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Sedentary Time, Physical Activity, and Adiposity: Cross-sectional and Longitudinal Associations in CARDIA

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Abstract

Introduction—Higher sedentary time (ST) and lower moderate to vigorous intensity physical activity (MVPA) have each been associated with greater adiposity, but most studies are cross-sectional and measure ST and MVPA by self-report. This study evaluated associations between objective ST and MVPA with current and 5-year changes in BMI and waist circumference.

Methods—The Coronary Artery and Risk Development in Young Adults longitudinal cohort study recruited black or white young adults from four U.S. cities. This analysis (conducted in 2016) used data from 2005 to 2006 as baseline and 2010 to 2011 as 5-year follow-up. Accelerometers measured baseline ST (total and prolonged in bouts of ≥10 minutes) and MVPA (bouts of ≥10 minutes). BMI and waist circumference were assessed at baseline and repeated 5 years later. Regression models included sedentary time and MVPA simultaneously with adjustment for demographics and lifestyle factors.

Results—Participants (n=1,826) were 57% female, 40% black, aged 38–50 years, and had BMI of 28.7 (SD=6.3) kg/m^2. At baseline, total and prolonged ST were directly associated with BMI and waist circumference, whereas MVPA was inversely related (all p<0.05). Longitudinally, only prolonged ST (per hour/day) was associated with greater increases in BMI (0.077 kg/m^2, p=0.033) and waist circumference (0.198 cm, p=0.028). Associations between ST and adiposity were more

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apparent in less active participants. Risk of ≥5% increase in BMI across assessments increased by 8%–10% (p<0.05) per hour/day of ST.

Conclusions—Time spent sedentary was associated with increases in adiposity over time. Reducing sedentary time may be a novel strategy for weight control.

INTRODUCTION

Obesity affects one third of the U.S. adult population,[1] increases the risk of diabetes, cardiovascular disease, and some cancers,[2] and decreases life expectancy.[3] Central adiposity, often measured by waist circumference (WC), may be more strongly associated with premature mortality as compared with overall adiposity (i.e., BMI).[4] Though treatment for obesity can be successful in the short-term, effective strategies for long-term weight loss maintenance remain elusive.[5] Thus, identifying strategies to prevent weight gain and obesity are a major public health priority.

Consistent engagement in moderate to vigorous intensity physical activity (MVPA) has been associated with attenuated weight and WC gains over time.[6,7] Sedentary behavior has been established as a behavior distinct from inactivity or a lack of MVPA.[8] Yet, whether sedentary behavior is a risk factor for weight or WC gains is less clear.

If sedentary behavior replaces tasks with slightly higher metabolic costs (i.e., light intensity activities)[9] throughout the day, this could lead to less daily energy expenditure, a state of positive energy balance, and weight gain. However, some studies suggest a reverse direction of association where obesity leads to increased sedentary behavior over time.[10,11] Though greater sedentary behavior has been associated with higher BMI and WC,[12–17] most studies are cross-sectional and therefore cannot establish a temporal relationship. Another limitation is that most studies measure sedentary time (ST) by self-report, which can be poorly correlated to objectively measured ST[9,17,18] and cannot evaluate patterns of sedentary behavior (such as prolonged bouts) which may be more closely related to adverse outcomes.[16,19] Recent research also suggests that the risks of sedentary behavior may be attenuated among individuals who are more active,[20,21] though whether relationships between sedentary behavior and adiposity differ in active versus inactive individuals remains unclear. Thus, longitudinal studies using objectively measured ST (from which prolonged ST can be extracted) and evaluating effects within higher and lower MVPA strata are needed to evaluate whether higher amounts of sedentary behavior are related to greater adiposity over time.

This study investigated whether accelerometer-measured ST and MVPA are associated with cross-sectional and 5-year changes in BMI and WC in a large, biracial cohort of middle-aged adults. Further, associations of ST with adiposity outcomes within strata of higher and lower MVPA, race and gender interactions, and associations with clinically meaningful 5-year adiposity gains are evaluated.

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METHODS

Study Population

The Coronary Artery Risk Development in Young Adults (CARDIA) cohort study enrolled 5,115 black and white young men and women in four U.S. cities in 1985–1986 to longitudinally study determinants of cardiovascular disease.[22] The current study uses data collected in 2005–2006 as baseline and 2010–2011 as 5-year follow-up. Each of these follow-up examinations included 72% of the surviving cohort. Of n=2,047 with valid accelerometry data, participants with missing anthropometric data (n=172), history of bariatric surgery (n=38), or pregnancy/breastfeeding at exams (n=11) were excluded, resulting in n=1,826. IRBs at each field center and the coordinating center approved the study annually.

Measures

Activity was measured by an ActiGraph uniaxial accelerometer (model 7164) at baseline only. Participants were asked to wear the accelerometer during all waking hours (except water activities) for 7 days. Movement was captured in 1-minute epochs. 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.[23] Accelerometry data were considered valid with ≥4 days of monitoring with ≥10 hours/day and <20,000 average cpm. Importantly, ST was measured as the total duration of time spent in limited movement (0–99 cpm); posture and the definition of ST that includes posture were not measured.[8] Freedson cutpoints classified total duration of MVPA (≥1,952 cpm).[24]

Daily ST was calculated as hours accumulated in 1-minute (total) and ≥10-minute (prolonged) bouts. The threshold for prolonged ST reflects research reporting that the direct relationship between ST and adiposity begins at a minimum bout length of 10 minutes.[16] Weekly MVPA was calculated by averaging minutes/day of MVPA accumulated in bouts of ≥10 minutes, with allowance for 2 minutes with <1,952 cpm, over valid days and multiplying by 7 days/week.[24] Weekly vigorous physical activity was similarly calculated with the cutpoint ≥5,725 cpm. Based on guidelines,[25] participants were classified as sufficiently active (“sufficient”) if they achieved ≥150 minutes/week of bouted MVPA or ≥75 minutes/week of bouted vigorous physical activity. Otherwise, they were classified as “insufficient.”

Height and weight were measured in light clothing without shoes. WC was averaged over duplicate measurements by trained research personnel at the narrowest point of the torso. Clinically meaningful BMI or WC gains were defined as 5-year increases of ≥5%.[26] Demographic characteristics, smoking, and alcohol were measured at baseline by standardized questionnaires. Energy intake was estimated from the CARDIA diet history at baseline.[27]

Statistical Analysis

Baseline characteristics were related to overall ST in linear regression models and compared across MVPA categories. Spearman’s correlations assessed relationships between measures

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of ST and MVPA. Linear regression models estimated cross-sectional associations with BMI and WC. Because 5-year changes in adiposity were of interest, longitudinal models used 5-year change in adiposity as the dependent variable with adjustment for baseline value. Model fit was assessed by visual plots evaluating linear relationships and examining residuals. Logistic regression estimated the odds of clinically meaningful increases (≥5%) in BMI or WC.[28] All models included simultaneous adjustment for ST (total or prolonged) and MVPA, gender, race, center, alcohol, education, smoking, dietary energy intake, height (WC only), and accelerometer wear time. Analyses were repeated after stratification by MVPA category, and, reflecting the design of CARDIA, by gender and race. Data analyses were conducted using Stata, version 14 in 2016.

RESULTS

Age, race, gender, education, alcohol, and smoking were all significantly associated with total ST. Participants classified as sufficiently active were more likely to be white and had higher education and alcohol intake (Table 1). Mean total ST was 8.2 (SD=1.7) hours/day and prolonged ST was 4.5 (SD=1.7) hours/day. Median (25th, 75th percentile) MVPA was 43 (0, 130) minutes/week. MVPA was not related to total ($r_{spearman}$ = −0.03, p=0.160) or prolonged ST ($r_{spearman}$ =0.01, p=0.60). Total and prolonged ST were highly correlated ($r_{spearman}$ =0.92, p<0.001).

At baseline, mean BMI was 28.6 (SD=6.3) kg/m^2 and WC was 90.4 (SD=14.5) cm. Cross-sectionally (Table 2), both total and prolonged ST were associated with a higher BMI. Similar patterns were observed for WC. Higher MVPA was related to lower adiposity.

Over the 5-year follow-up, mean BMI increased by 1.8% (0.53 [SD=2.37] kg/m^2) and WC by 2.6% (2.38 [SD=5.85] cm). Higher total ST at baseline was not associated with 5-year BMI gain. However, each hour of prolonged ST at baseline was associated with an additional BMI gain of 0.077 kg/m^2 (p=0.033). Associations between 5-year changes in WC and baseline total ST were not significant, but each additional hour of baseline prolonged ST was associated with an additional 0.198 cm (p=0.028) gain in WC. Baseline MVPA was not significantly related to 5-year changes in adiposity.

Participants with sufficient (n=417, 23%) versus insufficient (n=1,409, 77%) MVPA had lower mean total ST (8.01 [SD=1.7] vs 8.23 [SD=1.7] hours per day, p=0.018) but not prolonged ST (4.41 [SD=1.65] vs 4.49 [SD=1.72] hours per day, p=0.414). Participants with sufficient and insufficient MVPA had mean baseline BMI of 26.5 (SD=4.9) kg/m^2 and 29.3 (SD=4.9) kg/m^2 (p<0.001), respectively and baseline WC of 85.7 (SD=13.1) cm and 91.8 (SD=14.6) cm (p<0.001), respectively. Cross-sectional associations between ST and adiposity were more pronounced and only retained statistical significance among participants with insufficient activity (Table 3). Participants with sufficient versus insufficient baseline MVPA had similar mean 5-year changes in BMI (0.34 [SD=1.96] kg/m^2 vs 0.58 [SD=2.47] kg/m^2, p=0.074) and WC (2.10 [SD=5.00] cm vs 2.46 [SD=6.08] cm, p=0.278). In longitudinal models evaluating associations between baseline ST and 5-year changes in adiposity, only prolonged ST in participants with insufficient MVPA was related to change in BMI (0.087 kg/m^2 per hour/day, p=0.042).

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Results stratified by race and gender are presented in Appendix Tables 1 and 2. In general, ST was more often associated with adiposity in men than women. ST was cross-sectionally associated with adiposity only in whites, whereas longitudinal associations were only observed in blacks. Associations between MVPA and adiposity were similar by race and gender.

Thirty percent (n=548) and 34% (n=662) of participants had clinically meaningful (≥5%) weight and WC gains over the 5-year follow-up, respectively. These proportions were similar in participants with sufficient and insufficient baseline MVPA (weight gain: 31% vs 27%, p=0.175; WC gain: 35% vs 31%, p=0.160). The adjusted odds of clinically meaningful BMI (weight) gain over 5 years were elevated with each additional hour/day of baseline total ST (OR=1.09, 95% CI=1.02, 1.16) and prolonged ST (1.10, 95% CI=1.03, 1.17). Though the OR estimates were almost identical in participants with sufficient or insufficient MVPA, wide CIs among the sufficiently active resulted in significantly increased odds occurring only in the insufficient MVPA group (Figure 1 and Appendix Table 3). Total ST was not associated with increased odds of WC gain. Interestingly, prolonged ST was associated with higher odds of clinically meaningful WC gain among participants with sufficient (OR=1.16, 95% CI=1.01, 1.34), but not insufficient MVPA (OR=1.02, 95% CI=0.96, 1.10). Baseline MVPA was not associated with clinically meaningful adiposity gains.

DISCUSSION

The primary findings of this study were that having greater objectively measured ST at baseline, particularly greater prolonged ST accumulated in bouts of >10 minutes, was related to higher current BMI and WC, but also greater 5-year increases in these adiposity measures. MVPA at baseline was associated with lower adiposity in cross-sectional analyses but not 5-year changes. Associations with BMI, WC, and 5-year BMI change were present only in participants that did not meet recommendations for MVPA (insufficiently active). The risk of clinically meaningful 5-year changes in BMI, reflecting a failure to maintain weight, was elevated with increased total and prolonged ST and risk estimates were similar after stratification into sufficient and insufficient MVPA groups. Risk of clinically meaningful gains in WC was not related to ST, except for an increased risk observed with prolonged ST among sufficiently active participants.

Because American adults spend an average 97% of waking hours engaging in sedentary or light intensity activities,[29] and sedentary behavior has slightly lower energy costs than light intensity activities,[30] it is plausible that excessive sedentary behavior might disrupt energy balance and contribute to obesity and weight gain. Some,[13–16,19] but not all,[16,17,31] studies with objective measurement of ST have found direct associations with overall or central adiposity. This current study's cross-sectional findings are similar to results from the National Health and Nutrition Examination Survey (NHANES; 2003–2006) where objectively measured ST across (as ST quartiles,[14] continuous ST, or prolonged ST bouts[16]) was related to greater central adiposity. The NHANES analysis also found that prolonged ST was associated with BMI (β=0.002, p=0.024) whereas total ST was not (BMI: β=0.001, p=0.521).[16] Further, shorter-bout ST (1–9 minutes) was inversely related to BMI. The

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current study found that both prolonged and total ST were cross-sectionally related to BMI; the different results may be due in part to age-related differences between study populations.

To the authors' knowledge, the current study is the largest to date examining longitudinal associations between objectively measured ST and adiposity over time, and the only to evaluate prolonged sedentary behavior. In the few studies that measured sitting time by self-report, most have found that higher sitting time did not predict changes in weight[10,32–34] and some have found a reverse direction of effect whereby greater adiposity at baseline was associated with increased ST at follow-up.[10,34] The authors are aware of only two studies with longitudinal assessment of both objectively measured total ST and adiposity. Among 393 healthy adults in the Medical Research Council Ely Study, ST (by heart rate monitor) was not associated with weight gain; however, baseline BMI was associated with increased ST over the 5.6-year follow-up.[11] In the ProActive Study, 6-year changes in accelerometer-measured ST and WC were not associated among 171 adults with metabolic risk factors.[35] The current study similarly found that total ST was not associated with 5-year changes in BMI and WC, but uniquely identified that prolonged ST was associated with 5-year increases in BMI and WC. These findings underscore the need to extract prolonged ST from objective monitors when evaluating the health risks associated with sedentary behavior. These findings also inform interventions that seek to reduce sedentary behavior.

The results of the current study stratified by MVPA level are also comparable to other research. In NHANES, more ST was associated with an increased risk of mortality in low active but not high active individuals.[20] A recent meta-analysis found that associations between ST and cardiometabolic outcomes or mortality were of greater magnitude in the lowest versus highest MVPA groups.[21] The current study found that cross-sectional relationships between sedentary behavior and adiposity were indeed only apparent among insufficiently active participants. For 5-year changes, only associations with prolonged sedentary behavior among participants with insufficient activity remained after stratification. Thus, sedentary behavior may be a risk factor for weight gain, particularly among less active individuals.

Though most associations between ST and adiposity were in the same direction across race or gender strata, statistically significant associations were more often observed in men, in whites cross-sectionally, and in blacks longitudinally. The reasons for these race and gender differences are not clear and an area for further research.

This analysis also considered a dichotomous outcome of whether individuals had clinically meaningful gains in adiposity over the 5-year follow-up defined as an increase of ≥5%.[28] This outcome gives consideration to any clinically meaningful adiposity gain as a negative health outcome, rather than allowing large adiposity gains to potentially have more influence on estimated associations in a continuous variable analysis. Approximately a third of the participants had such gains as they progressed through middle age. Each additional hour/day of total or prolonged ST was associated with an 8%–10% increased risk of clinically meaningful weight gain and this estimate was similar among participants with sufficient and insufficient MVPA (though the risk estimate was not significant in the sufficiently active participants, likely a result of the small sample size). Thus, lowering ST may be a strategy

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for maintaining weight. Only prolonged ST in sufficiently active participants was associated with a 16% increase in the odds of clinically meaningful WC gains. Though the reasons for this stronger effect in the presence of sufficient MVPA are not clear, one explanation could be the lower WC at baseline in the sufficiently active group. Overall, lower ST appears to be helpful for maintaining weight and WC, regardless of activity level.

Though higher baseline MVPA was related to lower adiposity cross-sectionally, the lack of longitudinal associations differs from existing studies showing that MVPA protects against weight gain.[7,36,37] Over the first 20-years of the CARDIA Study (prior to these analyses), participants with consistently high versus low self-reported MVPA gained less weight and WC.[7] In another study of 421 young adults over 1 year, those in the lowest objectively measured MVPA quintile at baseline gained the most fat mass and were 3.8 times more likely to increase their weight by ≥3% as compared with those in the middle MVPA quintile.[37] Baseline MVPA may not have associated with 5-year changes in adiposity in the current study for two reasons. First, though controversial, the National Academy of Medicine[38] (formerly known as the Institute of Medicine) recommends that as much as 420 minutes/week of MVPA may be necessary to maintain a healthy weight. Only 2.1% (n=39) of participants achieved >420 minutes/week of MVPA. It is possible that the scarcity of participants achieving these levels of MVPA may have limited the ability to detect an association. Another possibility is that the single assessment of MVPA, with no additional measures to account for changes in behavior over follow-up, may have resulted in misclassification and attenuation of relationships between MVPA and changes in adiposity.

The public health and clinical significance of these findings are that time spent in sedentary behavior, particularly when accumulated in prolonged bouts, might be a new behavioral target to decrease weight gain and obesity during midlife. Though significant associations were more consistently observed among inactive individuals, there was also a suggestion that active individuals could benefit from lower ST. Though the U.S. does not currently have sedentary behavior guidelines,[25] generally reducing sedentary behavior is part of the Australian physical activity guidelines. An expert statement commissioned by Public Health England and the Active Working Community Interest Company recently concluded that desk-based employees should accumulate 2–4 hours of standing or other light activity in each 8-hour workday. [39] The current study informs potential sedentary behavior guidelines, though evidence of a health benefit from natural experiments (e.g., demonstrated health improvements with large-scale sit-stand desk implementation) and randomized trials that experimentally decrease sedentary time long-term will provide further support for such recommendations.

Limitations

This study is strengthened by the large sample size, objective measurements, longitudinal follow-up of obesity outcomes, and inclusion of other relevant confounders (e.g., energy intake, smoking) in CARDIA. One limitation was the inability to study some temporal relationships because of the single assessment of objective activity at baseline. Another limitation is that the objective monitor used measures time spent in limited movement (0–99 cpm), which some may refer to as “stationary time,”[40] rather than time spent in low intensity

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and a seated or reclining posture, the more commonly accepted definition of sedentary behavior.[9] Though free-living ST measured by accelerometer have been shown to be highly correlated (e.g., R^2=70%[28]) with ST measured by devices also capable for measuring posture, interpretation of the results should acknowledge ST as “limited movement” rather than “sitting at low intensity” in this study.

CONCLUSIONS

Greater time spent in objectively measured ST and lower levels of MVPA were associated with higher levels of adiposity, but only ST was associated with greater increases in BMI and WC and elevated the risk of clinically meaningful adiposity gains over 5 years. These results suggest that lowering ST, or time spent with limited movement, may be protective against obesity and a novel strategy for weight control.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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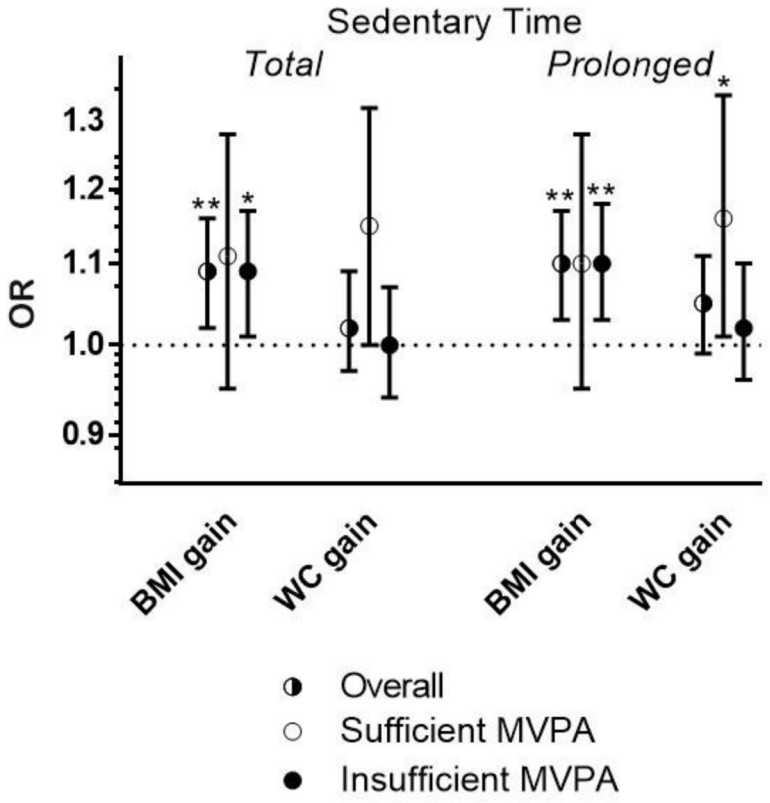

Figure 1.

Adjusted odds of clinically meaningful (≥5%) 5-year gains in BMI and waist circumference (WC) with each 1-hour increase in total or prolonged sedentary time.

Notes: Data are presented overall (split circle, n=1,826) and stratified into participants with sufficient (white circle, n=417) and insufficient (solid black circle, n=1,409) moderate-to-vigorous physical activity. ORs are adjusted for moderate-to-vigorous physical activity, age, gender, race, center, education, alcohol, smoking, energy intake, height (waist only), and baseline value. *p<0.05; **p<0.01

MVPA, moderate-to-vigorous intensity physical activity

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Table 1

Baseline Participant Characteristics Overall and by Physical Activity Group in the CARDIA Study

Characteristic	Overall (n=1,826)	R^{2a} (*p*-value)	Sufficient MVPA[b] (n=417)	Insufficient MVPA[b] (n=1,409)	*p*-value[c]
Age, years	**45.4 (3.5)**	**0.5% (0.002)**	45.5 (3.4)	45.3 (3.6)	0.242
Race		**0.9% (<0.001)**			**<0.001**
White	**1,102 (60%)**		**309 (74%)**	**793 (56%)**	
Black	**724 (40%)**		**108 (26%)**	**616 (44%)**	
Gender		**0.6% (0.001)**			0.330
Male	**781 (43%)**		187 (45%)	594 (42%)	
Female	**1,045 (57%)**		230 (55%)	815 (57%)	
Education		**4.2% (<0.001)**			**<0.001**
<12 years	**54 (3%)**		**10 (2%)**	**44 (3%)**	
High school	**794 (43%)**		**133 (32%)**	**661 (47%)**	
College	**515 (28%)**		**120 (29%)**	**395 (28%)**	
Masters, PhD, etc.	**463 (25%)**		**154 (37%)**	**309 (22%)**	
Alcohol, mL/d	**2.4 [0, 13.6]**	**0.2% (0.029)**	**7.2 [0, 19.1]**	**2.4 [0, 13.6]**	**<0.001**
Smoking[d]		**1.6% (<0.001)**			0.108
Never	**1,148 (63%)**		274 (66%)	874 (62%)	
Former	**383 (21%)**		88 (21%)	295 (21%)	
Current	**281 (15%)**		50 (12%)	231 (16%)	
Energy intake, kcals/d[d]	2,146 [1,638, 2,782]	0.2% (0.111)	2,144 [1,663,	2,147 [1,663, 2,776]	0.936

Notes: Data presented as mean ± SD, median [25th percentile, 75th percentile] or n (%). Boldface indicates statistical significance ($p<0.05$).

[a] From unadjusted linear regression models predicting total sedentary time.

[b] Sufficient MVPA defined as ≥150 minutes/week of MVPA or ≥75 minutes/week of VPA.

[c] *p*-value compares values in the sufficient and insufficiently active groups.

[d] Missing data for smoking (0.8%) and dietary intake (10%).

MVPA, moderate-to-vigorous intensity physical activity

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Table 2

Cross-sectional and Longitudinal Associations of Prolonged and Total Sedentary Time, and MVPA With Adiposity

Variable	Sedentary time (per hour/day)		MVPA (per 30 minutes/week)	
	β	*p*-value	β	*p*-value
Cross-sectional				
BMI, kg/m^2				
Total	**0.20**	**0.047**	**−0.15**	**<0.001**
Prolonged	**0.23**	**0.013**	**−0.18**	**<0.001**
WC, cm				
Total	**0.67**	**0.003**	**−0.46**	**<0.001**
Prolonged	**0.73**	**<0.001**	**−0.47**	**<0.001**
5-year change				
BMI, kg/m^2				
Total	0.065	0.108	0.004	0.750
Prolonged	**0.077**	**0.033**	0.003	0.811
WC, cm				
Total	0.151	0.130	0.006	0.851
Prolonged	**0.198**	**0.028**	0.004	0.898

Notes: Boldface indicates statistical significance ($p<0.05$). All β coefficients adjusted for sedentary time (separate models include either total or prolonged), MVPA, age, race, gender, center, education, alcohol, smoking, energy intake, height (waist only), wear time, and baseline value (5-year change models only).

MVPA, moderate-to-vigorous intensity physical activity; WC, waist circumference.

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Table 3

Associations of Prolonged and Total Sedentary Time With Adiposity by Sufficient and Insufficient MVPA Category

Variable	Sufficient MVPA (n=417)		Insufficient MVPA (n=1,409)	
	β	*p*-value	β	*p*-value
Cross-sectional				
BMI, kg/m^2				
Total	−0.05	0.777	**0.25**	**0.042**
Prolonged	0.03	0.822	**0.25**	**0.019**
WC, cm				
Total	−0.22	0.577	**0.86**	**0.001**
Prolonged	0.12	0.736	**0.84**	**<0.001**
5-year change				
BMI, kg/m^2				
Total	0.032	0.666	0.074	0.116
Prolonged	0.039	0.553	**0.087**	**0.042**
WC, cm				
Total	0.338	0.081	0.104	0.372
Prolonged	0.260	0.134	0.180	0.086

Notes: Boldface indicates statistical significance ($p<0.05$). Total and prolonged sedentary time were included in separate models. All β coefficients adjusted for MVPA, age, race, gender, center, education, alcohol, smoking, energy intake, height (waist only), wear time, and baseline value (5-year change models only).

[a]Sufficient activity defined as ≥150 minutes/week of MVPA or ≥75 minutes/week of VPA

MVPA, moderate-to-vigorous intensity physical activity; WC, waist circumference.