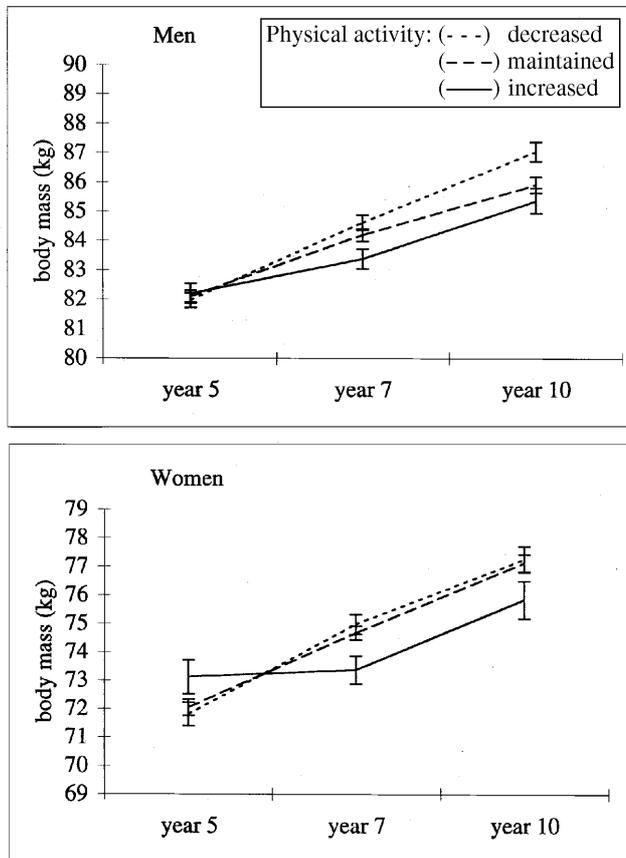
## Discussion

This longitudinal, 10 y observational study found an inverse association between PA and body weight in a bi-racial cohort of young free-living adults, confirming the findings of previous studies,<sup>10–14</sup> which involved older and less diverse population samples. The size of the predicted change in body weight with change in PA varied across race and sex sub-groups. There was also important variability in the association of body weight with PA across the 10 pairs of examinations. This variability occasionally reduced the strength of the association to the point that statistical significance was lost. In a previous paper involving the CARDIA cohort which analyzed data limited to the baseline and the year 7 follow-up, Lewis *et al*<sup>29</sup> reported no longitudinal association of PA and body weight change in this cohort; however, the race- and sex-adjusted regression coefficient for this interval happened to be the seventh largest among the 10 exam year intervals (data not shown). Further, another study with multiple follow-up assessments has also shown variability in the association of two physiological variables according to the specific pair of assessments compared.<sup>30</sup>

The variability in the estimate of the association of PA and body weight changes across time and race/sex groups may have occurred because of measurement error in self-reported PA or individual and sub-group differences in the biological response of body weight to exercise training. In addition, there may be varia-

**Table 6** Body weight change from year 5 to year 10 according to physical activity change category during years 5–7 and years 7–10

PA change, years 5–7	PA change, years 7–10	Men		Women	
		n	Weight change	n	Weight change
Decrease	Decrease	73	5.36 ± 0.83	34	5.64 ± 1.33
	Maintain	228	4.71 ± 0.47	184	5.68 ± 0.57
	Increase	184	4.56 ± 0.52	87	2.41 ± 0.83
Maintain	Decrease	170	4.61 ± 0.54	88	6.15 ± 0.83
	Maintain	385	3.95 ± 0.36	432	4.98 ± 0.37
	Increase	167	2.49 ± 0.55	105	3.56 ± 0.75
Increase	Decrease	186	4.09 ± 0.52	98	5.42 ± 0.78
	Maintain	81	2.16 ± 0.78	50	3.22 ± 1.09
	Increase	36	4.45 ± 1.18	19	1.08 ± 1.77
Decrease	Held constant	485	4.93 ± 0.33	305	5.05 ± 0.45
Maintain	Held constant	722	3.80 ± 0.27	625	4.92 ± 0.31
Increase	Held constant	303	3.26 ± 0.43	167	3.64 ± 0.65



**Figure 3** Weight gain during years 5–10, according to physical activity during years 5–7.

tion between sub-groups in the compensatory changes in dietary energy intake that may accompany changes in exercise habits. Examination of these sources of variability in future population-based observational studies with repeated measures might improve the ability to predict the range of responses that can be expected from community-wide PA intervention programs and might be useful for designing appropriate public health messages geared to reach sub-popula-

tions most likely to show significant changes in body weight from a change in PA.

Williamson<sup>12,13</sup> has noted that, when measurements of PA and weight are taken at the same time in clinic visits for longitudinal observational studies, the problem of disentangling cause and effect in associations of concurrent changes in PA and body weight are essentially the same as they are in cross-sectional analyses. Nevertheless, findings pertaining to hypothesis 2 suggest that, whatever the direction of causality, the attenuated weight gain associated with concurrent PA changes is maintained for several years. Both increased PA and decreased body weight may reduce chronic disease risk.

In addition, if recent weight changes influence recent PA and the measurement of physical activity is made during this period of transient weight and PA changes, the assumption that serial measurements of weight and PA represent ‘average’ levels during a given year may be invalid. Therefore, the current observations may be an underestimation of the true association of PA and body weight changes and may partly explain the lack of a consistent association between average PA and average body weight over 10 y in this cohort.

#### Impact of baseline BMI on the PA and weight association

CARDIA participants who were above the sex-specific 75th percentile for BMI from NHANES II at the baseline examination showed a 4–7 times larger body weight change associated with a 200 EU change in PA than participants who were below the same BMI cutpoint at baseline. This is not a surprising finding, given that heavier people are likely to be further from their own genetically determined body weight set point, at which physiological changes occur to protect the body from weight change. To our knowledge, differences in the association of PA and body weight changes according to baseline BMI have

not been reported previously in a longitudinal, observational study.

We compared the weight gain attenuation expected from a 200 EU increase in PA to observed yearly weight gain. In participants who were above a specific BMI cut-off point at baseline, this amount of PA increase exceeded the observed yearly weight gain, indicating that PA may be helpful for weight loss in individuals who are higher weight.

In contrast, the potential for partial attenuation of weight gain through increased PA was demonstrated in participants below the same BMI cut-off point at baseline.

The model of a stronger association of change in PA and change in BMI in participants above the 75th percentile of BMI at baseline is a simplification; the amount of weight gain attenuation associated with increased PA was shown to increase continuously throughout the range of baseline BMI. PA may operate on body weight differently according to baseline adiposity. After physical maturity, lean body mass tends to decrease with age if PA level is not maintained. Perhaps in the lower weight participants, the principal effect of a higher average PA level is to maintain lean mass. If so, this would result in a higher total body mass in lower weight individuals who are physically active than in lower weight individuals who are physically inactive. Measurement of lean body mass in a longitudinal observational study may help determine if this contributes to the direct association of average PA and body weight in lower weight participants observed in the present cohort.

#### **Maintenance of PA-associated weight gain attenuation**

This study and previous longitudinal, observational studies suggest that a substantial increase in PA is generally associated with concurrent decreases in body weight<sup>10–12,14</sup> However, such increases in PA often are not maintained over long periods, eg dropout rates for exercise programs (supervised or community-based) are reported to be as high as 50% within 6 months of starting a program.<sup>31–33</sup> In weight loss intervention programs, recidivism from increased PA is generally associated with regain of lost weight. However, attenuation of weight gain from PA may be maintained beyond the period of PA increase, regardless of whether the PA increase is maintained. This study suggests that these young adult participants attenuated long-term weight gain after they did not gain as much weight as expected for their age during a period of increased PA. For years 2–7, the amount of weight gain attenuation associated with a self-report of increasing PA by 100 EU or more (eg jogging for at least 2 h weekly for 6 months of the year) vs decreasing PA by 100 EU was 1.46 and 2.05 kg in men and women, respectively. This effect was present in both men and women participants for two of the three 5 y intervals examined. The variability discussed earlier in relation to concurrent changes in PA and body

weight (Table 4, hypothesis 1) was evident in the earliest 5 y interval: the men showed no concurrent inverse association of PA change and body weight from years 0 to 5. The findings for the earliest 5-y follow-up interval are statistically weakest, because of the variation in estimation of the year 0 body weight, ie at year 0 there was no known previous body weight for which to adjust. It is encouraging that the association still appeared to be present in the last 5 y of follow-up, when the age range in the study cohort was 28–40 y old. This suggests that the sustained attenuation of weight gain from an increase in self-reported physical activity may not be limited to young adults.

Weight loss intervention studies that have included PA in the treatment program consistently show that PA is a strong contributor to maintaining weight loss, but that it is difficult to get adherence to exercise programs prescribed for weight loss or maintenance.<sup>17,34–36</sup> Conclusions from such intervention studies imply that PA is only useful for weight control if the increase in PA is maintained indefinitely. Since recidivism is common, it is tempting to conclude that PA is not a practical mode for weight loss and its maintenance. In the present observational study, we have shown that the weight gain attenuation associated with a self-reported increase in PA may be sustained for years, independent of PA changes reported during the years following an initial period of PA increase. We speculate that the attenuation of weight gain may be a process distinct from weight loss or even maintenance of weight loss, either behaviorally, physiologically or both. It is possible that a temporary increase in PA could lead to improved eating habits, and that these habits may be maintained even if the increase in PA is not sustained. However, it is more likely that those who prevent weight gain through a temporary increase in PA just never catch up with those who did not prevent progressive weight gain through an increase in PA. These results imply that it is feasible to maintain a given weight if a weight gain never happened. The question that remains to be answered is why it is so difficult to maintain a weight loss through the same treatment approach.

#### **Strengths and limitations**

As reported in previous CARDIA publications,<sup>29,37</sup> changes in total dietary energy intake were not related to change in body weight. Therefore, change in total energy intake was not included in the present analyses. Instead, the percentage of total energy intake from fat and change in this variable were included in the present analyses as covariates to control for energy intake compensation for exams when these data were available. Change in percentage of total energy intake from fat has previously been shown to be associated with body weight changes in the CARDIA data.<sup>37</sup> It is recognized that inclusion of percentage of energy intake from fat for two of the five examinations

does not, by any means, constitute complete adjustment for caloric intake in these analyses. Compensation for change in energy expenditure from PA by changing energy intake would be expected in free-living populations. Future studies of the association of PA changes and body weight changes with more accurate measures of energy intake would be helpful in determining if the present results can be explained by caloric compensation effects.

Although a cohort as large as CARDIA necessitates measurement of PA by questionnaire, the potential for reporting error cannot be ignored. At least some of the current findings undoubtedly result from the well-known limitations of self-reported PA data, including inaccurate reporting or recall of PA and a greater focus on leisure time PA than occupational expenditure and household chores, which may contribute significantly to total daily energy expenditure.<sup>38,39</sup> The survey instrument used focused on leisure time PA, with only one question on occupational lifting and carrying, and thus may have missed other important sources of daily energy expenditure, including other occupational activities, household chores, child care and PA for transportation. In particular, it is possible that the modest size of the associations presented from hypothesis 2 fall within the range of measurement error inherent in such self-reported data.

Exclusion of the women who were pregnant or less than 6 months post-partum at any given examination resulted in the exclusion of about 20% of the total cohort. This exclusion may limit the generalizability of the results to the general population of women during child-bearing years. However, the physiological and behavioral variables affecting the association of weight-change and child-bearing may differ from the variables affecting the association of PA and weight change. Further, the results differed when these women were included, particularly for the black women (results not shown).

The present investigation expands on previous reports of the longitudinal observational association of PA and body weight in numerous ways. The repeated measures approach allowed for an examination of the variability in the association of PA and weight over numerous exam year intervals in the same cohort. The decades between age 20 and 40 y are a prime period for adult weight gain<sup>15,28</sup> and this is the first report of an inverse association between PA and body weight in a population-based bi-racial cohort of free-living adults in this important age range. The high retention of participants decreases the possibility of bias from loss to follow-up. The examination of the effect of baseline BMI on the association between PA and body weight also represents a novel analysis in longitudinal observational data. The ability to replicate the analyses across several pairs of examinations and over three separate 5 y intervals improves confidence that the observed findings are not due to chance.

## Conclusions

In conclusion, the association between PA change and body weight change was shown to be inverse and strongly affected by initial relative weight status in this bi-racial cohort of young men and women. The magnitude of body weight change that can be expected from a change in PA is subject to numerous sources of variability in free-living young adults, including biological variability, compensatory changes in energy intake, and initial body weight. As a result, caution should be used in trying to predict the amount of weight change that 'should' result from a given change in self-reported PA. That PA is still found to be inversely associated with body weight in free-living adults, even with less than perfect measurements and many potential sources of variability, in the response to PA change is an indication of the strength of the association.

In addition, we found that there is a carry-over of the effect of self-reported PA on body weight beyond when the physical activity was performed. The present results suggest that a temporary increase in PA may have health benefits beyond the period of increase, through attenuation of weight gain. The mean weight gain attenuation was about 1 kg per year for a modest increase in self-reported PA in the free-living young adults of the CARDIA cohort. These findings should not detract from focusing PA promotion efforts on lifestyle changes that can be maintained indefinitely. The public health goal of increasing the proportion of the population who perform regular PA for health promotion is well founded<sup>40</sup> and should remain an important public health goal. There are numerous health benefits from adopting and maintaining a lifestyle that includes regular PA on a long-term basis, independent of body weight changes. These include a reduction in the incidence of premature mortality from all causes<sup>41–44</sup> and mortality from cardiovascular disease<sup>45–47</sup> and colon cancer,<sup>48,49</sup> reduced risk of type 2 diabetes mellitus,<sup>50–52</sup> osteoporosis,<sup>53</sup> and reduced symptoms of anxiety and depression.<sup>54,55</sup> The results of these analyses support the need for public health messages to increase PA for weight maintenance and attenuation of age-related weight gain, especially in higher weight sub-populations.

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