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Exploring the effect of sedentary behavior on increased adiposity in middle-aged adults

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Abstract

Background Sedentary behavior is linked to excess fat mass; however, this association may be inconclusive due to potential measurement errors in self-reported sedentary behavior.

Objective To assess the association between changes in sedentary behavior and fat mass in a Cohort of Health Workers (HWCS) from 2004 to 2010.

Methods A total of 1,285 adults participating in the Cohort of Health Workers were evaluated in 2004 and 2010. Fat mass (kg) was measured by dual X-ray absorptiometry. A self-administered questionnaire was used to estimate the sedentary behavior. Sedentary behavior was also estimated using accelerometry in a sample of 142 health workers. Accelerometry data were used to correct self-reported sedentary behavior using a generalized linear model, which included values for sleeping time, age, sex, sedentary behavior, glucose, and triglycerides. Concordance between both methods was assessed using a kappa and Bland–Altman analysis. Once sedentary behavior was corrected, the values were used to evaluate the association between changes in sedentary behavior and body fat mass using a fixed effect model in the cohort, adjusting for confounders.

Results Self-reported sedentary behavior was 2.8 ± 1.8 and 2.3 ± 1.6 h/day, and body fat mass was 24.9 ± 8.1 and 26.8 ± 8.5 kg in 2004 and 2010, respectively. After applying the correction model, the self-reported sedentary behavior was 7.6 ± 1.2 and 7.5 ± 1.2 h/day in 2004 and 2010, respectively. For every hour increase in corrected sedentary behavior, there was an observed increase of 0.847 ($p > 0.001$) kg in body fat mass during the 6.8 years in the Cohort of Health Workers from 2004 to 2010. Conversely, non-corrected self-reported sedentary behavior was associated with a non-significant reduction of 0.097 kg ($p = 0.228$) for every hour of sedentary behavior.

Conclusions Increased sedentary behavior was associated with increased body fat mass when corrected self-reported sedentary behavior was used. Implementing public health strategies to reduce sedentary behavior is imperative.

Keywords Sedentary behavior, Body fat, Cohort study, Middle-aged adults, Self-report correction

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Introduction

Sedentary behaviors (SB) have garnered significant attention in the public health spotlight due to their association with adverse health outcomes. There exists a dose–response relationship between SB and a greater risk of obesity, cardiovascular disease, diabetes mellitus type 2 (DMT2), and all-cause mortality, placing a burden on both populations and the health system [1, 2]. A projection based on data from half the global population indicates a reduction in energy expenditure attributable to physical activity. This projection indicates a forthcoming decrease in physical activity levels, coinciding with a significant rise in SB. Such an increase in sedentary lifestyles may contribute to higher rates of excessive adiposity and the subsequent development of chronic diseases associated with fatness [3].

Recent studies have shown a positive association between uninterrupted sitting for over three hours and increased body fat mass, as well as related complications, independent of physical activity [4, 5]. In 2016, an estimated 31.6% of Mexican men and 22.45% of Mexican women population reported spending more than 4 h/day in SB, which may explain an overweight and obesity prevalence of 84% in our population [6]. The complications stemming from excessive fat mass, including disability and mortality from chronic diseases, pose significant public health challenges in nearly 200 countries, including Mexico [7, 8].

Despite recognizing the strong association between SB and body fat mass, longitudinal studies investigating their long-term consequences are scarce. While some studies have found an association between increasing SB and rising body fat mass, evidence remains inconclusive [9–11]. Notably, methodological differences, such as accelerometer use versus uncorrected self-reported SB, may contribute to these discrepancies. Implementing strategies to correct measurement errors in self-reported SB, such as developing predictive equations using more accurate methods like accelerometry [12, 13], can help mitigate bias and provide a clearer understanding of SB's impact on the obesity epidemic [14–16].

Additionally, previous studies often fail to account for various confounding variables, such as age, tobacco consumption, calorie intake, and physical activity, which may influence the association between SB and fat mass [17]. Failure to address these confounders could contribute to inconsistencies in reported results. Therefore, our study aims to assess the association between changes in sedentary behavior and fat mass in a cohort of health workers (HWCS) from 2004 to 2010.

Methods

We evaluated both non-corrected and corrected self-reported SB to determine if correction reduces our questionnaire' measurement error and information bias. Moreover, we included relevant confounders in our analysis to improve the accuracy of our findings. In essence, comprehending the association between SB and body fat mass holds pivotal significance for devising effective public health interventions to combat the obesity epidemic, particularly within populations with elevated prevalence rates like the adult population in Mexico.

This study comprises three stages. First, we assessed the association between changes in self-reported SB or non-corrected SB and body fat mass in the HWCS from 2004 to 2010. Second, we developed a correction model for self-reported SB using accelerometry in a subset of healthcare workers. Lastly, we evaluated the association between corrected SB and fat mass in the HWCS from 2004 to 2010.

First stage: association between non-corrected SB and body fat mass

Population and study design

The HWCS evaluates the relationship between lifestyles and chronic diseases among Mexican adults. Comprehensive details regarding the study design and cohort characteristics can be found elsewhere [18]. The participants of the HWCS consist of employees from three health systems and academic institutions located in Cuernavaca and Toluca, Mexico. Among the initial cohort of 1,776 males and nonpregnant females aged 18 and above who underwent follow-up from 2004 to 2010, we excluded individuals with missing data on body fat mass ($n = 165$) or SB measures ($n = 100$), as well as those lacking information or presenting implausible values for calorie intake, physical inactivity, and tobacco use ($n = 226$). The final sample size for longitudinal analysis comprised 1,285 participants, with data collected in 2004 and 2010 (Fig. 1).

Measurements

Self-reported sedentary behaviors

We employed an adapted and translated version of the Nurses' Health Study questionnaire to capture self-reported SB [19]. The questionnaire included 21 activities with a metabolic equivalent (MET) value lower than 1.5 METs, covering a range of contexts such as recreation (e.g., writing, using a computer for leisure, reading, watching TV, and watching movies), household activities (e.g., sewing), and activities in a work setting (e.g., time spent sitting). Participants reported their SB activities for a typical week using predefined categories: never, < 15

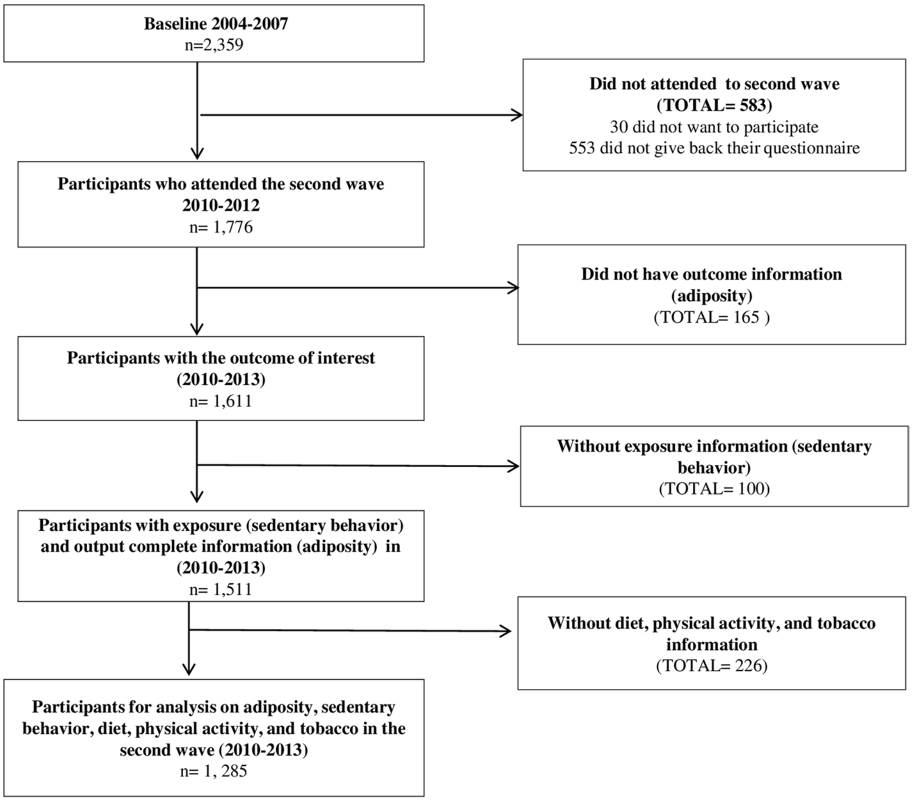

Fig. 1 Diagram of participation in the Cohort of Health Workers (HWCS)

min, 16–29 min, 30–59 min, 1–2 h, 3–4 h, 5–6 h, and > 6 h per week. The total weekly time spent in SB activities was calculated by summing all reported durations and then dividing by 7 to obtain the average daily duration of SB in hours [18].

Body fat mass

Dual X-ray absorptiometry (DXA) using a Lunar densitometer (model: DPX-GE 73735, serial number: 638405U77) (Lunar Radiation Corporation, Madison, WI, USA; software version.35, fast scan mode) was used to measure total fat mass (kilograms). DXA accurately quantifies fat mass and soft lean tissue separately from bone mass [20]. Highly trained technicians conducted daily quality control checks using a manufacturer's phantom, a standardized quality control instrument, to warrant the accuracy of the DXA measurements. Participants attended the research unit for medical history performed by a medical doctor and received the questionnaires (physical activity, sedentary behavior, dietary habits, and other lifestyle factors). After a month they went for DXA measurements with 24 h of fasting with completed questionnaire, this procedure was done at least two times (2004 and 2010).

Other variables

All participants finished a self-administered questionnaire that included socio-demographic information regarding education level and job position (retired, assistant, medical doctor, dietitian, nurse, manager, laboratory analyst, pharmacy attendant, researcher, etc.) and lifestyle (e.g., diet, smoking status, and physical activity) in 2004 and 2010 assessments.

Sex was defined as female = 0 and male = 1. We also included other variables, such as age (in years as a continuous variable or as categories of < 30, 30–39, 40–49, 50–59, > 60 years), and an education level variable for elementary school (where yes = 1, no = 0), middle school (where yes = 1, no = 0), high school (where yes = 1, no = 0), university and postgraduate (where yes = 1, no = 0). Weight and height were measured with standard techniques and were used to calculate BMI categories for nutritional status.

Physical activity (PA) was assessed using a self-administered questionnaire, which captured the duration (in hours per week) and intensity (light, moderate, and vigorous) of activities undertaken during a typical week over the past year. Participants reported their activity levels using predefined categories ranging from "never" to " > 6 h per week." Total weekly PA time was calculated by summing the reported durations, which were then converted into minutes. We classified participants as physically inactive if they engaged in less than 150 min per week of moderate activity or less than 75 min per vigorous activity, based on the World Health Organization (WHO) recommendations for adults aged 18–64 [21].

Dietary intake was evaluated with a semiquantitative Food Frequency Questionnaire to record the consumption frequency and standard portion size of 116 food items during the previous year. Total calorie intake was calculated by multiplying the consumption frequency of each food by its nutrients and calorie content, and it was used as a continuous variable in the association analysis, such as kcal/day [18]. Smoking status was classified as nonsmokers, ex-smokers, and smokers.

Information analysis

In our study, the dependent variable was fat mass, quantified in kilograms, while the explanatory variable was sedentary behavior adjusted by age, physical activity, tobacco consumption, and energy intake. Due to the nature of the fixed-effects model, which subtracts the beta coefficients of the explanatory variables for each time point, factors such as sex, which remain constant, were consequently omitted from estimating the relationship between sedentary behavior and adiposity. In other words, although sex was initially considered a confounding factor according to the DAG and causal inference theory, the fixed-effects model effectively mitigates confounding by unchanging factors in its estimation of effects (refer to Additional file 1 “DAG figure sedentary behavior”).

We employed a fixed-effect model to assess the relationship between changes in self-reported sedentary behavior (non-corrected SB) and changes in fat mass (measured in kilograms by DXA). Fixed-effects models are designed to evaluate within-person changes while controlling for time-invariant confounding factors (differences between individuals’ values from 2010 to 2004); hence, we utilized this model to estimate the association between individual changes in self-reported SB and the increase in body fat mass [22].

Second stage: SB correction model estimation

Population and study design

In a cross-sectional study, we used a subsample of 142 health workers to correct the SB from the self-administered questionnaire. The correction model was obtained of a sub-sample of the 2004 -2010 waves of HWCS.

Measurements

Self-reported sedentary behaviors

We collected SB data following the methodology outlined in the first stage section. Our approach involved utilizing self-reported SB hours per day and a categorical classification of occupational SB based on daily hours spent (< 8 h, 8–9 h, > 9 h) to predict SB levels measured via accelerometry.

Accelerometer-based sedentary time

We utilized the ActiGraph GT3X + accelerometer to assess SB in the 142 participants. The ACTiGraph GT3X + is a triaxial device commonly employed as a reference method for movement assessment [23]. Participants removed the accelerometers during periods of sleep and showering. The accelerometers provided data on time spent across different intensity spectra of movement. Participants wore the accelerometer for seven consecutive days, secured with an adjustable hip belt positioned along the mid-axillary line of their dominant side. It was required to contain a minimum of 60 consecutive minutes to consider a set of valid accelerometry values of nonzero values. We also permitted one-to-two-minute intervals ranging from 0 to 99 counts per minute (CPM) (Actilife5 Software v5.7.4.12). We utilized counts below 100 to classify SB, and we included all participants who had at least four valid days of measurements totaling a minimum of 10 h [24]. The accelerometer data underwent processing using a MATLAB code developed by coauthors DS, UV, and other collaborators involved in international studies [25].

Sleeping time

Sleeping time was self-reported by questionnaire using the following questions: How many hours do you sleep on average from Monday to Friday? How many hours do you sleep on average during a typical weekend? We added the sleeping time (hours/day during the week and weekend). We divided it by seven—the prediction models for sedentary behavior utilized sleeping time, measured in hours per day.

Glucose and triglycerides

A phlebotomist obtained an 8-h blood fasting sample to quantify glucose (mg/dL) and triglycerides (mg/dL) by chemiluminescence (Acces2; Beckman Coulter) with a routine and standardized enzymatic colorimetric method (Selectra XL instrument, Randox). Glucose and triglycerides were used as continuous values to correct self-reported SB. Participants attended the research unit for triglyceride and glucose blood sampling, which were conducted simultaneously with DXA measurements after 24 h of fasting. The time between visits was kept to less than a month and a half.

Other variables

We also evaluated other variables, back pain (yes = 1, no = 0), BMI (kg/height (m^2)), chronic diseases (yes = 1, no = 0 for DMT2, hypertension, depression, overweight/obesity), occupation classified considering the time spent in SB (< 8 h, 8–9 h, < 9 h), caloric intake, sweetened beverages, saturated fat, sex, moderate/vigorous physical activity, sleep time, back pain, BMI, triglycerides, glucose, age (years), and education (elementary school, no = 0), middle school, high school, university and postgraduate) [14, 15, 26–28]. These predictor variables may explain SB accelerometry values and have been reported by other authors in similar studies to generate SB correction models.

Correction model

One hundred forty-two participants were randomly divided into two groups, with half ($n = 71$) constituting the training sample. This sample was utilized to develop a generalized linear model (GLM) for predicting accelerometer-based SB time (hours/day). The prediction model was constructed with accelerometer-based SB as the dependent variable (measured in hours per day). The following explanatory variables were included: self-reported SB, occupation classified considering the time spent in SB, schooling, caloric and saturated fat intake, sweetened beverages, sex, moderate/vigorous physical activity, sleep time, back pain, BMI, triglycerides, glucose, chronic diseases, age, and education (refer to Additional file 2 "2.1 Equations and 2.2 Concordance analysis"). We conducted variable selection for the SB correction model, assessing the natural distribution of each continuous variable, potential mathematical transformations, and interactions to enhance the predictive model. We graphically identified the most promising predictors of SB measured using accelerometry and consolidated them into a generalized linear model (GLM). Each variable was systematically removed, and its contribution to the model was assessed based on beta values and significance ($p < 0.01$) to discern the optimal predictor combination. We assessed the Akaike criterion and retained models with the lowest values.

Cross-validation and agreement

After obtaining the best predictive models from the training sample of 71 subjects, we tested and estimated the SB values in the second half of the participants, constituting our testing sample. Using kappa statistics, we compared the corrected and non-corrected SB values with accelerometry-derived SB values, categorized as terciles, for categorical concordance analyses. We utilized Bland–Altman analyses to assess the agreement between the self-reported SB values corrected and uncorrected and those obtained from accelerometry, expressed in hours per day, within the training and testing samples.

Third stage*:* association between corrected-SB and fat mass

We applied the top-performing SB correction models and computed the corrected SB values for all participants in the HWCS (see Additional file 2 "2.1 Equations and 2.2 Concordance analysis"). Models generating more than 30% of implausible predicted SB values were excluded. The correction for sedentary behavior was determined as hours per day using data collected during assessments conducted in 2004 and 2010.

Statistical analyses

As part of the initial stage, we conducted descriptive data analysis, presenting means and standard deviations or proportions for assessments conducted in 2004 and 2010. We employed the Wilcoxon rank-sum or paired t-test for continuous variables to evaluate differences between the two time points. In contrast, categorical variables were compared using the chi-square test.

As previously described, the initial stage of our study involved employing a fixed-effects modeling approach to estimate the association between changes in non-corrected sedentary behavior and the increment in body fat mass [22]. Once we obtained the SB corrected values with the prediction model generated in the second stage, using a fixed effect model, we performed a bivariate analysis of each DAG variable (SB, physical activity, caloric intake, and tobacco use) and its association with adiposity change. Additionally, we analyzed the association between each DAG variable and SB change using a fixed model.

We evaluated the association between SB and fat mass change in the third study stage. We compared the corrected and non-corrected SB association with body fat mass change, adjusting by age, physical inactivity, tobacco, and calorie intake to avoid confounding bias. This group of confounding variables is the result of a literature review used to obtain an acyclic diagram of causality (DAG) with age, physical inactivity, tobacco, and calorie intake to avoid confounding bias from the statistical analysis (Daggity program, refer to Additional file 1 "DAG figure sedentary behavior").

We performed probability marginal analysis after running the fixed effect model to calculate the magnitude of the association between more than an hour increment of corrected SB with body fat mass change. We also conducted a linear regression analysis using deltas to assess the discrepancies between the fat mass (kg) and sedentary behavior (hrs./d) values in 2004 and 2010. We incorporated potential confounding variables to validate our fixed effect findings. All analyses were performed using Stata version 14 (Stata Corp LLC).

Results

In the HWCH cohort from 2004 to 2010, consisting of 1,285 adult participants, the mean age was 45.4 ± 12.6 years, with the majority falling into the 30–39 (23%) and 40–49 (30%) age groups in 2004. Approximately half of the participants reported high levels of education, including university and postgraduate studies. The average fat mass measurements were 24.9 ± 8.1 kg in 2004 and 26.8 ± 8.5 kg in 2010 (Table 1). Self-reported SB without correction averaged 2.8 ± 1.8 h/day in 2004 and 2.3 ± 1.6 h/day in 2010 for the entire HWCH population ($n = 1,285$). The proportion of adults reporting physical activity decreased from 56.9% in 2004 to 46.2% in 2010. Average calorie intake was estimated at 2,136 cal in 2004 and approximately 1,879 cal in 2010. Lastly, the proportion of participants reporting tobacco use decreased from 16.9% in 2004 to 12.9% in 2010 (Table 1).

Table 1 General characteristics of HWCS participants in 2004 and 2010: non-corrected self-reported sedentary behavior phase[a]

	2004–2006	**2010–2012**	
Characteristics	n = 1,285	n = 1,285	*p-value*
Sex			
Female, n (%)	951 (73.7)	___	
Age, years	45.4 ± 12.6	52.2 ± 12.7	< 0.0001
Time between measurements (years)	___	6.8 ± 1.1	
Age categories, n (%) *			
< 30	139 (10.8)	38 (3.0)	
30–39	290 (22.6)	156 (12.1)	
40–49	380 (29.6)	333 (25.9)	
50–59	285 (22.1)	385 (30.0)	
> 60	191 (14.9)	373 (29.0)	< 0.0001
Education level, % (n)[b]			
Basic	326 (26.3)	___	
Medium	297 (24.0)	___	
High	614 (49.6)	___	0.069
Weight (kg)[g]	66.6 ± 12.8	67.8 ± 13.3	< 0.001
BMI (kg/m2) [g]	26.3 ± 4.2	26.9 ± 4.3	< 0.05
BMI categories, n (%)[c]			
Overweight			
Yes	538 (41.9)	571 (44.4)	< 0.05
Obesity			
Yes	222 (17.3)	249 (19.4)	< 0.05
Body fat (kg)[g]	24.9 ± 8.1	26.8 ± 8.5	< 0.0001
Self-reported SB (hrs./day)[g]	2.8 ± 1.8	2.3 ± 1.6	< 0.05
Physical activity (hrs./day) [d,e, f]	1.0 ± 0.9	0.8 ± 0.8	< 0.0001
Active, n (%)			
Yes	732 (56.9)	593 (46.2)	
Energy intake (kcal/day) [f,g]	2136.1 ± 850.6	1878.9 ± 786.0	< 0.0001
Smoking, n (%)			
Yes	217 (16.9)	166 (12.9)	< 0.001

[a] Health Workers Cohort (HWCS)

[b] Basic education: elementary and middle school, medium level: high school / technical schools, high level: graduated and postgraduate education

[c] Overweight: BMI > 25 y < 30; Obesity: BMI > 30

[d] Additional minutes invested in a week doing activities with a MET value less than < 1.5 at work, household, and recreation

[e] Additional minutes are invested in moderate and vigorous weekly recreation and work activities (running, walking, biking, etc.)

[f] Continuous variables are presented as mean ± standard deviation. Differences between 2004 and 2010 measurements were tested with a t-pair test for normal distribution variables, Wilcoxon for non-parametric distribution variables, and categorical variable differences with a Chi-square test

[g] Daily energy intake

The optimal predictors of SB determined through accelerometry in the randomly selected training sample ($n = 71$) were cross-validated in the remaining 71 participants. These predictors included self-reported SB (hours/day), SB attributed to occupational activities (hours/day), sleep duration along with its quadratic term (hours/day), body mass index (BMI) and its quadratic and cubic terms, triglyceride levels measured in mg/dL and their quadratic and cubic terms, glucose levels in mg/dL and their quadratic and cubic terms, gender (female), and education level (elementary school, secondary school, high school) (refer to Additional file 2 in section“2.1 Equations”).

The kappa value increased from 0.13 ($p = 0.11$) to 0.37 ($p = 0.000$) in the sample of 71 adults in the training group. Additionally, in the testing sample, the kappa value rose from 0.03 ($p = 0.739$) to 0.11 ($p = 0.18$). Bland–Altman analysis further demonstrated an improvement in agreement within the training and testing samples. Consequently, the agreement limits and bias were reduced in the corrected self-reported SB values using the prediction model across training and testing samples (refer to Additional file 2 in section “2.2 Concordance analysis”). Subsequently, after the agreement was evaluated in the validation samples, we corrected the self-reported SB questionnaire values for the 2004 and 2010 assessments. Corrected SB was 7.6 h/day at the 2004 and 2010 assessments.

The bivariate analysis identified a positive association between SB and aging with body fat mass. Notably, aging emerged as the sole variable positively and significantly associated with increased SB-corrected values. Interestingly, none of the other theoretical confounders exhibited any association with changes in SB or body fat mass (refer to Table 2).

We observed a non-significant negative association between self-reported non-corrected SB and fat mass. Conversely, corrected self-reported SB values indicated that each additional daily hour of SB from 2004 to 2010 was linked to a 0.847 kg increase in body fat mass after adjusting for age, calorie intake, physical activity, and tobacco use category (refer to Table 3). Marginal probability analysis of the fixed effect model revealed that a three-hour per day increase in corrected self-reported SB over the six-year follow-up period corresponded to a 2.5 kg increase in fat mass ($p < 0.0001$). On the other hand, the Table 4 displays the linear regression model results illustrating the difference between corrected SB and non-corrected SB in 2004 and 2010.

Discussion

In this longitudinal study, we found that corrected SB using accelerometers in a cohort of health workers was positively associated with body fat mass, in contrast to non-corrected SB values. Furthermore, the strength of

Table 2 Body fat mass and corrected self-reported sedentary behavior changes due to the difference in age, calorie intake, physical activity, and tobacco use in HWCS ($n = 1{,}285$)[a]

	Change in body fat mass (kg)	**β [IC 95%]**	***p***
SB (hrs/d) [b]	0.913	[0.490,1.336]	< 0.001
Physically active [c]	-0.135	[-0.593, 0.323]	0.563
Aging [d]	0.593	[0.348, 0.838]	0.000
Caloric intake increment (100 kcal/day)	0.013	[-0.018, 0.043]	0.415
Tobacco use			
Quit smoking [e]	0.468	[-0.538, 1.473]	0.362
Current smoker [f]	0.459	[- 0.828, 1.747]	0.484
	Change in SB (hours/d)[b]	**β [IC 95%][2]**	***p***
Physically active [c]	0.038	[-0.020, 0.097]	0.201
Aging [d]	0.051	[0.019 0.082]	0.002
Caloric intake increment (100 kcal/day)	-0.001	[-0.004, 0.003]	0.790
Tobacco use			
Quit smoking [e]	-0.096	[-0.222, 0.037]	0.160
Smoker [f]	-0.083	[-0.245, 0.086]	0.346

[a] Health Workers Cohort (HWCS)

[b] Corrected sedentary behavior

[c] Physically active in 2010 (moderate and vigorous physical activity > 150 min/week)

[d] Age change during 2010

[e] Quit smoking in 2010

[f] Becoming a smoker in 2010

Table 3 Change in body fat mass due to difference in time invested in non-corrected and corrected self-reported SB in participants of HWCS ($n=1, 285$)[a]

	Changes in fat mass (kg)[b]		
	Without correction	**IC [95%]**	**p**
1. SB change (hours/day)	-0.085	[-0.243, 0.074]	0.295
2. SB change (hours/day) and age change (years)[c]	-0.096	[-0.254, 0.060]	0.227
3. SB (hours/day), calorie intake (100 kcal/day), age change (years)[c], and physically active (yes)[d] and tobacco use[e]	-0.097	[-0.254, 0.061]	0.228
	Corrected	IC [95%]	p
4. SB change (hours/day)	0.913	[0 .490, 1.336]	< 0.001
SB change (hours/day) and age change (years)[c]	0.830	[0.409, 1.252]	< 0.001
5. SB (hours/day), calorie intake (100 kcal/day), age change (years)[c], and physically active (yes)[d] and tobacco use [e]	0.847	[0.425, 1.270]	< 0.001

[a] Health Workers Cohort (HWCS)

[b] Fixed effects models

[c] Age change between 2004 and 2010

[d] Becoming physically active in 2010

[e] Quitting smoking or becoming a smoker in 2010

Table 4 Change in body fat mass due to difference in time invested in self-reported non-corrected and corrected SB in participants of HWCS ($n=1, 285$)[a, b]

	Changes in fat mass (kg)		
	SB without correction [c]	**IC [95%]**	**p**
Model 1: SB (hours/day delta)	-0.236	[-0.396, -0.076]	0.004
Model 2: SB delta (hours/day) and age delta (years)	-0.080	[-0.240,0.079]	0.325
Model 3: SB (hours/day delta), caloric intake (kcal/day delta), physical activity (hours/day delta), and age (years delta)	-0.082	[-0.193, -0.029]	0.146
	Corrected SB	IC [95%]	p
Model 1: SB (hours/day delta)	0.915	[0 .444, 1.385]	< 0.001
Model 2: SB delta (hours/day) and age (years delta)	0. 870	[0.407,1.333]	< 0.001
Model 3: SB (hours/day delta), caloric intake (kcal/day delta), physical activity (hours/day delta), age (years delta)	0.778	[0.476, 1.080]	< 0.001

[a] Health Workers Cohort (HWCS)

[b] Linear regression model

[c] β coefficients

this association during the observation period aligns with findings from studies that have assessed sedentary behavior using accelerometers [9, 29].

Before applying the correction model to the self-reported non-corrected SB, in the first stage of our study, we observed that each hour of SB increment was non-significantly and negatively associated with a decrease in fat mass. Other authors, such as Ekelund et al., reported no association between SB, assessed using heart rate monitors, and the increase in fat mass measured with bioelectrical impedance analysis (BIE) in 393 middle-aged adults after 5.6 years of follow-up [11]. The discrepancies between their findings and ours could be attributed to methodological differences. Heart rate monitors have limited validity in measuring SB compared to more accurate approaches such as accelerometry [30]. Furthermore, accurate estimations of fat mass using bioelectrical impedance analysis (BIE) require specific and validated equations, which Ekelund and colleagues did not employ for their study population.

Regarding the second stage of our study, the SB correction model incorporated self-reported SB, BMI, occupation, schooling, sleep duration, triglyceride levels, and glucose levels as covariates.

Other authors, including Gupta et al. and Metcalf et al., have utilized body mass index (BMI) and SB to adjust self-reported SB values with accelerometry data, corroborating our findings [14–16]. Our study similarly found that self-reported SB and occupation-related SB were significant predictors of accelerometry values, consistent with the findings of Gupta et al. [14, 15]. In addition to the formerly mentioned variables, we investigated glucose and triglycerides as predictors of SB in the correction model. The rationale for including these biomarkers is their associations with lifestyle factors such as diet and physical activity [26–28]. While biochemical parameters like glucose and triglycerides may limit the utility of our correction model, they are not prohibitively costly and offer the advantage of providing a more accurate estimation of lifestyle behaviors.

It is relevant to emphasize that accelerometers are precise instruments employed as reference methods to validate self-reported instruments. Cleland and colleagues reported poor correlation and agreement between self-reported data from the Global Physical Activity Questionnaire (GPAQ) and accelerometer measures [31]. They found an average difference of nearly 6 h between self-reported sedentary SB and accelerometer data, similar to the difference observed in our study. Given the low agreement between self-reported SB and accelerometer values, the importance of conducting correction processes, such as the one proposed in this study, becomes evident.

While accelerometers offer accurate measurements of sedentary time, their stringent requirements for obtaining valid data restrict their utility in large population samples and surveillance efforts. In our study, only around 35% of participants complied with wearing accelerometers for a minimum of 10 h on at least four days, including one weekend day. This compliance rate is lower than that reported in other population studies, such as NHANES. The limited adherence to accelerometer protocols hampers their application in large-scale studies [32]. Therefore, the correction or calibration of self-reported SB may present a cost-effective solution to enhance accuracy in estimating this behavior in epidemiological settings.

Once we applied the SB correction model, in the third stage of our study, our analysis revealed that each additional hour of self-reported corrected sedentary behavior was associated with an increase of 0.847 kg in fat mass. Other researchers have also noted an association between SB and increased body weight and fat mass among different populations [4, 33, 34]. Golubic et al. reported a change in fat mass of 1.5 kg for every 1.5 h of SB over seven years of follow-up, equivalent to a 0.990 kg increase in body fat per additional hour of SB, a magnitude of association similar to our findings [29].

Meanwhile, Drenowatz et al. found that each hour increase in SB was associated with a 0.064% increase in body fat after one year of follow-up, translating to a 0.017 kg gain in body fat. This association was specific to adults with obesity and observed during weekends; however, when the fat change during weekdays was added, the total fat change amounted to 0.030 kg per year for every hour of SB. After extrapolating the one-year results found by Drenowatz et al. to a 6.8-year follow-up period, the total fat mass increment would be 0.205 kg, which is lower than what we observed in our study. These discrepancies between our findings and those of Drenowatz et al. may be attributed to differences in the age distribution of our study populations. Participants in the Drenowatz study were aged between 30 and 40 years, an age range associated with lower rates of body fat accumulation [9]. More significant fat gain is typically observed later in life when there is a more pronounced loss of muscle and bone mass [35, 36]. However, there remains a lack of consensus regarding the relationship between SB and body fat mass.

This study is not free of limitations. Firstly, the interval between the 2004 and 2010 assessments spanned over six years without intermediate measurements. The extended study period may introduce memory bias and restrict our ability to obtain detailed information about lifestyle changes. This limitation could hinder our comprehensive understanding of these changes and impede our ability to design interventions effectively. Secondly, the sample size for the correction study was limited. However, the sample of 142 subjects is comparable to the size of the sample used in Metcalf's calibration study [16]. The limitation associated with non-corrected self-reported sedentary behavior also applies to self-reported physical activity. Despite our efforts to develop a correction model for physical activity, we were unsuccessful. The models we obtained did not accurately predict physical activity measured with accelerometry. Future efforts in this area are strongly recommended to improve the prediction of the association between SB and body fat mass and enhance our understanding of movement behaviors and their association with health outcomes.

In conclusion, our study revealed that each additional hour spent in SB was associated with an increase in fat mass of approximately 0.847 kg over an average follow-up period of 6.8 years. This association closely aligns with findings from studies that utilized accelerometry to measure sedentary behavior, validating our correction approach. Our results accentuate the importance of examining the association between SB and excess body fat, particularly in societies with high rates of overweight and obesity, like the Mexican population. Moving forward, further research investigating SB and its determinants' impact on the obesity epidemic is crucial for developing effective population-level prevention strategies.

Abbreviations

SB	Sedentary behaviors
HWCS	Health Worker Cohort Study
DXA	Dual X-ray absorptiometry
DMT2	Diabetes Mellitus Type 2
MET	Metabolic equivalent
CPM	Counts per minute
WHO	World Health Organization
BMI	Body mass index
GLM	Generalized linear model
DAG	Acyclic causal diagram
HRMs	Heart rate monitors
BIE	Bioelectrical impedance
GPAQ	Global physical activity questionnaire

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Authors' contributions

NM conceptualized this work, curated data, performed formal statistical analysis, self-reported validation study performance SB, and wrote the original draft, including model creation. EM took on leadership responsibility for performing statistical analysis and reviewing and editing. JS provided study materials mentorship to the core team and contributed to manuscript review and editing. JMO curated data and contributed to manuscript review and editing. YNF contributed to the conceptualization of the validation study, as well as writing, reviewing, and editing the manuscript. AJ and DS reviewed the validation study, provided accelerometers, and contributed to manuscript review and editing. UV and AGO were involved in accelerometer data processing, manuscript review, and editing. KG took on leadership responsibility for research activity planning and execution, including external mentorship and model creation, in addition to manuscript review and editing.

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Availability of data and materials

The datasets and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The study protocol was conducted according to the guidelines in the Declaration of Helsinki. All procedures involving research study participants were approved by the IRBs of the Mexican Social Security Institute (2005–785-012), the National Institute of Public Health (13CEI 17 007 36), and the Autonomous University of the Mexico State (1233008X0236). Written informed consent was obtained from all participants.

Consent for publication

"Not applicable".

Competing interests

The authors declare no competing interests.

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