Annals of Behavioral Medicine, 2025, **59**, kaae074
https://doi.org/10.1093/abm/kaae074
Advance access publication 13 December 2024
Regular Article

Associations of nonoccupational sedentary behaviors with cardiometabolic outcomes: coronary artery risk development in young adults (CARDIA)

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Abstract

Background: The association between sedentary behavior (SB) and cardiometabolic risk may differ by SB domain and context. Nonoccupational SB is particularly important because it is discretionary and more amenable to change. This study estimated associations of nonoccupational SB contexts with hypertension (HTN) and diabetes mellitus (DM).

Methods: A total of 3370 middle-aged adults (50.1 ± 3.6 years; 56% F) from the Coronary Artery Risk Development in Young Adults (CARDIA) study were included. Cross-sectional and 5-year prospective associations between self-report total SB and 6 context-specific SBs (television—TV, computer, transportation, phone, music, and paperwork) with HTN and DM were tested using logistic regression. Fully adjusted models controlled for sociodemographic variables, body mass index, and self-report moderate-vigorous intensity physical activity.

Results: Prevalences of HTN and DM at baseline were 48% (1618 cases) and 10% (320 cases), respectively. Each hour per day of total-SB was cross-sectionally associated with HTN (OR: 1.03, 95% CI, 1.01-1.05) but not DM, with nonsignificant prospective associations for HTN and DM. Of the context-specific SBs, only TV-SB was significantly associated with HTN or DM. Each hour of TV-SB was cross-sectionally associated with HTN (OR: 1.09, 95% CI, 1.03-1.15) and DM (OR: 1.18, 95% CI, 1.09-1.29), and prospectively with HTN (OR: 1.14, 95% CI, 1.04-1.26) but not DM.

Conclusion: When comparing total-SB and the 6 context-specific SBs, TV-SB was most robustly associated with HTN. The findings were less clear for DM. Behavior change strategies that target TV-SB reduction may be effective at reducing HTN risk in middle-aged adults.

Lay Summary

The link between sedentary behavior (SB) and health risks may differ by the type (context) of SB. Nonwork-related SB is important because it is discretionary and can more easily be changed. This study looked at associations of nonwork-related SB contexts with high blood pressure (BP) and diabetes in 3370 middle-aged adults from the Coronary Artery Risk Development in Young Adults (CARDIA) study. Cross-sectional and 5-year prospective associations between total SB and 6 context-specific SBs (television—TV, computer, transportation, phone, music, and paperwork) with high BP and diabetes were tested. Our analyses controlled for sociodemographic variables, body mass index, and physical activity.

At baseline, 48% of participants had high BP and 10% had diabetes. At baseline, each hour per day of total-SB was associated with high BP. Additionally, each hour of TV-SB was associated with high BP and diabetes. TV-SB also predicted high BP 5 years later. When comparing total-SB and the 6 context-specific SBs, TV-SB was most strongly associated with high BP. The findings were less clear for diabetes. Behavior change strategies that target TV-SB reduction may be effective at reducing high BP risk in middle-aged adults.

Key words: sedentary behavior; hypertension; diabetes; cardiometabolic risk; observational cohort.

Introduction

The average United States (US) adult engages in more than 9 hours per day of sedentary behavior (SB).[1] SB is biologically distinct from physical inactivity, which is not meeting physical activity guidelines (150 minutes/week of moderate-intensity activity).[2] While SB and physical activity do share some co-dependency, given they are both constrained to the 24-hour movement behavior framework,[3,4] SB is an independent risk factor for cardiometabolic diseases, including hypertension (HTN) and diabetes mellitus (DM).[5,6] Behavioral interventions to reduce SB may be an effective strategy for mitigating cardiometabolic disease risk.[7,8] SB modification is potentially more achievable compared with traditional lifestyle intervention targets, such as meeting physical activity guidelines.[7,8] From a socio-ecological model perspective,[9,10] there are limited intrapersonal (eg, self-efficacy, confidence), interpersonal (eg, peer support), and environmental (access to a fitness facility) barriers to SB modification.[11]

US adults spend approximately half of their total SB time engaged in nonoccupational SB.[1] The available evidence, which includes studies conducted by members of the current authorship team,[12,13] suggests that compared with occupational SB, nonoccupational SB is perhaps more strongly associated with cardiometabolic disease risk.[12–14] This may be due to a number of factors including: (1) greater total time spent in leisure versus occupational SB,[15] (2) more prolonged SB bouts in leisure versus occupational settings,[15] (3) greater opportunities for co-occurring poor dietary behaviors during leisure compared with occupational SB,[16] and (4) occupational SB may be more associated with "white-collar" occupations associated with greater salary and workplace autonomy, and access to plentiful health resources.[17–19] From a public health perspective, reducing nonoccupational SB (rather than occupational SB) may be a more attractive target for improving cardiometabolic outcomes. When considering the physical and social determinants of behavior change, as outlined within the socio-ecological model for behavior change,[9,10] there are greater opportunities for changing this discretionary behavior. This could include substituting nonoccupational SB with light intensity physical activity (eg, walking or gardening), thereby improving an individual's daily activity profile as contextualized within the 24-hour movement behavior framework.[3,4]

Few rigorous studies have examined the nonoccupational SB domain in relation to cardiometabolic disease risk. Prior studies have reported negative associations between nonoccupational SB and both overt HTN[20,21] and DM,[20,22–24] only one of which was prospective.[21] While the nascent existing literature provides a useful foundation, gaps in knowledge remain which hamper the ability to develop effective nonoccupational SB reduction strategies. First, the reliance on cross-sectional data limits insight regarding temporality and thus causality. Second, prior studies have mainly focused on total nonoccupational SB exposure[12,20] or specific aspects of nonoccupational SB (eg, leisure screen time).[21,22,24,25]

Nonoccupational SB is a multidimensional behavior. Considering these dimensions is important for the identification of optimal nonoccupational SB intervention targets and beginning to disentangle the effects of co-occurring lifestyle factors. SB interventions will be more likely to be cost-effective and clinically impactful if resources are focused toward context-specific behavioral targets that have well-evidenced links to cardiometabolic risk.[26] Nonoccupational SB can be accumulated across various contexts (settings), such as while watching television (TV-SB), using the computer, or driving to work. Compared with self-reporting of general SB across a day, self-reporting about distinct SB contexts makes it easier for people to recall.[27] More accurate SB recall in turn yields more accurate estimates of associations between SB and cardiometabolic disease risk, in addition to providing more useful information about intervention targets.

The sole prior prospective study[21] investigated associations between 3 context-specific nonoccupational SBs (TV-SB, computer, driving) with incident HTN across a 12.5-year follow-up. The authors found that only TV-SB was prospectively associated with HTN, reporting that compared with those who watched ≤1 hour of TV per day, individuals who watched >3 hours of TV-SB per day had a 24% higher risk of developing HTN.[21] The association between TV time and HTN is consistent with cross-sectional findings.[28,29] These findings suggest that TV-SB time may be a particularly important target for SB reduction. That said, the prior prospective study[21] investigated a narrow range of nonoccupational SB contexts and only focused on HTN as an outcome. To address this knowledge gap, the objective of the current observational cohort study was to estimate the cross-sectional and 5-year prospective associations of total and 6 context-specific nonoccupational SBs (TV-SB, computer, transportation, phone, music, and paperwork) with HTN and DM.

Methods

This observational study is reported in accordance with STROBE (Strengthening the Reporting of Observational studies in Epidemiology) guidelines.[30] Participants provided informed consent, and the study was approved by Institutional Review Boards at all study centers.

Study population

Data are from the Coronary Artery Risk Development in Young Adults (CARDIA) study. A total of 5115 Black and White men and women (ages 18-30) were enrolled in 1985-1986 at 1 of 4 clinical centers (Birmingham, AL, Chicago, IL, Minneapolis, MN, or Oakland, CA). An in-person clinical exam occurred at the original baseline (year 0) and follow-up exams were held every 2-5 years. This analysis used data from year 25 (2010-2011; henceforth termed "baseline") and year 30 (2015-2016). Year 25 was used as our baseline since it was the first time point in which a comprehensive SB questionnaire including SB contexts was included by CARDIA. For the second time point, we used the most recent CARDIA follow-up assessment (year 30) at the time of project proposal and data request. A participant was eligible if full exposure and outcome data were available at baseline and year 30. Individuals were eligible for the prospective analyses if they were free of HTN or DM at baseline. Additional eligibility, selection, and follow-up procedures have been previously reported[31,32] and are described in the Supplementary Material.

Exposure: nonoccupational total and context-specific SBs

SB was assessed using the shortened version of the Sedentary Behavior Questionnaire (SBQ) for Adults.[33] The SBQ has been reported to significantly agree (r range: 0.28-0.31, all P <.005) with the SB measure from the widely used International Physical Activity Questionnaire[34,35] and

has moderate-to-high reliability (Intraclass correlation coefficient range: 0.64-0.86, all P <.05).[33] The questionnaire explicitly asks individuals to report how much time they "spend sitting" while engaging in 6 types of context-specific nonoccupational SBs (henceforth termed "context-specific SBs": (1) TV-SB; (2) using the computer for nonwork activities or playing video games, (3) doing noncomputer office work or paperwork; (4) listening to music, reading, or doing arts and crafts; (5) talking on the telephone or texting; and (6) sitting in a car, bus, train, or other mode of transportation. Participants were asked to report sitting time spent engaging in these SB contexts separately for weekdays and weekend days. Response options included: none, 15 minutes or less, 30 minutes, 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, or 6 hours or more. Endorsement of the "15 minutes or less" category was scored as 0.25 hours (15 minutes), and endorsement of the "6 hours or more" category was scored as 6 hours. The number of hours engaged in SB per day was computed for each of the 6 context-specific SBs by multiplying the hours spent on each task on a weekday by 5 and the hours spent on each task on a weekend day by 2. Values were summed and then divided by 7 to derive the average hours spent performing each of the 6 context-specific SBs per day. An estimate of total nonoccupational minutes of SB per day (henceforth termed "total-SB") was calculated by adding the daily averages across the 6 different sedentary activities. Relative contributions of each context-specific SB to total SB are reported in Figure 1. Descriptive statistics for context-specific SBs are reported in Supplementary Table S1.

Outcomes

Participants were asked to fast for ≥12 hours and to abstain from smoking and engaging in exercise for ≥2 hours before clinic visits.

Hypertension

HTN was determined based on clinical measurements and medication information. For the clinical readings, blood pressure (BP) was measured following 5 minutes of seated rest, in triplicate with 1-minute rest intervals using an oscillometric BP monitor (HEM-907XL, Omron, Kyoto, Japan). The average of second and third readings was used for analyses. HTN was defined by meeting either of 2 criteria (1) BP ≥ 130/80 mmHg (American Heart Association—AHA Criteria)[36] or (2) use of BP medication. Trained staff administered the medications inventory and BP measurement following a standardized protocol.

Diabetes mellitus

DM was determined based on laboratory measurements and medication use. For the laboratory measurements, fasting serum glucose from venous blood samples was measured using hexokinase coupled to glucose-6-phosphate dehydrogenase. DM was defined by meeting either of 2 criteria (1) fasting blood glucose ≥ 126 mg/dL or (2) use of DM medication. Trained staff administered the inventory of the medications, and certified phlebotomists completed the blood draw for blood glucose following a standardized protocol.

Covariates

Sociodemographics and clinical enrollment field center

Sociodemographic covariates included age, biological sex, race (Black/White), and income due to known associations between these factors and cardiometabolic risk.[37–40] We also included the clinical enrollment field center as a covariate to help control for geographical differences that may influence cardiometabolic health[41] and health behaviors (eg, physical activity levels).[42]

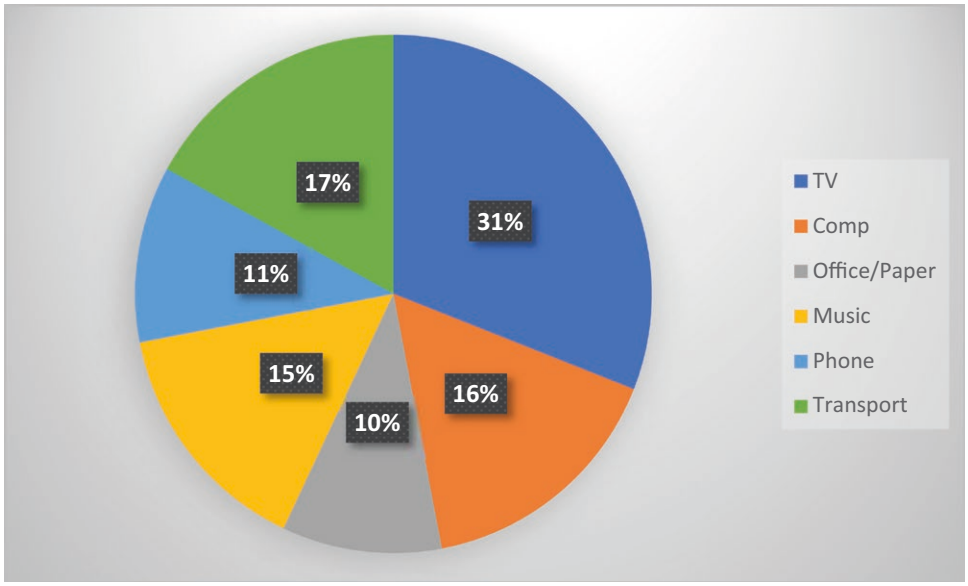

Figure 1. Relative contributions of context-specific sedentary behaviors to total sedentary behavior. The individual slices of the pie chart represent the relative daily time (duration) contributions of each of the 6 context-specific sedentary behaviors. Altogether, the context-specific sedentary behaviors cumulatively reflect the total amount of daily SB which we term "total SB" in the current study. (n = 3370). Abbreviations: Comp, Computer; Office/paper, non-work-related office or paperwork; SB, sedentary behavior; TV, Television.

Anthropometry

Height and weight assessed at the testing visits were used to determine body mass index (BMI; kg/m^2). While BMI has limited utility at the individual level (it cannot determine relative proportions of muscle versus fat tissue),[43] in larger samples such as the current prospective cohort study, BMI is associated with body composition and cardiometabolic disease risk.[44]

Moderate-vigorous intensity physical activity

We also covaried for leisure moderate-vigorous intensity physical activity (MVPA) given its positive preventive effects on cardiometabolic risk.[45,46] Self-reported MVPA was estimated using the CARDIA Physical Activity History Questionnaire and expressed in Exercise Units (EU)[47–49]. The questionnaire asks about participation in 8 vigorous-intensity and 5 moderate-intensity activity categories (of similar activity types) over the previous year and has high test-retest reliability (0.77-0.84) over a 2-week period.[50] To align with nonoccupational sedentary activities that are included in the SBQ , the contribution of the vigorous intensity occupational physical activity (ie, 1 of 13 original items) was removed. Each activity category included (n = 12) was assigned an intensity score ranging from 3 to 8 metabolic equivalents. The EU represents a weighted sum based on the activity intensity, and number of months of less frequent participation (ie, months when the reported duration was at least 1 hour, but less than the specified hours per week), plus 3 times the number of months of frequent participation. "Frequent" participation was operationalized as between 2–5 hours per week depending on the activity. An overall score was calculated and summarized as EU with 300 EU corresponding to public health recommendations for physical activity (eg approximately meeting aerobic physical activity guidelines).[48,49] Cross-sectional associations between SB variables and MVPA at baseline are presented in Supplementary Tables S2 and S3.

Sample size

Sample size calculations were conducted using G*Power (Version 3.1, Dusseldorf, Germany) software. For the cross-sectional analyses, with 80% statistical power and a 5% chance of a type I error, the critical threshold for the odds ratio (OR) was 1.129 for both HTN and DM. For the prospective analyses, the critical OR threshold was 1.194 and 1.146 for HTN and DM, respectively.

Statistical analysis

Data were analyzed using Stata 18 (College Station, TX) statistical software. Individuals who had missing medication or laboratory data were only included if the other criteria indicated disease (eg, for DM, if medication data were missing, but blood glucose levels indicated diabetes). Incident disease was defined as an absence of disease at baseline, but disease presence at year 30. Baseline covariate and outcome data were summarized across quartiles of total SB using means and SDs or numbers and percentages; quartile comparisons were tested using chi-squared (X^2) or analyses of variance (ANOVA) for categorical and continuous variables, respectively. For the strength of associations, the primary binary variables (HTN and DM) were tested using logistic regression with the OR corresponding to 1 additional hour of SB per day. Model 1 was unadjusted. Model 2 was adjusted for sex, race, age, income, and field center. Model 3 included the Model 2 covariates plus BMI and MVPA. Post-hoc, the following steps were taken: (1) we tested for significant interactions between SB variables and covariates including age, sex, race, BMI, and MVPA; (2) we determined postestimation probabilities using average marginal effects (partial derivatives of the predicted probabilities) at observed values; and (3) we re-ran HTN models using the previous (2003–2016) AHA HTN criteria.

Results

Population

Sociodemographic and baseline anthropometric, activity behavior, and cardiometabolic data are presented in Table 1. Following exclusions, 3359 and 3346 participants were included in the baseline cross-sectional analyses for HTN and DM, respectively. Following additional exclusions for prevalent cardiometabolic disease at baseline, plus exclusions for missing exposure, outcome, and covariate information at year 30, 1563, and 2647 were included for the prospective HTN and DM analyses, respectively. Baseline prevalences for HTN and DM were 48% (1618 cases) and 10% (320 cases), respectively. Additional details regarding individuals with missing data, exclusions, and the determination of final analytical samples are described in the Supplementary material.

Cross-sectional analyses

Total SB

Cross-sectional associations between total-SB and cardiometabolic outcomes at baseline are reported in Table 2. In the fully adjusted model, a 1 hour per day higher amount of total-SB was associated with 3% higher odds of HTN (OR: 1.03, 95% CI, 1.01-1.05), but not DM (OR: 1.01, 95% CI, 0.98-1.04).

Context-specific SBs

Cross-sectional associations between context-specific SBs and cardiometabolic disease outcomes at baseline are reported in Table 2. In the fully adjusted model, a 1 hour per day higher amount of TV-SB was associated with 9% higher odds of HTN (OR: 1.09, 95% CI, 1.03-1.15), as well as 18% higher odds of DM (OR: 1.18, 95% CI, 1.09-1.29). Besides TV-SB, there were no associations between context-specific SBs and cardiometabolic outcomes.

Longitudinal analyses

The total number of individuals at risk, the number of incident cases (events), and the 5-year cumulative incident rates for both HTN and DM are presented in Table 3.

Total SB

The 5-year prospective associations between baseline total-SB and incident HTN and DM at year 30 are presented in Table 3. In the fully adjusted model, total-SB was not associated with higher odds of HTN (OR: 0.98, 95% CI, 0.94-1.02) or DM (OR: 1.04, 95% CI, 1.00-1.08).

Context-specific SBs

The 5-year prospective associations between baseline context-specific SBs and incident HTN and DM at year 30 are presented in Table 3. After adjustment, a 1 hour per day higher amount of TV-SB was associated with higher odds of incident HTN (OR: 1.14, 95% CI, 1.04-1.26), but not DM

Table 1. Baseline (year 25) participant characteristics across total sedentary behavior quartiles (n = 3370).

Total non-occupational Sedentary Behavior					
Characteristic (year 25)	**Quartile 1 (0-4.39 h/day)**	**Quartile 2 (4.39-6.14 h/day)**	**Quartile 3 (6.14-8.71 h/day)**	**Quartile 4 (8.71-24)**	P_{trend}
	Mean (SD) or N (%)				*X2 or ANOVA*
Age *(mean, SD)*	50.44 (3.49)	50.21 (3.58)	50.25 (3.63)	49.62 (3.79)	<.001
Sex *(n, %)*					.415
Female	482 (55.98)	472 (56.73)	457 (54.40)	489 (58.42)	
Male	379 (44.02)	360 (43.27)	383 (45.60)	348 (41.58)	
Race *(n, %)*					<.001
Black	231 (26.83)	301 (36.18)	436 (51.90)	606 (72.40)	
White	630 (73.17)	531 (63.82)	404 (48.10)	231 (27.60)	
Combined family income *(n, %)*					<.001
<$5000	17 (1.97)	21 (2.52)	19 (2.26)	35 (4.18)	
$5000-$11 999	26 (3.02)	24 (2.88)	43 (5.12)	67 (8.00)	
$12 000-$15 999	15 (1.74)	22 (2.64)	35 (4.17)	49 (5.85)	
$16 000-$24 999	35 (4.07)	41 (4.93)	54 (6.43)	72 (8.60)	
$25 000-$34 999	49 (5.69)	50 (6.01)	53 (6.31)	74 (8.84)	
$35 000-$49 999	57 (6.62)	61 (7.33)	95 (11.31)	133 (15.89)	
$50 000-$74 999	146 (16.96)	129 (15.50)	158 (18.81)	151 (18.04)	
$75 000-$99 999	122 (14.17)	144 (17.31)	119 (14.17)	78 (9.32)	
≥$100 000	384 (44.60)	331 (39.78)	249 (29.64)	171 (20.43)	
"Don't know"	6 (<1)	5 (<1)	8 (<1)	3 (<1)	
No response	4 (<1)	4 (<1)	7 (<1)	4 (<1)	
Field center *(n, %)*					<.001
Birmingham, AL	163 (18.93)	179 (21.51)	201 (23.93)	243 (29.03)	
Chicago, IL	210 (24.39)	184 (22.12)	206 (24.52)	207 (24.73)	
Minneapolis, MN	226 (26.25)	223 (26.80)	200 (23.81)	189 (22.58)	
Oakland, CA	262 (30.43)	246 (29.57)	233 (27.74)	198 (23.66)	
BMI (kg/m²) *(mean, SD)*	27.82 (6.52)	29.53 (6.57)	31.25 (7.28)	32.09 (7.72)	<.001
Leisure MVPA (Exercise units) *(mean, SD)*	349.71 (262.74)	309 (253.99)	282.97 (252.11)	252.74 (244.23)	<.001
Systolic blood pressure (mmHg) *(mean, SD)*	117.18 (15.74)	118.81 (15.79)	120.19 (16.31)	122.36 (16.48)	<.001
Diastolic blood pressure (mmHg) *(mean, SD)*	72.23 (10.82)	74.22 (11.22)	75.77 (11.07)	77.24 (11.40)	<.001
Fasting blood glucose (mg/dL) *(mean, SD)*	96.51 (23.26)	97.69 (24.59)	100.96 (30.67)	102.68 (33.71)	<.001

In interpreting this table, it is important to recall that on the Sedentary Behavior Questionnaire, the highest Likert scale response for sedentary behavior variables (each questionnaire item) was "6 hours or more," and this response was scored conservatively as 6 hours. Abbreviations: AL, Alabama; ANOVA, Analysis of variance; BMI, body mass index; CA, California; dL, deciliters; h, hours; IL, Illinois; kg, kilograms; m, meters; mg, milligrams; mmHg, millimeters of mercury; MN, Minnesota; SB, sedentary behavior; SD, standard deviation; $, United States dollars; X^2, Chi-squared.

(OR: 1.06, 95% CI, 0.93-1.20). No other context-specific SBs besides TV-SB were associated with incident HTN or DM.

Sensitivity and ancillary analyses

Participant characteristics across TV-SB quartiles

Given that TV-SB was the only context-specific SB that associated with the cardiometabolic outcomes, participant characteristics across TV-SB quartiles are reported in Supplementary Table S4.

Exploration of covariate effect modifications

To better contextualize results, we tested for potential interactions between the significant SB variables (total-SB and TV-SB) and important covariates, including age, sex, race, BMI, and MVPA. Briefly, in the cross-sectional HTN model, we observed an interaction between BMI with total SB (P =.021) and TV-SB (P =.045). In the prospective HTN model, we observed an interaction between sex and total-SB (P =.004). No other significant interactions between SB variables and covariates were observed in cross-sectional or prospective models for either HTN or DM (all P >.05). Full details and stratified follow-up analyses, as well as detailed rationale for investigating effect modification for these specific covariates, are outlined in the Supplementary Material.

Postestimation predicted probabilities

To aid in our interpretation of clinical and practical relevance, we calculated postestimation predicted probabilities

Table 2. Baseline (year 25) cross-sectional associations between SB and cardiometabolic outcomes.

	Hypertension			Type II diabetes		
	1618 Cases (48% prevalence)			320 Cases (10% prevalence)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Total SB						
OR	**1.10**	**1.05**	**1.03**	**1.06**	1.02	1.01
95% CI	**1.08, 1.12**	**1.02, 1.07**	**1.01, 1.05**	**1.04, 1.09**	1.00, 1.05	0.98, 1.04
TV						
OR	**1.28**	**1.15**	**1.09**	**1.34**	**1.22**	**1.18**
95% CI	**1.21, 1.35**	**1.09, 1.21**	**1.03, 1.15**	**1.24, 1.44**	**1.12, 1.32**	**1.09, 1.29**
Computer						
OR	1.03	1.05	1.01	1.03	1.04	0.99
95% CI	0.97, 1.09	0.99, 1.12	0.95, 1.08	0.94, 1.12	0.95, 1.14	0.90, 1.09
Non-computer (office/paper) work						
OR	1.07	1.03	1.03	1.04	1.00	1.00
95% CI	0.97, 1.17	0.94, 1.14	0.93, 1.14	0.90, 1.19	0.87, 1.16	0.86, 1.16
Music						
OR	1.01	0.97	0.98	0.96	0.93	0.93
95% CI	0.94, 1.09	0.90, 1.05	0.91, 1.06	0.86, 1.08	0.83, 1.05	0.83, 1.05
Telephone						
OR	1.08	1.01	1.02	0.96	0.93	0.94
95% CI	0.99, 1.18	0.92, 1.10	0.93, 1.12	0.84, 1.10	0.82, 1.07	0.82, 1.08
Transportation						
OR	1.06	1.03	1.01	1.01	0.99	0.99
95% CI	0.99, 1.13	0.96, 1.10	0.94, 1.09	0.91, 1.12	0.89, 1.10	0.89, 1.11

Hypertension: 3359 observations; Diabetes: 3346 observations. Odds ratios for hypertension and diabetes correspond to 1 hour per day higher amount of context-specific SB. Model 1: unadjusted. Model 2: adjusted for demographic variables (sex, age, race, income, testing center). Model 3: Model 2 adjustments plus adjustments for body mass index and moderate-vigorous physical activity. Bolded data indicate statistical significance. Abbreviations: ß, Beta coefficient; CI, confidence interval, SB, sedentary behavior.

of variables within the prospective, context-specific HTN model since this was the only model in which an SB variable (TV-SB) significantly predicted incident cardiometabolic disease. A 1 hour per day higher amount of TV-SB was associated with a 2 percentage point increase (marginal effect: 0.02, 95% CI, 0.01-0.03) in the probability of 5-year incident HTN. There were no significant marginal effects for any of the other context-specific SBs (all P >.05). Postestimation predicted probabilities are plotted in Figure 2.

Analyses using previous (2003-2016) AHA HTN Criteria

Given data collection occurred before the current AHA criteria, we repeated our analyses using the previous AHA criteria (>140/90 mmHg). Besides a nonsignificant cross-sectional association between Total SB and HTN, findings were comparable to our original analyses (Supplementary Table S6).

Discussion

This study determined the cross-sectional and prospective associations of SB (including total-SB and 6 nonoccupational context-specific SBs) with HTN and DM. In this middle-aged cohort, we found fully adjusted cross-sectional associations between total-SB and HTN, and between TV-SB and both DM and HTN. The only prospective association we observed was between TV-SB and HTN.

Hypertension

Our finding of a cross-sectional association between total-SB and HTN is consistent with previous studies utilizing both accelerometry-derived[51] and self-reported[52] total-SB. However, we did not observe a prospective association between total-SB and 5-year incident HTN. Our prospective results are consistent with findings from the European Prospective Investigation Into Cancer and Nutrition-Norfolk study (n = 5585 British adults),[53] which reported that accelerometry-derived total-SB (including occupational and nonoccupational SB combined) was not associated with incident cardiovascular disease after 5.6 years of follow-up.

The current study extends the literature by investigating associations between context-specific SB contexts and HTN. Of the context-specific SBs, only TV-SB was associated with HTN. A previous meta-analysis by Lee et al.[54] demonstrated a 0.08-mmHg increase (95% CI, 0.004-0.15) in systolic BP with every additional hour of self-reported SB per day. Of note, more than half of the studies included in the meta-analysis by Lee et al.[54] used TV-SB as the SB outcome. The Australian Diabetes, Obesity, and Lifestyle study (n = 3429)[14] similarly reported that every additional hour per day of TV-SB, but not occupational SB or transport SB, was cross-sectionally associated with systolic (ß = 1.82 mmHg; 95% CI, 1.20-2.43) and diastolic (ß = 0.58 mmHg; 95% CI, 0.25-0.91) BP. We further extend the literature by investigating prospective associations between context-specific SB and incident HTN. Our findings of an association between TV-SB and 5-year incident HTN

Table 3. Association between SB at baseline (year 25) and incident cardiometabolic outcomes at year 30.

	Hypertension			Diabetes		
	Incident events: 324 (21%)			Incident events: 147 (6%)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Total SB						
OR	**1.04**	1.00	0.98	**1.07**	1.04	1.04
95% CI	**1.01, 1.08**	0.96, 1.04	0.94, 1.02	**1.03, 1.11**	1.00, 1.08	1.00, 1.08
TV						
OR	**1.27**	**1.18**	**1.14**	**1.19**	1.10	1.06
95% CI	**1.16, 1.39**	**1.08, 1.30**	**1.04, 1.26**	**1.06, 1.33**	0.98, 1.25	0.93, 1.20
Computer						
OR	0.96	0.97	0.95	1.04	1.07	1.05
95% CI	0.86, 1.08	0.87, 1.09	0.84, 1.07	0.91, 1.18	0.93, 1.23	0.91. 1.20
Noncomputer (office) work						
OR	0.85	0.84	0.83	1.00	0.99	1.02
95% CI	0.70, 1.03	0.69, 1.03	0.68, 1.02	0.82, 1.23	0.81, 1.23	0.83, 1.26
Music						
OR	0.96	0.94	0.92	0.98	0.96	0.98
95% CI	0.84, 1.10	0.82, 1.07	0.80, 1.06	0.83, 1.15	0.81, 1.13	0.83, 1.16
Telephone						
OR	1.08	1.02	1.01	1.04	1.00	1.00
95% CI	0.92, 1.28	0.86, 1.21	0.85, 1.21	0.87, 1.25	0.83, 1.20	0.83, 1.21
Transportation						
OR	1.00	0.96	0.96	1.13	1.10	1.10
95% CI	0.89, 1.14	0.85, 1.10	0.84, 1.09	0.99, 1.30	0.96, 1.26	0.96, 1.27

Hypertension models: *n*=1563 observations (# at risk). Diabetes models: *n*=2647 observations (# at risk). ORs for incident hypertension and diabetes correspond to 1 hour per day higher amount of context-specific SB. Model 1: unadjusted. Model 2: adjusted for demographic variables (sex, age, race, income, testing center). Model 3: Model 2 adjustments plus adjustments for body mass index and moderate-vigorous physical activity. Bolded data indicate statistical significance. Abbreviations: CI, confidence interval; OR, odds ratio; SB, sedentary behavior.

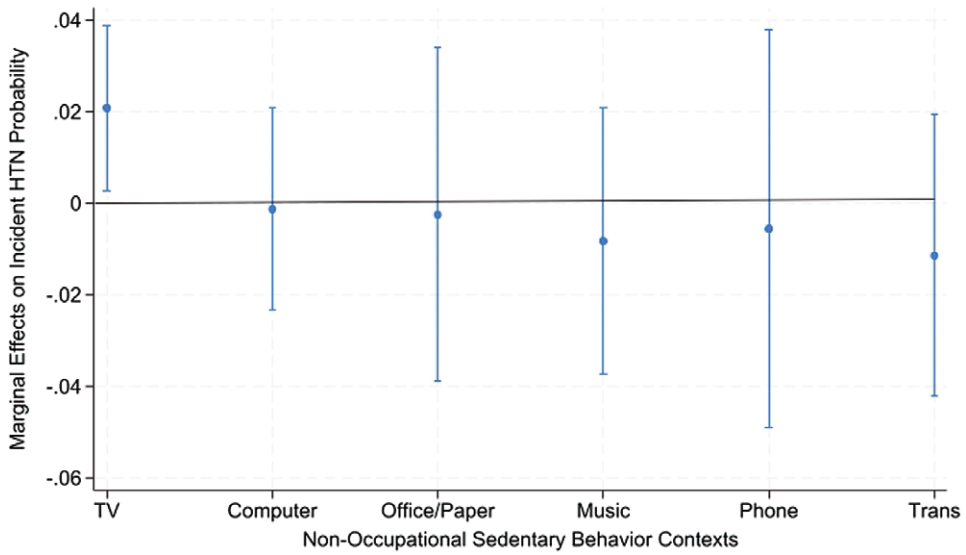

Figure 2. Postestimation probability plot for marginal effects of context-specific sedentary behaviors on incident hypertension. This figure shows the marginal effects of context-specific sedentary behaviors on incident hypertension. Note that television is the only context-specific sedentary behavior in which error bars do not cross zero. Abbreviations: HTN, hypertension; Office/paper, non-work-related office or paperwork; Trans, transportation; TV, television.

contrast those of several prior prospective studies that did not report significant associations.[55,56] The null findings for one of these studies may be at least partially attributable to the relatively short (2-year) follow-up period.[56]

We also note that ancillary analyses revealed significant interaction effects between SB variables with key covariates including BMI and sex on HTN. BMI (or more precisely, body composition) is often highlighted as an important

confounding variable in the SB-CVD risk relationship since excessive SB can lead to elevations in body fat, which is itself an independent CVD risk factor.[57–59] Compared with under/normal-weight individuals, higher total-SB and TV-SB in those with a greater BMI were more likely to have concurrent HTN. This finding is not surprising since higher body fat is associated with elevated BP.[60] In terms of sex, total-SB was associated with lower odds of future HTN in females but not for males. Taken together, there are important confounding biological, lifestyle, and sociodemographic variables, which may impact the link between SB and CVD risk and which should be controlled for in future population-level studies. Nonetheless, SB, and in particular TV-SB, seem to be important independent predictors of HTN and, therefore, CVD risk in middle-aged adults.

Diabetes

We observed unadjusted associations between total-SB and DM. However, following adjustment for covariates, these associations were both attenuated. Previous studies have yielded mixed results. In a prior CARDIA study,[61] accelerometry-derived total-SB was cross-sectionally associated with higher fasting blood glucose and 2-hour glucose. Like the current findings, these associations did not persist after adjusting for MVPA. In contrast, data from the Hispanic Community Health Study (HCHS)[62] reported significant cross-sectional associations of accelerometry-derived total-SB with 2-hour glucose and fasting insulin which persisted after adjustment for MVPA, BMI, and waist-to-hip ratio. A commonality among these prior studies was the use of DM risk factors as outcomes. We extend the literature by using overt DM as a primary outcome.

The current study further extends the literature by investigating associations between nonoccupational context-specific SBs and DM. Of the context-specific SBs, only TV-SB was associated with DM. Following adjustments, we found a cross-sectional, but not a prospective, association between TV-SB and DM. Adjusted cross-sectional associations between TV-SB and cardiometabolic disease risk have been reported,[14] as have adjusted prospective associations between TV-SB and incident DM.[63,64] Among 37 918 US men[63] and 68 497 US women[64] from the Health Professional's Follow-Up Cohort (HPHS), greater TV-SB was prospectively associated with higher 6-10 years DM risk in males, but not females (highest quintile [>40 hours/week]: males[63] RR: 2.31, 95% CI, 1.17-4.56; females RR: 1.17, 95% CI, 0.82-1.67) after adjustment for MVPA and BMI. In the current study, sex did not significantly interact with SB variables in DM models, nor did we see sex differences across total-SB (Table 1) or TV-SB (Supplementary Table S4) quartiles. It should be emphasized, however, that this study was not designed to assess sex differences and the smaller sample size compared with the HPHS cohort may have contributed to the observed discrepancy.

Physiological rationale

The current study is an observational cohort study, not a physiological experiment in which potential mechanisms could be thoroughly investigated. Nevertheless, for effective behavioral interventions or policy initiatives to be successful, it is important that they must be grounded in a physiological framework. As such, below, we briefly outline possible mechanisms contributing to the link between SB and cardiometabolic disease risk.

The mechanisms contributing to HTN and DM risk with repeated exposure to SB are likely distinct. Hemodynamic dysregulation may be particularly important to SB-related HTN risk. BP is the net result (product) of cardiac output and total peripheral resistance; thus, changes in these factors must be implicated in SB effects on HTN.[4,65,66] Reduced skeletal muscle pump action during an SB bout has been reported to induce lower-extremity venous pooling, leading to decreased venous return, stroke volume, and laminar shear stress through the conduit arteries.[66,67] The decrease in venous return reduces laminar shear stress between red blood cells and the endothelial wall of the vessel, which in turn lowers the bioavailability of nitric oxide, a key vasodilatory, and antiatherosclerotic molecule.[68,69] While hemodynamic dysregulation may be particularly important to HTN risk, metabolic dysregulation may be the critical biological factor linking SB to DM risk. Limited muscular contractile activity during an SB bout, which can dysregulate glycemic control and lipid metabolism, may contribute to DM risk.[70–73] The negative physiological changes may be compounded if an individual is predisposed to other risk factors known to impair metabolic control, including an unhealthy body composition profile. In support of the latter, some of the cross-sectional and all of the prospective associations between SB variables and DM in the current study were attenuated when adjusted for MVPA and BMI.

Implications and future research

Four potential implications arise from this study. First, the associations between SB and cardiometabolic outcomes (ie, HTN and DM) were weaker for the prospective versus cross-sectional analyses. This observation is consistent with the aforementioned findings from Gibbs et al.[61] and the HCHS data,[62,74] and supports caution against overinterpretation of cross-sectional outcomes. This trend may also point to the possibility that, from a cardiometabolic risk standpoint, perhaps SB matters more in younger life. There is a need to strengthen the field using prospective data, and for researchers to report cross-sectional results alongside prospective results to provide greater context regarding temporality and thus causality.

Second, TV-SB may be a particularly important public health target. In-line with prior research, TV-SB was most robustly associated with cardiometabolic outcomes.[28,75,76] The strength of this association could be attributable to the negative association between screen time and mental health,[77–79] which itself is a cardiometabolic disease risk factor.[80–82] Another commonly cited negative behavioral association with TV-SB is concomitant poor dietary choices;[16] however, the analyses were controlled for BMI making this rationale—at least in terms of the significant prospective TV-SB and HTN association—less likely in the current study. Additionally, TV time was historically easier to recall than total-SB and other context-specific SBs and has been widely utilized as a surrogate for nonoccupational-SB.[83] Yet, changes to leisure screen time behaviors over the past decade indicate a need for updated measurement methodology on this exposure. For example, should streaming a TV series on one's laptop be considered TV-SB? There is a need for future studies to define various screen-based behaviors in a more granular manner that is also universally acceptable and measurable.

Only thereafter can the associations of these emerging leisure screen time behaviors with cardiometabolic risk be clarified.

Third, limited evidence indicates that nonoccupational and occupational SB are distinct cardiometabolic disease risk factors.[12–14] For example, a prior study in Australian adults reported that when keeping total SB constant, leisure-based computer SB and TV-SB, but not occupational SB, were associated with higher cardiometabolic risk.[14] Differences in cardiometabolic risk between contexts are likely partially attributed to the fact that they may each associate uniquely with psychosocial factors (eg, stress, autonomy, and effort-reward balance)[17–19] and co-occurring lifestyle behaviors. Taking MVPA as an example, some, but not all[12] research has suggested a compensatory effect such that those with high occupational SB compensate with greater leisure MVPA, while those with less occupational SB are more likely to engage in greater leisure SB.[84] Future studies are warranted to measure both occupational and nonoccupational SB simultaneously (including context-specific SBs within each), both in relation to other lifestyle factors (eg, MVPA) and cardiometabolic parameters to better inform SB intervention considerations. From a behavior change standpoint, one particularly interesting possibility is that nonoccupational SB may be more amenable to change.[11] Viewed within the context of the Socio-ecological Model,[9,10] individuals may perhaps have a greater capacity to regulate physical and socio-cultural environments during leisure time as opposed to during work time. While occupational SB is also a worthwhile domain to investigate (and arguably at least partly the responsibility of the employer to offer tools to support occupational SB mitigation, eg, standing desks), reducing nonoccupational SB may be a more feasible public health target and therefore may more realistically translate to lessened cardiometabolic risk at the population level.

Lastly, we comment on the potential clinical significance of these findings. It is important to reiterate that the current study used overt cardiometabolic endpoints as outcomes rather than risk factors, which underscores the potential clinical relevance arising from these findings. In addition, postestimation probability testing using marginal effects revealed that an additional hour of TV-SB was associated with a 2 percentage point increase in the probability of 5-year incident HTN (Figure 2). While this is a small absolute effect, the logistic regression OR used in the present study was based on an easily interpretable and theoretically feasibly modifiable 1 hour per day increase in SB. Feasible recommendations for lessening TV-SB in middle-aged adults could include taking a short walk with family or friends after dinner instead of (or before) sitting down to watch TV, or cultivating nonscreen-related domestic hobbies such as gardening or cooking. Encouraging TV-related SB interruptions could also be a useful recommendation as well as a potential focus for future interventions. For example, individuals could be encouraged to get up to stand or stretch during commercial breaks if watching traditional cable TV or in-between episodes to break up "binge-watching" series on streaming services. It should also be emphasized that these recommendations can be viewed within the 24-hour Movement Behavior Framework.[3,4] That is, time spent engaging in one activity behavior will likely influence another behavior; thus 24-hour movement behaviors should not be considered independently from one another when trying to optimize SB behavior change recommendations.[85] For example, TV-SB reduction may intrinsically lead to walking (an increase in light-intensity physical activity) or—in the case of another 24-hour activity behavior—improving sleep quality and duration.

Limitations and strengths

Several limitations should be acknowledged to help contextualize findings. First, as with all self-report measures, the physical activity and SB questionnaires may have been subject to recall and prevarication bias.[27,86] Unless a study is directly designed to investigate SB, this construct is difficult to measure precisely. For example, large observational cohort studies (eg, CARDIA) typically include many laboratory and self-report variables over multiple time points. An accepted approach for directly capturing SB duration and context, such as accelerometry coupled with ecological momentary analysis, is both labor-intensive and increases participant burden. Several cohort studies have included accelerometry by design, though SB is often not the intended primary activity-based outcome, nor can it capture SB contexts, and only 1 device has been validated and widely accepted for measuring SB.[87,88] More complex techniques (eg, coupling a validated accelerometry device such as the ActivPal with ecological momentary analysis) are required to more confidently measure context-specific SB. Second, unlike accelerometry devices such as the ActivPal, the SBQ does not capture SB interruptions, which may dampen the deleterious cardiometabolic effects of SB.[89,90] Third, the current findings may be affected by attrition bias. We do not account for attrition from lost-to-follow-up or death which may be related to HTN, DM, and/or baseline SB. Fourth, the highest duration of the Likert response options on the SB questionnaire was "6 hours or more," which we scored uniformly as 6 hours. This likely resulted in conservative point estimates in the present study. The average US adult sits more than 9 hours per day,[1] and the relationship between SB and cardiometabolic disease is dose-dependent,[91,92] meaning that the highest-risk individuals in the current study (from a SB standpoint) may not have been adequately accounted for. Lastly, the longitudinal analysis was limited to a 5-year time frame. Perhaps, significant prospective associations between nonoccupational SBs and DM would be illuminated with a longer follow-up period, paralleling findings from cohorts with longer follow-ups.[63] It will be worthwhile for future studies to investigate prospective associations across medium- and longer-term follow-up periods (eg, 10 or 15 years given many cohorts use 5-year assessment intervals) as additional data becomes available from CARDIA and/or other cohorts. Doing so will enable us to better understand the trajectory of cardiometabolic risk associated with SB across adulthood and will assist in optimizing efforts to identify and target relevant facilitators and barriers to SB behavior change. On the other hand, the 5-year assessment period used in the current study can also be viewed as a study strength. That is, despite the relatively short follow-up period, clear signals were nonetheless detected in the associations between SB variables and cardiometabolic disease. This suggests that SB effects on cardiometabolic risk may not simply be a bi-product of a lifetime of sedentariness and that, alternatively, SB-related risk may be accrued relatively rapidly (eg, within years rather than decades).

Study strengths included the use of a large US sample of Black and White middle-aged adults, the inclusion of 2 prevalent, costly, and modifiable cardiometabolic diseases, and

conducting both cross-sectional and prospective analyses. Another major strength of this study was the measurement of nonoccupational SB contexts which is critical for designing effective SB-reduction interventions.

Conclusion

The purpose of this study was to determine the strength of cross-sectional and prospective associations between total-SB and 6 context-specific nonoccupational SBs with HTN and DM. Cross-sectional associations were observed between total-SB and HTN, and between TV-SB and both DM and HTN. The only observed prospective association was between TV-SB and incident HTN. TV-SB reduction may be a particularly important intervention target for mitigating HTN risk in middle-aged adults. Our findings emphasize the need to avoid overinterpretation of cross-sectional associations between SB and cardiometabolic outcomes, while underscoring that other biological, behavioral, and socio-demographic factors influence the association between SB and cardiometabolic disease risk.

Supplementary material

Supplementary material is available at *Annals of Behavioral Medicine* online.

Acknowledgments

We would like to acknowledge Matthew Bhagat-Conway (Odum Institute for Social Sciences, University of North Carolina at Chapel Hill) for his contributions to the statistical analysis. The views expressed in this manuscript are those of the authors and do not necessarily represent the views of the National Heart, Lung, and Blood Institute; the National Institutes of Health; or the U.S. Department of Health and Human Services.

Author contributions

Gabriel Zieff (Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing—original draft, Writing—review & editing, Visualization, Project administration), Michael P. Bancks (Conceptualization, Methodology, Software, Formal analysis, Writing—review & editing), Kelley Pettee Gabriel (Conceptualization, Methodology, Resources, Writing—review & editing, Supervision, Project administration), Bethany Barone Gibbs (Conceptualization, Methodology, Writing—review & editing, Project administration), Justin B. Moore (Conceptualization, Methodology, Writing—review & editing), Jared P. Reis (Conceptualization, Methodology, Writing—review & editing), Keeron Stone (Conceptualization, Methodology, Writing—review & editing), and Lee Stoner (Conceptualization, Methodology, Writing—review & editing, Supervision, Project administration)

Funding

The Coronary Artery Risk Development in Young Adults Study (CARDIA) is conducted and supported by the National Heart, Lung, and Blood Institute (NHLBI) in collaboration with the University of Alabama at Birmingham (75N92023D00002 & 75N92023D00005), Northwestern University (75N92023D00004), University of Minnesota (75N92023D00006), and Kaiser Foundation Research Institute (75N92023D00003). This manuscript has been reviewed by CARDIA for scientific content.

Dr Keeron Stone is supported by the Health and Care Research Wales funded National Cardiovascular Research Network, Wales.

Conflicts of interest

None.

Open Science Transparency Statement:

1. **Study registration:** This study was not formally registered, but the research questions and a formal study proposal were proposed, reviewed, and approved internally by the CARDIA Presentations & Proposals Committee prior to study commencement.

2. **Analytic plan preregistration:** The analysis plan was not formally registered, but the analytic plan was internally proposed, reviewed, and approved internally by the CARDIA Presentations & Proposals Committee prior to study commencement.

3. **Data availability:** De-identified data from this study are not available in a public archive. However, CARDIA takes a collaborative approach to their cohort data. Schedule of exams, variables collected, and information pertaining to manuscript proposals and data requests can be found here: https://www.cardia.dopm.uab.edu/

4. **Analytic code availability**: Analytic code used to conduct the analyses presented in this study is not available in a public archive. However, the code may be made available by emailing the corresponding author.

5. **Materials availability**: The materials used to conduct the study are available in a public archive: https://www.cardia.dopm.uab.edu/exam-materials2

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