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Original article

# Association of daily sitting time and leisure-time physical activity with body fat among U.S. adults

Jingwen Liao [a,b,†,*], Min Hu [a,†], Kellie Imm [c], Clifton J. Holmes [d,e], Jie Zhu [f], Chao Cao [d,e], Lin Yang [g,h]

[a] *Guangdong Provincial Key Laboratory of Physical Activity and Health Promotion, Guangzhou Sport University, Guangzhou 510500, China*
[b] *Scientific Research Center, Guangzhou Sport University, Guangzhou 510500, China*
[c] *Division of Epidemiology & Genetics, Department of Population and Public Health Sciences, Keck School of Medicine of the University of Southern California, Los Angeles, CA 90033, USA*
[d] *Program in Physical Therapy, Washington University School of Medicine, St. Louis, MO 63110, USA*
[e] *Center for Human Nutrition, Washington University School of Medicine, St. Louis, MO 63110, USA*
[f] *Department of Plastic and Reconstructive Surgery, Shanghai East Hospital, Tongji University, Shanghai 200070, China*
[g] *Department of Cancer Epidemiology and Prevention Research, Alberta Health Services, Calgary T2S 3C3, Canada*
[h] *Department of Oncology and Community Health Sciences, University of Calgary, Calgary T2N 1N4, Canada*

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**Abstract**

*Background*: Prolonged sitting and reduced physical activity lead to low energy expenditures. However, little is known about the joint impact of daily sitting time and physical activity on body fat distribution. We investigated the independent and joint associations of daily sitting time and physical activity with body fat among adults.

*Methods*: This was a cross-sectional analysis of U.S. nationally representative data from the National Health and Nutrition Examination Survey 2011–2018 among adults aged 20 years or older. Daily sitting time and leisure-time physical activity (LTPA) were self-reported using the Global Physical Activity Questionnaire. Body fat (total and trunk fat percentage) was determined via dual X-ray absorptiometry.

*Results*: Among 10,808 adults, about 54.6% spent 6 h/day or more sitting; more than one-half reported no LTPA (inactive) or less than 150 min/week LTPA (insufficiently active) with only 43.3% reported 150 min/week or more LTPA (active) in the past week. After fully adjusting for sociodemographic data, lifestyle behaviors, and chronic conditions, prolonged sitting time and low levels of LTPA were associated with higher total and trunk fat percentages in both sexes. When stratifying by LTPA, the association between daily sitting time and body fat appeared to be stronger in those who were inactive/insufficiently active. In the joint analyses, inactive/insufficiently active adults who reported sitting more than 8 h/day had the highest total (female: 3.99% (95% confidence interval (95%CI):3.09%–4.88%); male: 3.79% (95%CI: 2.75%–4.82%)) and trunk body fat percentages (female: 4.21% (95%CI: 3.09%–5.32%); male: 4.07% (95%CI: 2.95%–5.19%)) when compared with those who were active and sitting less than 4 h/day.

*Conclusion*: Prolonged daily sitting time was associated with increased body fat among U.S. adults. The higher body fat associated with 6 h/day sitting may not be offset by achieving recommended levels of physical activity.

**Keywords:** Adults; Body fat distribution; Physical activity; Sitting time

## 1. Introduction

Sedentary behavior, which is defined as any waking behavior with energy expenditure 1.5 metabolic equivalents or fewer that is performed in a sitting, reclining, or lying posture,[1] is becoming increasingly prevalent in the population and is associated with a range of negative health effects.[2]

Emerging evidence from large-scale epidemiologic studies has suggested an association of sedentary behaviors, particularly prolonged sitting time, with higher risks of cardiovascular disease (CVD), diabetes,[3] cancer,[4] and overall mortality,[5–9] independent of physical activity levels. In a recent population-based study, prolonged sitting time was associated with higher risk of CVD and premature death in 21 low- to high-income

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* Corresponding author.
*E-mail address:* liaojw@gzsport.edu.cn (J. Liao).
† These two authors contributed equally to this work.

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countries, with the strongest associations observed in low- to middle-income countries.[10] Meanwhile, several studies that have analyzed these associations jointly have suggested that the elevated disease risks associated with sedentary behavior could be offset by meeting the physical activity guidelines.[5,6] Given the emerging evidence and increasing trend in sedentary behavior, the World Health Organization updated the guidelines on physical activity and sedentary behavior in 2020 and for the first time recommended limiting sedentary time and replacing sedentary behaviors with any physical activity to increase health benefits.[11] However, due to the low certainty level of the evidence, no quantitative guideline on sedentary behaviors could be made. To date, few studies have been conducted to examine the potential biological mechanisms underlying the joint association of sedentary behaviors and physical activity with disease outcomes at the population level.

Obesity is a national epidemic in the United States. In 2017−2018, researchers concluded that more than 40% of US adults were obese, and this was consistent between men and women as well as across age groups.[12] Excess fat accumulation, particularly in the abdominal region, is associated with metabolic dysregulation and increased risk of cardiometabolic disease and premature death.[13−15] Some experimental studies in the lab setting have suggested that prolonged sitting and reduced physical activity resulted in a lack of muscle contractions and low energy expenditure, leading to weight gain and obesity.[16−18] Other studies have suggested that prolonged sitting was consistently associated with a higher body mass index and waist circumference, which are markers of obesity,[19,20] but inconsistently associated with body fatness and fat accumulation.[21−24] Few studies have used validated measures of body fat (i.e., dual X-ray absorptiometry (DXA)) to investigate the impact of prolonged sitting on fat accumulation by body region, particularly at the population level. Also, the existing literature indicates that the effect of sedentary behaviors and physical activity on health outcomes might differ by sex.[25,26] Despite well-documented differences in fat accumulation and exercise habits by sex,[27,28] few studies have examined the sex-specific associations of sitting time and physical activity with body fat accumulation.

To address these knowledge gaps, the present study aimed to investigate the independent and joint associations of daily sitting time and leisure-time physical activity (LTPA) with DXA-measured body fat among a nationally representative sample of U.S. adults.

## 2. Methods

### 2.1. Study population

We obtained data from the National Health and Nutrition Examination Survey (NHANES), a continuous survey using a cross-sectional, stratified, multistage probability sampling method to obtain a representative sample of the U.S. population every 2 years since 1999. All NHANES protocols were approved by the Ethics Review Board of the U.S. National Center for Health Statistics, and written informed consent was provided by each participant. Detailed descriptions of the survey have been published elsewhere.[2,29,30] The present study included adults aged 20−59 years from 4 NHANES cycles (2011−2012, 2013−2014, 2015−2016, and 2017−2018) who had complete information on self-reported daily sitting time and LTPA as well as whole body DXA-measured fat (Supplementary Fig. 1). The NHANES data used are publicly available. The statistical code and working dataset are available from the corresponding author upon reasonable request.

### 2.2. Daily sitting time and LTPA

Self-reported time spent on daily sitting and weekly LTPA were based on respondent-level interviews using the Global Physical Activity Questionnaire.[2,31] Participants were asked to recall, “On a typical day, how much time do you usually spend sitting at school, at home, getting to and from places, or with friends, including time spent sitting at a desk, traveling in a car or bus, reading, playing cards, watching television, or using a computer (except for time spent sleeping)?” Responses were converted to hours per day and further categorized into: 0 to less than 4, 4 to less than 6, 6−8, and 8 h/day or more, which is in line with the recent studies.[5−7] The total time spent on LTPA was calculated as minutes of moderate- intensity recreational activities plus twice the minutes of vigorous-intensity recreational activities. According to the 2018 Physical Activity Guidelines for American adults: people without any LTPA, with LTPA more than 0 but less than 150 min/week, and with LTPA 150 min/week or more in the past week were classified as inactive, insufficiently active, and sufficiently active, respectively.[32]

### 2.3. Measurement of body fat

Whole body fat was determined by DXA scans acquired on a Hologic Discovery A, using software Version APEX 3.2 (Hologic, Bedford, MA, USA).[33] NHANES applied specific exclusion criteria to determine the eligibility of participants for DXA examination (i.e., ≥60 years; pregnant or menstruating women; self-reported body mass of more than 450 pounds, or height greater than 195.58 cm, and self-reported history of radiographic contrast material (barium) use in the past 7 days). The software Version APEX 4.0 (Hologic) was used to analyze the DXA examinations and provide the body composition data.[33] Fat percentages for total body (including the head, limbs, and trunk area) and trunk (only the trunk area) were derived to measure the magnitude and distribution of body fat. DXA-measured trunk fat reflects the fat accumulation in the central region of body (e.g., abdomen) and is a reliable and accurate surrogate of abdominal fat.[34]

### 2.4. Assessment of covariates

The covariates included sociodemographic data (age, sex, race/ethnicity, education attainment, and family poverty ratio), lifestyle behaviors (smoking status, alcohol use, total energy intake, and healthy eating index-2015 (HEI-2015)), and chronic conditions (hypertension, hypercholesterolemia, history of diabetes, history of CVDs, history of cancer, and

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depression). Race/ethnicity was categorized as non-Hispanic White, non-Hispanic Black, Hispanic, and other. Educational attainment was categorized as less than high school diploma (less than high school), high school graduate, and some college graduate or more (more than high school). Family poverty ratio was defined as the ratio of family income to the federal poverty level and categorized as <1.3, 1.3 to <3.5, and ≥3.5. Total energy intake and HEI-2015 were derived from a 24-h dietary interview. The HEI-2015 is a measure for assessing dietary quality and aligns with the Dietary Guidelines for Americans[35]; scores range from 0 to 100, with higher scores reflecting better diet quality.

Hypertension was determined by participants receiving a diagnosis from a health professional or NHANES-measured blood pressure 130 mmHg or more systolic or 80 mmHg or more diastolic. Hypercholesterolemia was determined by participants receiving a diagnosis from a health professional or NHANES-measured total cholesterol level of 240 mg/dL or more (to convert to millimoles per liter, multiply by 0.0259). History of chronic diseases (diabetes, CVD, and cancer) was determined by participants receiving these diagnoses from health professionals or if participants were instructed to take prescribed medications for these conditions. Depression was assessed using the Patient Health Questionnaire and individuals with Patient Health Questionnaire scores of 10 or more were considered as having major depression.[36]

### 2.5. Patient and public involvement

Neither patients nor the public were directly involved in the design, conduct, reporting, or dissemination of the present study.

### 2.6. Statistical analysis

Following the NHANES analytic guidelines, all analyses accounted for the unequal probability of selection, oversampling of certain subpopulations, and nonresponse adjustments to ensure nationally representative estimates.[2,29] Sample sizes and weighted percentages were calculated according to participants' characteristics and sex. Multivariable weighted linear regression models were applied to estimate $\beta$-coefficient and 95% confidence intervals (95%CIs) for the association of daily sitting time and LTPA with total and trunk fat percentages. Final-stage multivariable models were adjusted for age, sex, race/ethnicity, educational attainment, family poverty ratio, smoking status, alcohol use, HEI-2015, hypertension, hypercholesterolemia, history of diabetes, CVD, cancer, and depression. To examine joint associations, participants were classified based on daily sitting time and LTPA in order to estimate $\beta$-coefficient and 95%CIs using multivariable linear regression models adjusted for the same set of covariates. Dose−response relationships between sitting time and body fat percentages were evaluated using sitting time as a continuous variable (h/day). All analyses were conducted separately among females and males due to the biological difference in body composition. Multiple datasets were aggregated using SAS 9.4 (SAS Institute, Cary, NC, USA), and all statistical tests were done using Stata, Version 16.0 (StataCorp., College Station, TX, USA). Statistical tests were two-sided, and statistical significance was set at a $p$ value of less than 0.05.

## 3. Results

A total of 10,808 adults (weighted population: 127,746,295; age = 39.4 ± 0.2 years, mean ± SE; 5371 (49.7%) males) were included, and participant characteristics were presented by sex in Table 1. Approximately 54.6% of adults spent 6 or more h/day sitting, while 40.6% reported no LTPA (inactive), 16.1% reported less than 150 min/week LTPA (insufficiently active), and 43.3% reported 150 min/week or more LTPA (active) in the past week.

Table 1
Characteristics of U.S. Adults aged 20−59 years, according to sex, from NHANES 2011−2018.[a]

| | No. of participants (weighted%) | | |
|---|---|---|---|
| | All | Female | Male |
| Overall | 10,808 (100) | 5437 (100) | 5371 (100) |
| Race/ethnicity | | | |
| Non-Hispanic White | 3741 (61.3) | 1889 (62.1) | 1852 (60.5) |
| Non-Hispanic Black | 2261 (11.2) | 1136 (11.3) | 1125 (11.0) |
| Hispanic | 2746 (17.9) | 1436 (17.1) | 1310 (18.7) |
| Other | 2060 (9.6) | 976 (9.5) | 1084 (9.8) |
| Family poverty ratio | | | |
| <1.3 | 3222 (21.9) | 1689 (23.0) | 1533 (20.8) |
| 1.3 to <3.5 | 4441 (38.8) | 2179 (37.7) | 2262 (39.8) |
| ≥3.5 | 3145 (39.3) | 1569 (39.3) | 1576 (39.4) |
| Education | | | |
| <High school | 1976 (13.0) | 897 (11.6) | 1079 (14.3) |
| High school | 2360 (21.7) | 1064 (18.7) | 1296 (24.6) |
| >High school | 6472 (65.3) | 3476 (69.7) | 2996 (61.1) |
| Smoking status | | | |
| Never | 6590 (59.1) | 3725 (64.7) | 2865 (53.6) |
| Past | 1793 (19.3) | 713 (16.0) | 1080 (22.6) |
| Current | 2425 (21.6) | 999 (19.3) | 1426 (23.8) |
| Diabetes | | | |
| No | 10,008 (94.2) | 5037 (94.4) | 4971 (94.0) |
| Yes | 800 (5.8) | 400 (5.6) | 400 (6.0) |
| Cardiovascular disease | | | |
| No | 10,388 (96.8) | 5230 (96.9) | 5158 (96.7) |
| Yes | 420 (3.2) | 207 (3.1) | 213 (3.3) |
| Cancer | | | |
| No | 10,473 (96.4) | 5192 (94.9) | 5281 (97.9) |
| Yes | 335 (3.6) | 245 (5.1) | 90 (2.1) |
| Daily sitting time (h/day) | | | |
| <4 | 2690 (22.2) | 1333 (21.6) | 1357 (22.9) |
| 4 to <6 | 2524 (23.2) | 1252 (23.4) | 1272 (23.0) |
| 6−8 | 3149 (28.9) | 1588 (28.8) | 1561 (29.0) |
| >8 | 2445 (25.7) | 1264 (26.2) | 1181 (25.1) |
| LTPA | | | |
| Inactive | 4835 (40.6) | 2547 (41.5) | 2288 (39.8) |
| Insufficiently active | 1641 (16.1) | 931 (17.6) | 710 (14.5) |
| Physically active | 4332 (43.3) | 1959 (40.9) | 2373 (45.7) |

[a] Sample size was weighted to be nationally representative.
Abbreviations: LTPA = leisure-time physical activity; NHANES = National Health and Nutrition Examination Survey.

### 3.1. Daily sitting time and body fat

Prolonged daily sitting time was associated with greater total and trunk fat percentage in both females and males after adjusting for sociodemographic and lifestyle factors and chronic conditions (Table 2). Specifically, females and males who spent more than 8 h/day sitting had 1.97% (95%CI: 1.39%−2.55%) and 1.84% (95%CI: 1.06% −2.62%) higher total fat, respectively, compared with those who spent less than 4 h/day sitting. Meanwhile, females and males who spent more than 8 h/day sitting had 1.91% (95%CI: 1.11%−2.70%) and 2.03% (95%CI: 1.16%−2.90%) higher trunk fat, respectively. A significant dose−response relationship was exhibited between daily sitting time and body fat percentage, such that each 1 h/day increase in daily sitting time was associated with 0.23% (95%CI: 0.17%−0.29%) and 0.20% (95%CI: 0.13%−0.27%) higher total body fat among females and males, respectively, while these increases were 0.23% (95%CI: 0.14%−0.31%) and 0.22% (95%CI: 0.14%−0.30%) for trunk fat.

### 3.2. LTPA and body fat

Being physically active was associated with lower total and trunk fat percentages (Table 2). Adults engaging in sufficient LTPA tended to have lower total (female: −2.15%, 95%CI: −2.69% to −1.61%; male: −1.98%, 95%CI: −2.52% to −1.45%) and trunk (female: −2.26%, 95%CI: −2.96% to −1.57%; male: −2.12%, 95%CI: −2.71% to −1.52%) fat compared with those who were inactive after adjusting for sociodemographic factors, lifestyle behaviors, and health conditions. Among females, those engaged in insufficient LTPA also had lower total fat (−0.63%, 95%CI: −1.10% to −0.15%) and trunk fat (−0.67%, 95%CI: −1.31% to −0.04%) than those who were inactive, but this association was attenuated to null after additionally adjusting for lifestyle behaviors and chronic conditions (total fat: −0.47%, 95%CI: −0.97% to 0.03%; trunk fat: −0.55%, 95%CI: −1.22% to 0.13%). Similar findings were observed in males who engaged in insufficient LTPA.

### 3.3. Daily sitting time and LTPA with body fat

In the analysis stratified by LTPA, prolonged daily sitting time was associated with higher total and trunk fat among adults who were physically active and inactive/insufficiently active (Table 3). Compared to sitting less than 4 h/day, sitting more than 8 h/day was associated with 1.75% (95%CI: 0.75%−2.75%) and 1.47% (95%CI: 0.55%−2.38%) higher total fat and 1.65% (95%CI: 0.44%−2.87%) and 1.71% (95%CI: 0.73%−2.70%) higher trunk fat among physically active females and males, respectively. For those who were inactive/insufficiently active, sitting more than 8 h/day was associated with 1.91% (95%CI: 1.25%−2.58%) and 2.13%

Table 2
Association of daily sitting time and LTPA with total and trunk fat percentage among U.S. adults ≥20 years, NHANES 2011−2018.

| | β-Coefficient (95%CI) | | | | | |
|---|---|---|---|---|---|---|
| | Total fat percentage | | | Trunk fat percentage | | |
| | MV Model 1[a] | MV Model 2[a,b] | MV Model 3[a,b,c] | MV Model 1[a] | MV Model 2[a,b] | MV Model 3[a,b,c] |
| Male | | | | | | |
| Daily sitting time (h/day) | | | | | | |
| <4 | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) |
| 4 to <6 | 0.54 (−0.06 to 1.14) | 0.68 (0.08 to 1.29) | 0.53 (−0.11 to 1.18) | 0.70 (0.03 to 1.37) | 0.87 (0.19 to 1.55) | 0.66 (−0.05 to 1.38) |
| 6−8 | 1.49 (0.88 to 2.11) | 1.42 (0.78 to 2.07) | 1.30 (0.64 to 1.97) | 1.65 (0.97 to 2.33) | 1.57 (0.86 to 2.28) | 1.44 (0.70 to 2.19) |
| >8 | 1.90 (1.17 to 2.62) | 1.87 (1.11 to 2.63) | 1.84 (1.06 to 2.62) | 2.05 (1.22 to 2.89) | 2.07 (1.20 to 2.93) | 2.03 (1.16 to 2.90) |
| Per 1 h/day increase | 0.21 (0.14 to 0.28) | 0.20 (0.13 to 0.27) | 0.20 (0.13 to 0.27) | 0.22 (0.14 to 0.30) | 0.21 (0.13 to 0.30) | 0.22 (0.14 to 0.30) |
| LTPA | | | | | | |
| Inactive | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) |
| Insufficiently active | −0.65 (−1.43 to 0.13) | −0.56 (−1.31 to 0.19) | −0.51 (−1.24 to 0.21) | −0.73 (−1.63 to 0.16) | −0.64 (−1.48 to 0.20) | −0.66 (−1.47 to 0.15) |
| Physically active | −2.41 (−2.96 to −1.86) | −2.13 (−2.68 to −1.59) | −1.98 (−2.52 to−1.45) | −2.55 (−3.15 to −1.95) | −2.26 (−2.87 to −1.64) | −2.12 (−2.71 to −1.52) |
| Female | | | | | | |
| Daily sitting time (h/day) | | | | | | |
| <4 | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) |
| 4 to <6 | 0.56 (0.01 to 1.12) | 0.62 (0.08 to 1.16) | 0.53 (−0.04 to 1.10) | 0.63 (−0.06 to 1.33) | 0.70 (0.03 to 1.37) | 0.65 (−0.07 to 1.38) |
| 6−8 | 1.45 (0.89 to 2.00) | 1.39 (0.85 to 1.94) | 1.24 (0.73 to 1.75) | 1.62 (0.90 to 2.34) | 1.55 (0.87 to 2.24) | 1.32 (0.67 to 1.98) |
| >8 | 2.22 (1.64 to 2.80) | 2.17 (1.61 to 2.73) | 1.97 (1.39 to 2.55) | 2.29 (1.47 to 3.12) | 2.19 (1.40 to 2.98) | 1.91 (1.11 to 2.70) |
| Per 1 h/day increase | 0.26 (0.19 to 0.32) | 0.25 (0.18 to 0.31) | 0.23 (0.17 to 0.29) | 0.27 (0.18 to 0.36) | 0.26 (0.17 to 0.34) | 0.23 (0.14 to 0.31) |
| LTPA | | | | | | |
| Inactive | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) |
| Insufficiently active | −0.63 (−1.10 to −0.15) | −0.55 (−1.05 to −0.05) | −0.47 (−0.97 to 0.03) | −0.67 (−1.31 to −0.04) | −0.57 (−1.22 to 0.08) | −0.55 (−1.22 to 0.13) |
| Physically active | −2.77 (−3.27 to −2.26) | −2.34 (−2.87 to −1.82) | −2.15 (−2.69 to −1.61) | −3.05 (−3.73 to −2.37) | −2.50 (−3.19 to −1.80) | −2.26 (−2.96 to −1.57) |

[a] Multivariable model additionally adjusted for age (year), sex (male or female), race (non-Hispanic White, non-Hispanic Black, Hispanic, and other), educational attainment (less than high school, high school graduate, above high school), and family poverty ratio (<1.3, 1.3 to <3.5, and ≥3.5).
[b] Additionally adjusted for smoking status (never, former, and current), alcohol use (never, former, and current), total energy intake, and Healthy Eating Index−2015.
[c] Additionally adjusted for hypertension (yes or no), hypercholesterolemia (yes or no), history of diabetes (yes or no), history of CVD (yes or no), history of cancer (yes or no), and depression (yes or no).
Abbreviations: 95%CI = 95% confidence interval; CVD = cardiovascular disease; LTPA = leisure-time physical activity; MV = multivariable; NHANES = National Health and Nutrition Examination Survey.

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Table 3
Association of daily sitting time with total and trunk fat percentage among U.S. adults ≥20 years, stratified by leisure-time physical activity, NHANES 2011−2018.

| Daily sitting time (h/day) | β-Coefficient (95%CI) | | | | | |
|---|---|---|---|---|---|---|
| | Total fat percentage | | | Trunk fat percentage | | |
| | MV Model 1[a] | MV Model 2[a,b] | MV Model 3[a,b,c] | MV Model 1[a] | MV Model 2[a,b] | MV model 3[a,b,c] |
| Male | | | | | | |
| Physically active | | | | | | |
| <4 | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) |
| 4 to <6 | 0.69 (−0.37 to 1.75) | 0.70 (−0.34 to 1.75) | 0.56 (−0.52 to 1.64) | 0.86 (−0.3 to 2.02) | 0.85 (−0.31 to 2.01) | 0.72 (−0.43 to 1.87) |
| 6−8 | 1.24 (0.40 to 2.07) | 1.14 (0.30 to 1.98) | 1.15 (0.25 to 2.06) | 1.13 (0.21 to 2.04) | 1.05 (0.14 to 1.97) | 1.30 (0.31 to 2.30) |
| >8 | 1.68 (0.86 to 2.50) | 1.70 (0.87 to 2.54) | 1.47 (0.55 to 2.38) | 1.60 (0.68 to 2.51) | 1.71 (0.78 to 2.64) | 1.71 (0.73 to 2.70) |
| Inactive/insufficiently active | | | | | | |
| <4 | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) |
| 4 to <6 | 0.22 (−0.54 to 0.98) | 0.48 (−0.27 to 1.23) | 0.35 (−0.47 to 1.17) | 0.27 (−0.62 to 1.16) | 0.58 (−0.30 to 1.46) | 0.44 (−0.52 to 1.39) |
| 6−8 | 1.79 (0.98 to 2.59) | 1.70 (0.88 to 2.51) | 1.46 (0.61 to 2.31) | 1.80 (0.96 to 2.64) | 1.68 (0.82 to 2.53) | 1.56 (0.66 to 2.47) |
| >8 | 2.31 (1.28 to 3.35) | 2.22 (1.17 to 3.28) | 2.13 (1.04 to 3.23) | 2.14 (0.97 to 3.32) | 2.10 (0.92 to 3.28) | 2.24 (1.04 to 3.43) |
| Female | | | | | | |
| Physically active | | | | | | |
| <4 | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) |
| 4 to <6 | 0.32 (−0.64 to 1.28) | 0.33 (−0.61 to 1.27) | 0.34 (−0.63 to 1.31) | 0.36 (−0.80 to 1.51) | 0.39 (−0.77 to 1.54) | 0.64 (−0.54 to 1.82) |
| 6−8 | 1.18 (0.39 to 1.98) | 1.11 (0.31 to 1.91) | 1.36 (0.54 to 2.17) | 1.30 (0.32 to 2.28) | 1.22 (0.25 to 2.18) | 1.65 (0.65 to 2.65) |
| >8 | 1.76 (0.79 to 2.73) | 1.62 (0.66 to 2.57) | 1.75 (0.75 to 2.75) | 1.64 (0.45 to 2.84) | 1.42 (0.24 to 2.60) | 1.65 (0.44 to 2.87) |
| Inactive/insufficiently active | | | | | | |
| <4 | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) | 0 (reference) |
| 4 to <6 | 0.77 (0.09 to 1.45) | 0.91 (0.24 to 1.58) | 0.75 (0.07 to 1.42) | 0.89 (0.02 to 1.76) | 1.03 (0.21 to 1.84) | 0.78 (−0.02 to 1.58) |
| 6−8 | 0.86 (0.14 to 1.58) | 0.79 (0.10 to 1.47) | 0.89 (0.20 to 1.59) | 0.91 (−0.06 to 1.88) | 0.79 (−0.10 to 1.69) | 0.79 (−0.08 to 1.65) |
| >8 | 1.86 (1.15 to 2.56) | 1.87 (1.18 to 2.57) | 1.91 (1.25 to 2.58) | 2.03 (0.98 to 3.09) | 2.03 (0.99 to 3.06) | 1.86 (0.92 to 2.81) |

[a] Multivariable model additionally adjusted for age (years), sex (male or female), race (non-Hispanic White, non-Hispanic Black, Hispanic, and other), educational attainment (less than high school, high school graduate, above high school), and family poverty ratio (<1.3, 1.3 to <3.5, and ≥3.5).
[b] Additionally adjusted for smoking status (never, former, and current), alcohol use (never, former, and current), total energy intake, and Healthy Eating Index-2015.
[c] Additionally adjusted for hypertension (yes or no), hypercholesterolemia (yes or no), history of diabetes (yes or no), history of CVD (yes or no), history of cancer (yes or no), and depression (yes or no).
Abbreviations: 95%CI = 95% confidence interval; CVD = cardiovascular disease; MV = multivariable. NHANES = National Health and Nutrition Examination Survey.

(95%CI: 1.04% −3.23%) higher total fat and 1.86% (95%CI: 0.92%−2.81%) and 2.24% (95%CI: 1.04% to 3.43%) higher trunk fat among females and males, respectively.

In the joint analyses, we observed higher total and trunk fat percentages in the least active group (insufficiently active/inactive and sitting >8 h/day) as compared to the most active group (sufficiently active and sitting <4 h/day) (Figs. 1−2 and Supplemental Table 1). In the least group, females and males had 3.99% (95%CI: 3.09%−4.88%) and 3.79% (95%CI: 2.75%−4.82%) higher total fat and 4.21% (95%CI: 3.09%−5.32%) and 4.07% (95%CI: 2.95%−5.19%) higher trunk fat, respectively, when compared to the most active group. Notably, the higher total and trunk fat percentages compared to the most active group indicated statistical significance starting from the combination of sufficiently active and 6−8 h/day sitting time.

## 4. Discussion

In this nationally representative sample of U.S. adults, approximately two-thirds of participants spent 6 or more h/day sitting, and more than one-half reported not achieving 150 min/week of LTPA. In both females and males, prolonged daily sitting time was associated with higher total and trunk fat percentages, independent of LTPA levels. In the joint analysis, combinations of prolonged sitting and low LTPA were associated with significantly increased total and trunk body fat percentages. Of all groups, insufficiently active/inactive adults with more than 8 h/day sitting had the highest body fat percentages. Achieving the physical activity guideline of more than 150 min/week of LTPA does not appear to offset the negative effects on body fat of sitting 6 or more h/day. Nevertheless, adults who met the guideline had substantially lower levels of body fat than those who did not.

To our knowledge, this is the first study to investigate the independent and joint association of sitting time and LTPA with body fat in a nationally representative sample of U.S. adults. The association between sedentary behaviors and measures of adiposity (i.e., body weight, body mass index, or waist circumference) has been examined with inconsistent findings.[21] The negative effects of sedentary behavior on health calls for more accurate and direct measurement of fat accumulation among large populations. A previous study based on a sample of U.S. adults using DXA only suggested that objectively-measured sedentary time was significantly associated with obesity in adults when accounting for LTPA, but it did not provide dose−response evidence.[37] Among U.S. adults, association of objectively measured sedentary behavior and fat accumulation (as measured by DXA) was only consistently observed with respect to total body fat percentage (after adjusting for LTPA) and not with respect to obesity or overweight categories.[20] More accurate results based on magnetic resonance imaging suggested that accelerometer-measured sedentary time might have an independent association with heart, liver, and visceral fat and that every 30-min increase in sitting time was related to higher visceral fat; however, this study was limited by its small sample size of individuals with type 2

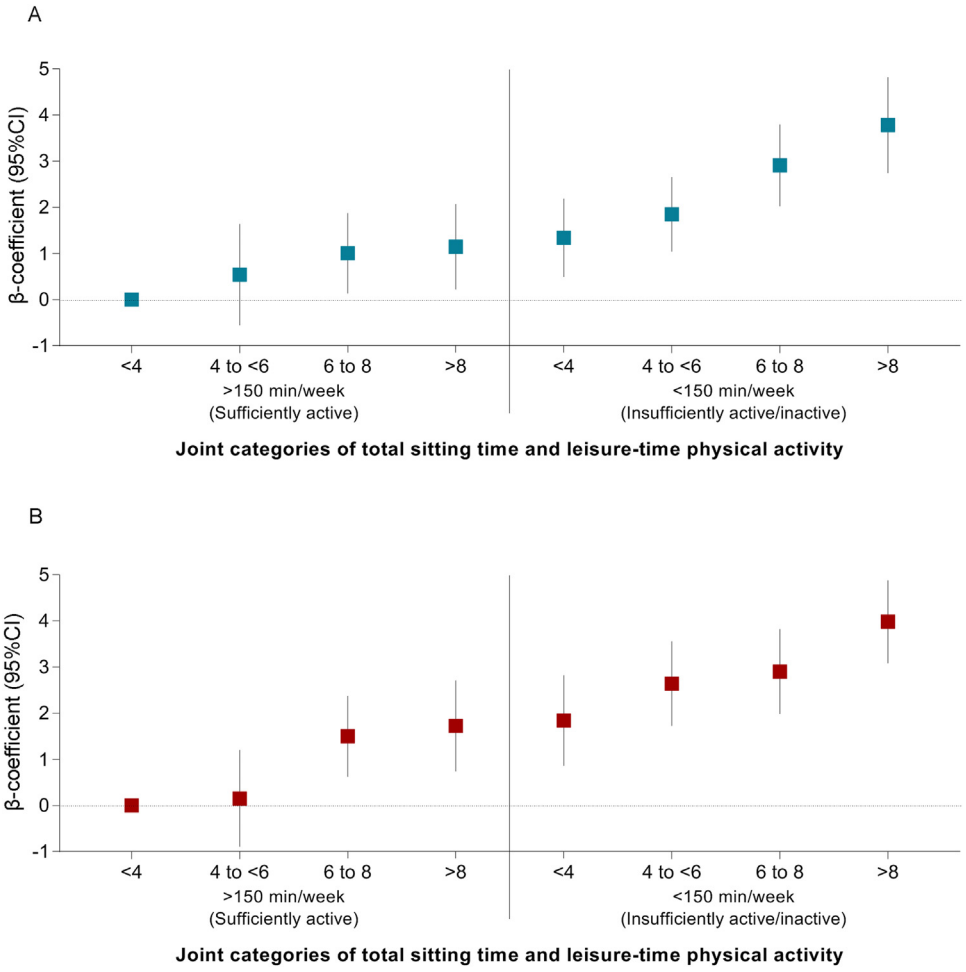


Fig. 1. Joint association of daily sitting time and leisure-time physical activity with total body fat percentage among US adults by sex, NHANES 2011−2018[a]. Joint association of daily sitting time (h/day) and leisure-time physical activity (min/week) with total fat percentage within each subgroup: (A) male and (B) female. Estimates were adjusted for age (years), sex (male or female), race (non-Hispanic White, non-Hispanic Black, Hispanic, and other), educational attainment (less than high school, high school graduate, above high school), family poverty ratio (<1.3, 1.3 to <3.5, and ≥3.5), smoking status (never, former, and current), alcohol use (never, former, and current), total energy intake and Healthy Eating Index-2015, hypertension (yes or no), hypercholesterolemia (yes or no), history of diabetes (yes or no), history of CVD (yes or no), history of cancer (yes or no), and depression (yes or no). 95%CI = 95% confidence interval; CVD = cardiovascular disease; NHANES = National Health and Nutrition Examination Survey.

diabetes.[38] None of these previous studies considered the joint association of sedentary behavior and physical activity with adiposity. This is important because despite the fact that sedentary behavior has been associated with increased all-cause mortality risk among adults, physical activity could offset the detrimental effect of prolonged sitting.[6] That is to say, achieving 150 or more min/week of LTPA could attenuate the elevated all-cause mortality risk due to prolonged sitting to null. The joint association of sitting and physical activity has been determined for other health outcomes, including incident CVD,[39] cardiometabolic health,[40] all-cause mortality,[41] and cancer survival.[7] Using a nationally representative sample of U.S. adults, the present study systematically evaluated the independent and joint associations of total sitting time and LTPA with body fat. A notable dose−response association between total sitting time and total and trunk fat was observed, and this association was exhibited not only in adults engaging in fewer than 150 min/week of LTPA, but also in those achieving 150 min/week of LTPA.

The mechanisms underlying the associations are largely unknown. At the lower end of the bodily movement continuum, large amounts of sedentary time and insufficient physical activity involve the reduction of muscle activation, which leads to decreased energy expenditure.[42] Previous studies have indicated that breaking prolonged sedentary behaviors could lead to weight loss.[16,43] Localized accumulation of adipose tissue in the abdominal area (trunk) has been reported to be the best correlate of dyslipidemia seen in the metabolic syndrome,[44] and this link may be explained by excess free fatty acid release, impaired carbohydrate oxidation and muscle glucose storage, reduced hepatic insulin clearance, and elevated triglycerides.[45] As physical activity is a major determinant of body composition (reflected by fat-free mass) and only partly contributes to accumulation of fat in aging adults,[46] sedentary behaviors may also play an important role in fat accumulation. Other hypotheses suggest that sedentariness may involve specific molecular responses, which contribute to poor lipid metabolism through suppressing skeletal muscle lipoprotein lipase activity.[47] If these

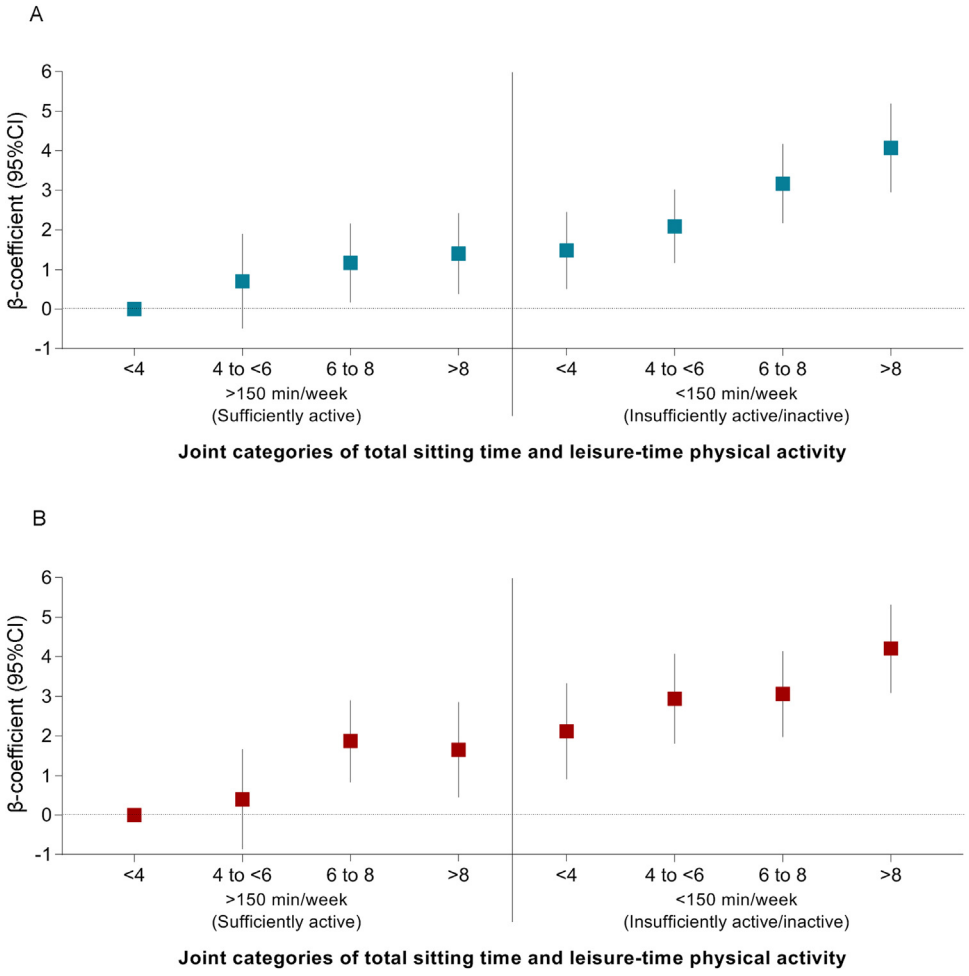


Fig. 2. Joint association of daily sitting time and leisure-time physical activity with trunk body fat percentage among US adults by sex, NHANES 2011−2018[a]. Joint association of daily sitting time (h/day) and leisure-time physical activity (min/week) with trunk fat percentage within each subgroup: (A) male and (B) female. Estimates were adjusted for age (years), sex (male or female), race (non-Hispanic White, non-Hispanic Black, Hispanic, and other), educational attainment (less than high school, high school graduate, above high school), family poverty ratio (<1.3, 1.3 to <3.5, and ≥3.5), smoking status (never, former, and current), alcohol use (never, former, and current), total energy intake and Healthy Eating Index-2015, hypertension (yes or no), hypercholesterolemia (yes or no), history of diabetes (yes or no), history of CVD (yes or no), history of cancer (yes or no), and depression (yes or no). 95%CI = 95% confidence interval; CVD = cardiovascular disease; NHANES = National Health and Nutrition Examination Survey.

associations are causal, then it is possible that prolonged sitting time might be a critical driver of metabolic derangement, which manifests in excess accumulation of fat in the abdominal area (mainly as visceral fat). Also, there is a possible bidirectional relationship between sitting time and physical inactivity and body fat. A mendelian randomization study found a bidirectional, causal relationship between sedentary time and body mass index, which highlights not only that limiting sedentary time is beneficial for weight control, but that fat loss may also lead to reduced sedentary time.[48] Altogether with our findings, clinicians, health professionals, and policy makers need to develop effective strategies to target obese adults who spend a prolonged amount of time sitting.

The new 2020 World Health Organization Global Guidelines on Physical Activity and Sedentary Behavior underscore the need to promote physical activity among adults and, for the first time, include guidelines for sedentary behaviors (but without a specific threshold, due to limited quantified evidence with respect to health outcomes).[11] The present study suggested a dose−response association between total sitting time and body fat percentage. The significant increase in body fat percentage (total and trunk) was observed starting with 6−8 h/day of sitting among adults who achieved at least 150 min/week of LTPA and with any amount of sitting for those engaged in less than 150 min/week of LTPA. Inactive or insufficiently active adults who spent more than 8 h/day sitting tended to have the highest percentage of body fat. Our results agree with those of a previous review which suggested that 6−8 h/day of total sitting (self-reported) was a threshold for increased risk of both all-cause and CVD mortality after adjusting for physical activity.[49] Additionally, our findings using the categorization of physical activity strongly supported current national and international guidelines on physical activity. In particular, the prevalence of obese and overweight adults is strikingly high in the United States. Although the 2018 Physical Activity Guidelines for Americans

acknowledged for the first time the health risks associated with sedentary behaviors, they were not able to specify or quantify recommendations for sedentary time. Our findings could inform evidence-based strategies to reduce the burden of obesity by increasing physical activity and decreasing sedentary behaviors in the United States.

The study has several strengths. It included a large, nationally representative sample of U.S. adults, which allowed our findings to be generalizable at the population level. Further, we examined the joint effects of sitting time and physical activity on body fat, which addresses the evidence gaps to inform quantitative guidelines on limiting sedentary behavior. One limitation of the study is the self-reported measure on daily sitting and LTPA. Indeed, wearable devices are frequently used to directly measure PA and to monitor sedentary time. But with the exception of thigh-worn monitors, many devices cannot distinguish prolonged sitting from sedentary behaviors in a lying or reclining posture and are likely to misclassify time spent in stationary behaviors (e.g., standing) as part of sedentary time.[50] Additionally, the observational design uses a cross-sectional study and so cannot infer directional causality. Further research using longitudinal data is required to elucidate the causal effect of sedentary behaviors on body adiposity.

## 5. Conclusion

In this nationally representative sample of U.S. adults, the combination of prolonged sitting and a lack of PA was associated with higher total and regional body fat. The higher body fat associated with 6 h/day of sitting may not be offset by achieving more than 150 min/week physical activity. Future studies are needed to confirm the casual direction of the observed associations.

## Authors' contributions

JL contributed to the conception and design of the study, data interpretation, manuscript drafting, and administrative support; MH provided administrative, technical, and material support; KI, CJH, and JZ contributed to critical revision of the manuscript; CC and LY had full access to all the data in the study, contributed to conception and design of the study, and provided critical revision of the manuscript for important intellectual content. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

## Competing interests

The authors declare that they have no competing interests.

## Supplementary materials

Supplementary materials associated with this article can be found in the online version at doi:10.1016/j.jshs.2022.10.001.

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