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Bidirectional 10-y Associations of Accelerometer-measured Sedentary Behavior and Activity Categories with Weight among Middle-aged Adults

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Abstract

Background—Though higher sedentary behavior (SB) with low light intensity (LPA) and moderate-to-vigorous intensity physical activity (MVPA) are thought to increase risk for obesity, other data suggest excess weight may precede these behaviors in the causal pathway. We aimed to investigate 10-y bidirectional associations between SB and activity with weight.

Methods—Analysis included 886 CARDIA participants (aged 38–50 years, 62% female, 38% black) with weight and accelerometry (≥4 d with ≥10 hr/d) collected in 2005–6 (ActiGraph 7164) and 2015–6 (ActiGraph wGT3X-BT). Accelerometer data were calibrated, harmonized, and expressed as counts per minute (cpm) and time-dependent intensity categories (min/day of SB, LPA, and MVPA; SB and MVPA were also separated into long-bout and short-bout categories). Linear regression models were constructed to estimate adjusted associations of baseline activity with 10-y change in weight and vice versa. When activity categories were the independent variables, standardized regression coefficients (βstd) estimated associations of replacing SB with a one SD increase in other categories, adjusted for accelerometer wear time.

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Results—Over 10-y, weight increased by a mean 2.55±8.05 kg and mean total activity decreased by 50±153 cpm. In adjusted models, one SD higher baseline mean total activity (βstd=−1.4 kg, $p<0.001$), LPA (βstd=−0.80 kg, $p=0.013$), total MVPA (βstd=−1.07 kg, $p=0.001$), and long-bout MVPA (βstd=−1.20 kg, $p<0.001$) were associated with attenuated 10-y weight gain. Conversely, a one SD higher baseline weight was associated with unfavorable 10-y changes in daily activity profile including increases in SB (βstd=12.0 min, $p<0.001$) and decreases in mean total activity (βstd=14.9 cpm, $p=0.004$), LPA (βstd=8.9, $p=0.002$), and MVPA (βstd=3.5 min, $p=0.001$). Associations varied by race and gender.

Conclusions—Higher SB with lower activity and body weight were bidirectionally related. Interventions that work simultaneously to replace SB with LPA and long-bout MVPA while also using other methods to address excess weight may be optimal.

INTRODUCTION

A recent pooled analysis from over 200 countries estimates that worldwide obesity rates have risen steadily over the past 40 years, with a global prevalence of approximately 12% in men and 15% in women.[1] In many higher income countries, obesity rates exceed 30%.[1] At the same time, 27.5% of adults worldwide engage in insufficient moderate-to-vigorous intensity physical activity (MVPA).[2] Obesity and inactivity are each leading risk factors for non-communicable diseases and reduced well-being that are primary targets of global public health campaigns.[1–4] Though physical activity is an often recommended strategy to prevent and treat obesity,[5] the relationship between physical activity and obesity may be bidirectional,[6] a complexity that is poorly understood.

A physical activity profile characterized by high sedentary behavior (SB), low light-intensity physical activity (LPA), and low MVPA may contribute to obesity, in part, through decreased energy expenditure and complex relationships with appetite control and metabolism that result in a positive energy balance and weight gain over time.[3, 7] A recent expert report from the United States 2018 Physical Activity Guidelines Advisory Committee[8] concluded that strong evidence supports a modest protective effect of MVPA on weight gain. However, the same report identified important gaps in understanding about activity profiles and weight gain over time. Specifically, it remains unclear whether shorter (e.g., <10 minutes) vs. longer (e.g., ≥ 10 minutes) bouts of MVPA have different effects on weight gain.[8] Further, whether low LPA, high SB, or high prolonged SB with few breaks are associated with weight gain is unclear.[8, 9] Improved understanding from longitudinal studies with objective measurement of clinically relevant activity categories [i.e., SB that occurs in short (less than or equal to 30 min) or long bouts; MVPA that occurs in bouts less than (short-bout) or greater than or equal to 10 min (long-bout)] would clarify appropriate behavioral activity targets for weight gain prevention.

A less studied but also plausible hypothesis is that excess weight could lead to increased SB and decreased LPA and MVPA over time.[6, 10] Obesity is an established barrier to MVPA[11] and is associated with the development of comorbid conditions and related symptoms such as type 2 diabetes, musculoskeletal pain, chronic fatigue, and depression,[12–14] which in turn could lead to increased SB and decreased LPA and MVPA.[15–17] This potential bidirectional relationship might explain stronger cross-sectional and weaker longitudinal associations between activity profile and weight gain[18] and could have implications when designing programming or interventions for obesity and inactivity. However, studies investigating this direction of effect are few[6, 10, 19–22] and most have limitations such as self-report of physical activity and weight, or do not evaluate associations across the spectrum of activity categories.

In this study, we examined associations of accelerometer-measured mean total activity (counts per minute [cpm]) and activity categories with 10-y weight gain in a cohort of middle-aged, white and black American adults from the Coronary Artery Risk Development in Young Adults (CARDIA) Study. In addition, we evaluated the reverse direction of association, whether baseline weight is associated with 10-y changes in accelerometer-measured SB and activity. Lastly, reflecting the stratified design of the CARDIA study,[23] we explored whether these bidirectional associations differed by sex or race.

METHODS

Participants and Setting

The current study is an analysis of data from CARDIA, a multicenter, prospective cohort study investigating the development and determinants of cardiovascular disease beginning in young adulthood (clinicaltrials.gov record).[23] CARDIA recruited 5,115 white and black young adults, aged 18–30 years, from four field centers in the United States (Birmingham, AL; Chicago, IL; Minneapolis, MN; and Oakland, CA) beginning in 1985–6 and has conducted follow-up exams at ≤ 5-year intervals thereafter. This analysis uses data from the year 20 (Y20) and year 30 (Y30) follow-up exams, which captured 72% and 71% of the surviving cohort, respectively. Data from the Y20 exam were considered ‘baseline’ and data from the Y30 exam were considered ‘10-y follow-up’. All participants provided informed consent and research procedures were approved by local Institutional Review Boards at each site.

A total of 2 936 provided weight data at both baseline and follow-up. Of these, n=26 were excluded for current pregnancy at either time point and n=89 were excluded for a history of bariatric surgery. A further n=1 958 were excluded because they either did not participate in the CARDIA Fitness and Activity Ancillary Studies or did not have valid accelerometry data at both exams, resulting in a final analytical sample of n=866. Of note, the Y30 CARDIA Activity Ancillary Study began midway through the exam period and thus missed a portion of potential participants due to timing.[24] Participants with vs. without valid accelerometer data were more likely to be white ($p<0.001$), female ($p<0.001$), and had lower BMI ($p<0.001$), but did not differ by age ($p=0.282$).

Measurements

SB and activity were measured by a uniaxial accelerometer (ActiGraph 7164, Pensacola, FL) at baseline and a triaxial accelerometry (ActiGraph wGT3X-BT, Pensacola, FL) at follow-up. At both visits, participants were asked to wear the accelerometers during all waking hours (except water activities) for 7 days. At baseline, accelerometers were initialized to collect count data in 60-second epochs; at follow-up raw data were sampled at 40 hertz and reintegrated to count data expressed in 60-second epochs (cpm). Using a validation study where both monitors were worn by a subset of n=87 CARDIA participants during the Y30 ‘follow-up’ exam,[25] a calibration factor which divided follow-up wGT3X-BT cpm from the vertical axis by 1.088 was applied to harmonize baseline and follow-up data. Wear time was calculated as 24 hours minus nonwear time, defined as time intervals with 0 counts per minute (cpm) for ≥60 consecutive minutes, but allowing ≤2 minutes at <100 cpm.[26] Accelerometry data were considered a valid representation of the seven-day data collection period with ≥4 days of monitoring with ≥10 hours/day.[27] One participant was removed due to implausible mean total activity (average >20,000 cpm).[28]

Daily averages of activity variables, including mean total activity (cpm) and activity category durations (min per day), were calculated by averaging across valid wear days. Freedson cutpoints were used to classify SB (<100 cpm), LPA (100 to <1952 cpm), and MVPA (≥1952 cpm).[29] To explore clinically relevant activity categories, SB was segmented into short-bout SB (accumulated in <30-minute bouts) and long-bout SB (accumulated in ≥30-minute bouts). The 30-minute threshold was selected based on research suggesting SB accumulated in bouts ≥30 minutes is most strongly associated with body mass index[30] and an expert review concluding that interrupting SB every 30 min is a potentially feasible and health-enhancing behavioral target.[31] Importantly, SB in this study reflects time spent stationary based on the waist-worn accelerometer; posture and the definition of SB that includes aspects of posture were not measured.[32] Similarly, to explore relevant activity categories, MVPA was segmented into short-bout MVPA (bouts of <10 minutes) and long-bout MVPA (accumulated in bouts of ≥10 minutes, with allowance for 2 minutes <1952 cpm).[29] Separation of accelerometer-measured activity into categories (long-bout SB, short-bout SB, LPA, short-bout MVPA, and long-bout MVPA) reflects a recent expert report stating a need for more longitudinal studies evaluating the health effects of prolonged SB vs. SB with more breaks and MVPA accumulated in durations of <10 minutes vs. ≥10 minutes.[8]

Within-subject differences in accelerometer wear time between the baseline and 10-year follow-up assessments were harmonized by rescaling 10-y follow-up activity category durations to baseline wear time as follows: 10-y follow-up activity category duration (min per day) x individual ratio of baseline|follow-up wear time. Ten-y differences in activity were calculated by subtracting baseline activity category duration from the rescaled follow-up activity category duration.

Height and weight were measured in light clothing and without shoes at baseline and follow-up. Demographic characteristics, smoking, alcohol, comorbidities, and medications were measured by standardized questionnaires at baseline. Coronary heart disease (CHD) was defined as self-reported heart problems (i.e., angina or heart attack). Diabetes was defined by reported use of glucose-lowering medication, HbA1c > 6.5%, fasting glucose > 126 mg/dL, or 2-hour glucose tolerance > 200 mg/dL. Energy intake was estimated from the CARDIA diet history at baseline.[33]

Statistical Methods

All analyses were conducted using Stata version 14 (STATA Corp, College Station, TX, USA). Baseline data were summarized across tertiles of baseline mean total activity using means and standard deviations (SD) or numbers and percentages; comparisons across tertiles used p-for-trend or chi-square tests, as appropriate. A series of linear regression models were fit to evaluate 10-y bidirectional associations between activity and weight as described in detail below. Though normality checks revealed baseline MVPA variables were not normally distributed, the original scale (min/day) was retained to aid in interpretation since results were similar with and without log transformation and model residuals were normally distributed and without influential points.

Activity and 10-y Changes in Weight—An initial model (Model 1) evaluated whether baseline mean total activity was associated with 10-y changes in weight. This model maintains a temporal relationship where the exposure occurs prior to the outcome. An additional model (Model 2) added adjustment for concurrent 10-y change in mean total activity. Next, to evaluate whether simple activity categories (i.e., SB, LPA, and MVPA) were associated with 10-y weight changes, a model was constructed including each activity categories and accelerometer wear time; one activity category (SB) was omitted as the reference category. Because durations in each intensity category are inter-related such that the total sum is equal to accelerometer wear time, this analysis examined associations when replacing SB with LPA, and MVPA. As above, Model 1 included baseline activity only and Model 2 added 10-y changes in activity. Lastly, the activity category analysis was repeated using expanded, bouted activity categories (i.e., long-bout SB, short-bout SB, LPA, short-bout MVPA, long-bout MVPA) with long-bout SB as the reference category. All beta coefficients were scaled to 1 SD of the independent variable (std. β) to aid in interpreting the meaningfulness of coefficients. All models were adjusted for baseline weight, height squared, research center, age, sex, education, lifestyle habits (smoking, energy intake), comorbidities (diabetes and coronary heart disease), and baseline accelerometer wear time. Accelerometer-measured ‘breaks’ in SB were considered as an additional independent variable of interest, but high correlations with short-bout SB and LPA ($r>0.5$, $p<0.001$) and high variance inflation factors when included in the adjusted model (VIF>5) precluded inclusion.

Weight and 10-y Changes in Activity—Separate models evaluated whether baseline weight was associated with 10-y changes in each mean total activity, SB, LPA, and MVPA as well short-bout and long-bout SB and MVPA (Model 1). Model 2 added adjustment for 10-y weight changes. Again, std. β are reported (per 1 SD of the weight variable) and models were adjusted for baseline activity, height squared, research center, age, sex, education, lifestyle habits (smoking, energy intake), comorbidities (diabetes and coronary heart disease), and baseline accelerometer wear time.

Race and Sex Interactions—Associations were evaluated for interactions by race (white, black) and sex (male, female) in finally adjusted models (Model 2). As significant interactions ($p<0.05$) were observed for race and sex, exploratory analyses were repeated in each race/sex strata. Of note, these strata had limited sample size as follows: white men (n=226); white women (n=321); black men (n=108); and black women (n=231).

RESULTS

At baseline, participants included in the study were, on average, 45.2 (3.5) years old, had a BMI of 28.1 (6.0) kg/m^2, and reported consuming 2 365 (1 230) kcal/day. Further, 38.3% were black, 62.3% were female, 63.5% had a Bachelor's degree or higher, 68.1% were non-smokers, 15.7% reported CHD, and 5.9% had diabetes. Characteristics that were associated with higher baseline mean total activity tertile included: male sex, white race, lower BMI, higher energy intake, and lower prevalence of diabetes (Table 1).

On average, participants had mean (SD) daily wear time of 14.9 (1.6) hours and spent most of their time in SB (mean: 501 min; SD: 112 min; 56%), followed by LPA (mean: 359 min; SD: 85 min; 40%) and MVPA (mean: 36 min; SD: 24 min; 4%). Mean (SD) daily time spent in short-bout SB was 389 (71) min, long-bout SB was 112 (75) min, short-bout MVPA was 21 (13) min, and long-bout MVPA was 15 (18) min. While 26% of participants had no long-bout MVPA at baseline, <1% had no long-bout SB.

Activity and 10-y Changes in Weight

During follow-up, participants gained an average 2.5 (8.0) kg. Having higher baseline mean total activity was associated with attenuated weight gain over 10 years in models without (Model 1) and with (Model 2) concurrent adjustment for 10-y changes in mean total activity (Table 2). Further, an increase in mean total activity over the 10-y follow-up was independently associated with attenuated 10-y weight gain.

When considering simple activity categories (SB, LPA, and MVPA) at baseline (Model 1), replacing SB (reference category) with LPA was not significantly associated with weight change while replacing SB with 24 min per day (one SD) of MVPA was associated with 0.96 kg less weight gain over the 10-y follow-up ($p<0.001$). When 10-y changes in activity were added (Model 2), associations between higher baseline activity and attenuated weight were strengthened and replacing baseline SB with 85 min per day of LPA became statistically significant (−0.80 kg, $p=0.013$). Though 10-y changes in LPA were not significantly associated with weight change, 10-y changes in MVPA were significantly associated with attenuated 10-y weight change. The interpretation of this coefficient would that a 10-y increase in MVPA of 24 min per day, in exchange for an equivalent 10-y decreases in SB, was associated with 0.75 kg less weight gain over the 10-y follow-up ($p=0.012$).

When considering bouted activity categories, where SB and MVPA were each separated into long and short bouts, and long-bout SB became the reference category, higher LPA and long-bout MVPA were associated with attenuated 10-y weight gain. Replacement of long-bout SB with short-bout SB or short-bout MVPA were not statistically significantly related to 10-y weight gain. Adding concurrent adjustment for 10-y changes in activity categories (Model 2) again strengthened associations between higher baseline LPA and long-bout

MVPA and attenuated weight gain; the only 10-y change activity category associated with attenuated 10-y weight gain was long-bout MVPA (Table 2).

Weight and 10-y Changes in Activity

Mean total activity decreased by −50 (153) cpm over the 10-y follow-up. Higher baseline weight was significantly associated with decreased mean total activity over the 10-y follow-up, both with and without concurrent adjustment for 10-y change in weight (Table 3).

In this study sample, participants had the following average 10-y changes by activity category (min per day): SB: 37 (96); LPA: −30 (88); MVPA: −7 (24); short-bout SB: −4 (73); long-bout SB: 41 (96); short-bout MVPA: −7 (13); long-bout MVPA: 0.0 (20). Baseline weight was associated with increases in long-bout SB and short-bout SB and decreases in LPA, and long-bout MVPA over the 10-y follow-up (Table 3). For example, in the finally adjusted model, each 18.8 kg (one SD) higher weight at baseline was associated with an additional 12 min per day increase in SB ($p<0.001$). Ten-y changes in weight were only associated with 10-y increases in total and long-bout SB and decreases in mean total activity, total and long-bout MVPA.

Race and Sex Interactions

Associations between mean total activity or activity categories and 10-y weight change were found to differ across race-sex groups (Supplemental Table 1). Higher baseline and greater 10-y increases in mean total activity were associated with reduced weight gain in white men and women but not black men or women. Similarly, in activity category models, the estimated associations when replacing baseline SB with MVPA were an attenuated 10-y weight gain in white men and women but not blacks. Ten-y changes in LPA and long-bout MVPA were associated with decreased weight gain in white men only.

Associations of baseline weight with 10-y changes in activity also differed by race and sex (Supplemental Table 2). From the stratified analyses, a higher baseline weight was associated with 10-y decreases in mean total activity in white women, increases in SB and long-bout SB in white men, and decreases in MVPA and long-bout MVPA in white and black women. In white men, 10-y increases in weight were associated with decreased mean total activity, increased total and long-bout SB, and decreased LPA, MVPA, and long-bout MVPA. In white women, 10-y weight gain was associated with decreased mean total activity and increased total and short-bout SB.

DISCUSSION

The current study supports bidirectional associations between accelerometer-derived mean total activity, SB and activity categories with weight change over 10 years in a cohort of middle-aged men and women. Higher mean total activity and a baseline activity profile favoring LPA and MVPA, with correspondingly lower SB, was associated with less weight gain over time. Conversely, higher baseline weight was associated with unfavorable 10-y changes in activity profile, where SB increased and physical activity decreased. Importantly, all of these associations were observed with direct measurement of activity and weight, and were robust to concurrent adjustment for 10-y changes in the independent variable (either weight or activity), strengthening our conclusion of a bidirectional relationship.

Physical activity profile and weight change

Higher volume of activity (mean total activity) consistently attenuated 10-y weight gains and suggests that more activity is better for long-term weight control. To better inform behavioral targets, this study separated activity into mutually exclusive and clinically relevant categories based on intensity and bout duration.[8] When all activities were included in the same model, long-bout SB was selected as the reference category because it is the most appropriate target for replacement in interventions to increase overall activity profile. Interestingly, short-bout SB did not differ from long-bout SB in its association with 10-y weight change, suggesting an equal volume of SB with more frequent ‘breaks’ does not protect from 10-y weight gain. Also of interest were different associations of short vs. long-bout MVPA in that only long-bout MVPA attenuated 10-y weight gain. A final important note is that the magnitude of these associations was rather small. For example, by combining the std. β coefficients from the finally adjusted model, an individual with an activity profile that displaced long-bout SB with 1 SD of both long-bout MVPA (19 min per day) and LPA (85 min per day) would be expected to gain about 2.31 kg less over 10 years. Taken together, these data suggest an activity profile that has a higher overall volume by replacing any SB with LPA or long-bout MVPA results in a modest prevention of weight gain over time.

Our findings are consistent with the recent scientific report from the 2018 United States Physical Activity Guidelines Advisory Committee[8] that graded the evidence as ‘strong’ with 26 of 33 identified studies in support of an inverse relationship between physical activity and weight gain. Our findings also add strength to previously ‘limited’ evidence supporting a direct relationship between sedentary behavior and weight gain.[8] However, it is important to consider inconsistent findings including a 2011 systematic review of prospective studies concluding that accelerometer-determined physical activity was not an important predictor of weight gain in adults[34] and a 2018 meta-analysis of prospective studies concluding that sedentary behavior is not prospectively associated with body weight.[9] These discrepant reviews could reflect the small overall effect size and study-specific differences in design (e.g., small sample sizes, heterogeneity in age, insufficient follow-up, or different statistical approaches) or measurement (e.g., self-report of activity or weight outcomes, or differences in objective data reduction).

Weight and changes in physical activity profile

Higher weight at baseline was consistently associated with decreased mean total activity, increased SB, and greater declines in activity over the 10-y follow-up. These data suggest that increased weight, the very condition that might prompt an intervention to increase physical activity levels, could inhibit adoption and long-term maintenance of a favorable activity profile. This might mean that physical activity interventions may need to be more intense or of longer duration in populations with elevated BMI and may be more effective in the primary prevention of obesity. Also of note, and similar to the observed associations in the opposite direction, the associations between baseline weight and 10-y changes in activity were small. Fewer studies have investigated this direction of association. The most similar studies include 1) a cohort analyses of 231 adults at risk for diabetes in the ProActive trial that found higher baseline weight was associated with lower MVPA and higher SB by accelerometer 7 years later;[21] and 2) a cohort study in 1,710 Norwegian adults that found self-reported weight at baseline was associated with declines in MVPA but not SB by accelerometer over a 6-year follow-up.[6] Though nonsignficant, the Norwegian study reported an effect of baseline weight on SB (0.26 min per day per kg, 95% confidence interval: -0.04, 0.55) in the same direction as our observed association; the difference in statistical significance might be attributable to the different population which included a broader age range in the study sample (20–85 years vs. our 38–50 years) and the use of self-reported rather than directly measured weights. Other studies using various assessment methods also suggest that higher weight is associated with future declines in PA[19, 20, 22, 35] and increases in SB.[10, 22]

Race and sex interactions

Race and sex interactions were observed in both directions. Of note, these exploratory analyses should be interpreted with caution as the stratified analyses resulted in reduced sample sizes, particularly for black men (n=108). Associations of baseline mean total activity and activity categories with 10-y weight gain were apparent in whites and not blacks. Higher weight at baseline was associated with 10-y decreases in mean total activity and MVPA only in women and increased SB with decreased LPA only in white men. We are unaware of other studies testing for similar interactions, though evaluating race and sex differences in physical activity patterns and outcomes was one of the 2018 Physical Activity Guidelines Committee's overarching recommendations for future research.[8] Thus, additional studies along with further exploration of the origins of these race and sex differences are needed.

Strengths and weaknesses

Our study is strengthened by the ability to assess bidirectional relationships between mean total activity, SB, and activity categories with weight using device-based measurement of activity (accelerometer) and weight, each at two time points over a 10-y follow-up. Further, this study was conducted in a well-defined cohort of over 800 middle-aged adults as they progressed through middle age, a relevant period for weight gain, replacement of activity with SB, and the development of chronic diseases. [24, 36–38] Lastly, we were able to assess overall activity and separate activity into time-dependent behavioral targets that can be translated into interventions and recommendations. Limitations include an activity monitor that did not assess posture, resulting in measurement of 'stationary behavior' rather than SB defined as low intensity behavior in a *seated, reclining, or lying posture*,[39] and a limited sample that provided valid accelerometry data at both time points, especially limiting race/sex subgroups.

Conclusions and implications

High SB with low activity and weight appear to be bidirectionally related. More modest longitudinal effects like those seen herein should be used for power calculations in longitudinal studies, as larger cross-sectional associations likely reflect the bidirectional effects. Clinical implications include that a favorable activity profile (higher overall volume accomplished through lower SB, higher LPA and, specifically, higher long-bout MVPA) might be most effective in the primary prevention of obesity, prior to the accumulation of excess weight. Second, a higher intensity or longer duration of intervention might be necessary when prescribing activity as a treatment for obesity and concurrent introduction of weight loss through non-physical activity methods (i.e., dietary restriction) might result in the best outcomes. Lastly, potential race and sex-specific associations might facilitate a precision-medicine approach, such as defining at-risk subgroups and informing intervention design for the achievement of healthy activity profiles and weight. Though we and others have observed only modest (but consistent) bidirectional relationships over 6–10 year timeframes, a lifetime in the 'positive' feedback loop between poor activity profile and weight gain could be a driver in the obesity epidemic that might be best addressed as a two-pronged approach at primary prevention.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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COMPETING INTERESTS

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Table 1.

Participant Characteristics by Baseline Mean Total Activity (cpm) Tertile in CARDIA (n=886)

	Low Total Activity n=296 (102–297 cpm)	Moderate Total Activity n=295 (298–412 cpm)	High Total Activity n=295 (413–1036 cpm)	*p*-value
Age, years	45.2 (3.6)	45.2 (3.4)	45.1 (3.4)	0.926
Sex, n (%)				**<0.001**
Male	**93 (31%)**	**102 (35%)**	**139 (47%)**	
Female	**203 (69%)**	**193 (65%)**	**156 (53%)**	
Race, n (%)				**<0.001**
White	**154 (52%)**	**183 (62%)**	**210 (71%)**	
Black	**142 (48%)**	**112 (38%)**	**85 (29%)**	
Baseline BMI, kg/m^2	**28.9 (6.3)**	**28.5 (6.4)**	**26.8 (4.9)**	**<0.001**
Education				0.492
< High School Degree	22 (7%)	27 (9%)	20 (7%)	
High School Degree	92 (31%)	79 (27%)	83 (28%)	
Bachelor's Degree	120 (41%)	127 (43%)	114 (39%)	
Post Graduate Degree	62 (21%)	62 (21%)	78 (26%)	
Smoking, n (%)				0.667
Non-smoker	204 (69%)	203 (69%)	196 (66%)	
Current Smoker	48 (16%)	55 (19%)	58 (20%)	
Former Smoker	43 (15%)	35 (1%)	37 (13%)	
Energy Intake, kcal/day	**2 220 (1 178)**	**2 349 (1 214)**	**2 529 (1 282)**	**0.002**
Coronary Heart Disease, %	54 (18%)	44 (15%)	41 (14%)	0.315
Diabetes, %	**28 (9.5%)**	**17 (5.8%)**	**7 (2.3%)**	**0.001**

Data are presented as mean (SD) or n (%). Tertiles are compared using a test-for-trend for continuous variables or a chi-square test for categorical variables

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Table 2.

Associations of Baseline and 10-y Change in Activity Categories with 10-y Weight Change (kg) in Middle-aged Adults in CARDIA (n=886)

		Model 1 (baseline + covariates)		Model 2 (Model 1 + 10-y change)	
	SD	**std. β**	**p-value**	**std. β**	**p-value**
Total Activity					
Mean Total Activity (cpm)					
Baseline	140	**−0.96**	**0.001**	**−1.40**	**<0.001**
10-yr change	153	-		**−0.89**	**0.004**
Simple Activity Category*					
SB, min/day					
Baseline		Reference		Reference	
10-yr change					
LPA, min/day					
Baseline	111	−0.54	0.057	**−0.80**	**0.013**
10-yr change	96	-	-	−0.41	0.176
MVPA, min/day					
Baseline	24	**−0.74**	**0.011**	**−1.07**	**0.001**
10-yr change	24	-	-	**−0.75**	**0.012**
Bouted Activity Category*					
Long-bout SB, min/day					
Baseline		Reference		Reference	
10-yr change					
Short-bout SB, min/day					
Baseline	71	0.11	0.792	−0.11	0.819
10-yr change	73	-	-	−0.05	0.898
LPA, min/day					
Baseline	85	**−0.80**	**0.025**	**−1.11**	**0.005**
10-yr change	89	-	-	−0.55	0.103
Short-bout MVPA. min/day					
Baseline	13	0.05	0.871	0.05	0.906
10-yr change	13	-	-	−0.12	0.744
Long-bout MVPA, min/day					
Baseline	19	**−0.89**	**0.002**	**−1.20**	**<0.001**
10-yr change	20	-	-	**−0.74**	**0.012**

Adjustment covariates include baseline weight, height squared, center, age, sex, education, and baseline lifestyle habits (smoking, energy intake) and comorbidities, and baseline accelerometer wear time.

*Analyses were additionally adjusted for all other activity categories; std. β coefficients represent the expected associations when replacing long-bout SB per each SD increment of the independent variable.

Table 3.

Associations of Baseline and 10-y Change in Weight with 10-y Change in Activity Categories in Middle-aged Adults in CARDIA (n=886)

	SD	Mean Total Activity (cpm)	SB (min/day)	LPA (min/day)	MVPA (min/day)	Short-bout SB (min/day)	Long-bout SB (min/day)	Short-bout MVPA (min/day)	Long-bout MVPA (min/day)
		std. β p-value	**std. β p-value**	**std. β p-value**	**std. β p-value**	**std. β p-value**	**std. β p-value**	**std. β p-value**	**std. β p-value**
Model 1 (baseline + covariates)									
Baseline Weight, kg	18.8	**−13.7 0.009**	**11.4 0.001**	**−8.5 0.006**	**−3.3 0.002**	**5.2 0.022**	6.7 0.059	−0.7 0.094	**−2.0 0.006**
Model 2 (Model 1 + 10-y change)									
Baseline Weight, kg	18.8	**−14.9 0.004**	**12.0 <0.001**	**−8.9 0.002**	**−3.5 0.001**	**5.4 0.019**	**7.2 0.043**	−0.8 0.76	**−2.1 0.004**
10-y Weight Change, kg	8.0	**−13.0 0.004**	**7.4 0.012**	−5.3 0.053	**−2.4 0.009**	1.9 0.353	**6.3 0.043**	−0.6 0.113	**−1.5 0.019**

Adjustment covariates include baseline activity, height squared, center, age, sex, education, and baseline lifestyle habits (smoking, energy intake) and comorbidities, and baseline accelerometer wear time.

std. β coefficients represent the expected association per SD increment of the weight variable.