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ARTICLE

Dose–response relationships between sedentary behaviour and the metabolic syndrome and its components

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Abstract
Aims/hypothesis The aim of this study was to examine the relationship among sedentary behaviour (SB) and the metabolic syndrome and its components by age, moderate-to-vigorous physical activity (MVPA) and sex.
Methods A cross-sectional analysis was performed on 2003–2006 National Health and Nutrition Examination Survey data from 5,076 adults aged ≥18 years (mean±SD=43.8±19.5). SB was measured using ActiGraph accelerometers worn for 1 week and defined as <100 counts/min. Metabolic syndrome was defined using the Adult Treatment Panel III criteria. Natural cubic spline logistic regression models were used to estimate the odds of meeting criteria for the metabolic syndrome and its components by total daily SB time and breaks in SB. Statistical interactions between SB and age, sex and MVPA were explored.
Results The prevalence of the metabolic syndrome was 19% and the average daily SB time was 8.1±2.8 h, with 90±25 breaks/day. The relationship between daily SB time and the metabolic syndrome was linear and characterised by an OR of 1.09 (95% CI 1.01, 1.18) for each hour of SB. Total SB was associated with the following components: high triacylglycerol, low HDL-cholesterol and high fasting glucose. All three associations were modified by MVPA level. No relationship between breaks in SB and the metabolic syndrome was found.
Conclusions/interpretation There appears to be no SB threshold at which the risk of the metabolic syndrome is elevated. Therefore, an effort should be made to maintain low levels of total time spent in SB and so lessen the risk of the metabolic syndrome.

Keywords Epidemiology · Metabolic syndrome X · Physical activity · Sedentary lifestyle

Abbreviations

MVPA	Moderate-to-vigorous physical activity
NHANES	National Health and Nutrition Examination Survey
SB	Sedentary behaviour

Introduction

Adults in the USA spend most of their day being sedentary. According to accelerometry data for a nationally representative sample from the 2003–2004 measurement cycle of the National Health and Nutrition Examination Survey (NHANES) [1], approximately 8 h/day are spent in sedentary behaviour (SB), that is, activities such as sitting and reclining that do not increase energy expenditure substantially [2]. Over the last 15 years, numerous studies have examined the health consequences of spending too much time in SB. A number of longitudinal studies have provided evidence for an association between SB (or proxy measures such as television viewing) and various health outcomes in adults, including increased risk of all-cause and cardiovascular disease related mortality, several site-specific cancers and type 2 diabetes [3].

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Importantly, these relationships remain after controlling for and investigating effect modification by participation in moderate-to-vigorous physical activity (MVPA).

Recently, there has been increased interest in the association between SB and the metabolic syndrome, which comprises a cluster of factors, including reduced HDL-cholesterol and elevated waist circumference, triacylglycerol, BP and fasting glucose, that are known to promote or increase the risk of developing cardiovascular disease and type 2 diabetes [4]. A number of recent studies have explored this association, including one meta-analytical review [5]. The review examined ten cross-sectional studies with an overall sample size of 21,393 and a 26.1% prevalence of the metabolic syndrome. Those in the highest quantiles of SB had a 73% increased odds (OR 1.73; 95% CI 1.55, 1.94) of the metabolic syndrome compared with those in the lowest quantiles. This relationship persisted following a sensitivity analysis including only studies that controlled for participation in physical activity. However, one area lacking in this field of inquiry is a dedicated examination of the dose–response relationship between SB and the metabolic syndrome.

Most dose–response studies have used study-specific quantiles of SB, often assessed using self-reported sitting time or television viewing as their SB measure. Studies with more accurate SB measures, such as accelerometry [6, 7], or more informative methods to address the dose–response, such as spline regression analysis [8], may be better suited to addressing this issue. However, as far as we are aware, no studies have combined both objective activity measurement and spline regression analysis to explore the association between SB and the metabolic syndrome. Therefore, we examined the dose–response relationship between SB, the metabolic syndrome and its components using a combination of accelerometry data from a representative sample of US adults and spline regression analysis to account for and more accurately describe the potential for non-linearity. We hypothesised that there would be a certain amount of SB that, once accumulated, would be related to an increased odds of the metabolic syndrome and its components, and that this amount would vary by sex, age and amount of MVPA.

Methods

Study population This study was conducted using data from NHANES, a continual US population-based survey conducted by the National Center for Health Statistics that consists of an in-home interview and a comprehensive medical examination. Each year, NHANES recruits roughly 5,000 non-institutionalised civilians using a multistage probability design with sampling domains defined by race, sex, age and income [9]. The current study's sample was drawn from the 8,363 adults aged 18 years or older who participated in an objective assessment of ambulatory activity substudy during the 2003–2004 and 2005–2006 measurement cycles. The study was approved by the National Center for Health Statistics Research Ethics Review Board and documented consent was obtained from all participants.

SB and physical activity assessment Participants of the ambulatory activity substudy wore an ActiGraph AM-7164 accelerometer (ActiGraph, Fort Walton Beach, FL, USA) for 1 week on an elastic belt over the right hip during all waking hours. Data in the form of activity counts per 1 min epoch were downloaded from the monitors upon receipt by mail. An explanation of the methods used for estimating wear time and time spent in SB and MVPA from the downloaded data has been described [10]. Briefly, monitor wear time was determined by subtracting non-wear time (i.e. periods of at least 60 consecutive minutes of no activity with an allowance for 2 consecutive minutes of observations between 1 and 100 counts) from the total daily observation time. Activity of between 1 and 100 counts/min was considered SB, while activity of at least 760 counts/min [11] with an allowance for interruptions of 1 or 2 min below threshold was considered MVPA. A valid day consisted of at least 600 min (10 h) of wear without excessive counts (>20,000 counts). Laboratory-based studies typically require 4 or more days of valid data for inclusion in their study sample. While this would have been preferable, the logistical challenges of using accelerometry in large-scale population-based surveys make this level of compliance difficult to obtain; therefore, we required at least 1 valid day to be included in the current analysis, a method consistent with the original examinations of NHANES data for MVPA [12] and SB time [1], so as to retain as many participants as possible and avoid selection bias.

Outcome and covariate assessment The primary outcome of interest in this study was the metabolic syndrome. We defined the metabolic syndrome according to the Third Report of the Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) [4]. According to these guidelines, the metabolic syndrome is the presence of three or more of the following: (1) waist circumference ≥102 cm for men and ≥88 cm for women; (2) serum triacylglycerol level of ≥1.69 mmol/l or drug treatment for elevated triacylglycerol; (3) HDL-cholesterol level of <1.04 mmol/l for men and <1.29 mmol/l for women or drug treatment for reduced HDL; (4) fasting glucose level ≥5.55 mmol/l or use of glucose-lowering medications (insulin or oral agents); or (5) systolic BP ≥130 mmHg and/or diastolic BP ≥85 mmHg or the use of antihypertensive medications. Waist circumference was measured twice using a steel tape at the iliac crest to the nearest 0.1 cm. Up to four BP measurements were obtained, with all but the first being averaged for the final value [13]. Twelve-hour fasting blood samples were

drawn from a subsample of 3,850 individuals to assess HDL-cholesterol, triacylglycerol, and plasma glucose according to standard procedures (see [14] for details of the laboratory methods). Glucose-lowering and antihypertensive medication use was assessed by questionnaire. Information regarding drug treatment for elevated triacylglycerol and reduced HDL were unavailable. Similar to the methods proposed by Bankoski et al, [7] participants who had at least three positive metabolic syndrome criteria were considered to have the metabolic syndrome, people who had at least three negative metabolic syndrome criteria were considered not to have the metabolic syndrome and the rest were considered to be of unknown status. Using these criteria, we were able to confidently classify the metabolic syndrome status of 5,864 individuals. The remaining 2,499 individuals with unknown metabolic syndrome status were removed from the final sample. Finally, a further 788 were excluded for missing covariates to give a final analytical sample of 5,076.

Statistical analysis All analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC, USA). To account for the complex, multistage probability sampling design, PROC SURVEY procedures were used with weights provided by the NHANES. To address the primary aim, the relationship of time spent in SB and breaks in SB with the metabolic syndrome and each of its components, we initially used natural cubic spline logistic regression models. Four knots were chosen at the minimum, maximum, and 25th and 75th percentiles of time spent in SB and breaks in SB; the significance of non-linearity was examined by a likelihood ratio test to comparing a model with the linear term only and a model with both linear and the cubic spline terms. Where there was evidence for a linear relationship, logistic regression models were used in place of the spline models. Covariates for all regression analyses included age, sex, race/ethnicity, education, marital status, family income and current smoking status. Average weekly MVPA, total SB time and accelerometer wear time were also controlled for where appropriate and were derived from accelerometry data, as previously described.

To address the secondary hypotheses, the analyses were then stratified by age, sex and physical activity status, and tests for significant statistical interactions were performed using cross-product terms in the regression models. Age and time spent in MVPA were divided into the following respective categories: 18–39, 40–59 and ≥60 years; and <75, 75–149, 150–299 and ≥300 min/week. There was evidence for a statistically significant interaction between SB and MVPA for several of the metabolic syndrome components; therefore, separate analyses were performed by MVPA level. Where the interaction was not statistically significant, estimates for combined MVPA groups are presented.

Results

Participant summary Full information about participant characteristics can be found in Table 1. Overall, the entire study sample had an average age of 43.8±19.5 (mean±SD) years, had a BMI of 27.9±6.3 kg/m^2 and was 54% female. The sample was also most likely to be non-Hispanic white (52%) and married (64%). Those with more than 8 h of total daily SB appeared to be older and more highly educated, but similar in other demographic variables to those with less than 8 h/day. The prevalence of the metabolic syndrome in the whole sample was 19% (Table 2). The median number of valid days that participants wore the activity monitors was 6 (4–7; interquartile range). The average daily SB time was 8.2±2.3 h, with 90±19 breaks/day and 179±183 min/week MVPA. Those with more than 8 h/day SB appeared to have a higher

Table 1 Participant characteristics by daily SB time

Participant characteristics	SB <8 h	SB ≥8 h	Total
n	2,496	2,580	5,076
Female	1,432 (57)	1,325 (51)	2,757 (54)
Age (years)			
18–39	1,238 (50)	829 (32)	2,067 (41)
40–59	805 (32)	732 (28)	1,537 (30)
60+	453 (18)	1,019 (39)	1,472 (29)
BMI			
Underweight	39 (2)	65 (3)	104 (2)
Normal	812 (33)	777 (30)	1,589 (31)
Overweight	838 (34)	873 (34)	1,711 (34)
Obese	807 (32)	865 (34)	1,672 (33)
Income			
<$20k	720 (29)	685 (27)	1,405 (28)
$20k–$44k	829 (33)	760 (29)	1,589 (31)
$45k–$75k	496 (20)	532 (21)	1,028 (20)
>$75k	451 (18)	603 (23)	1,054 (21)
Education			
<High school	785 (31)	543 (21)	1,328 (26)
High school	652 (26)	556 (22)	1,208 (24)
>High school	1,059 (42)	1,481 (57)	2,540 (50)
Marital status			
Married	1,667 (67)	1,585 (61)	3,252 (64)
Single[a]	537 (22)	675 (26)	1,212 (24)
Divorced	292 (12)	320 (12)	612 (12)
Race/ethnicity			
Non-Hispanic white	1,164 (47)	1,469 (57)	2,633 (52)
Non-Hispanic black	465 (19)	538 (21)	1,003 (20)
Mexican American	686 (27)	389 (15)	1,075 (21)
Other	181 (7)	184 (7)	365 (7)

Values presented as *n* (%)

[a] The marital status category of 'single' includes widows

Table 2 The metabolic syndrome, its components, SB and MVPA by daily SB time

Variable	<8 h	≥8 h	Total
n	2,496	2,580	5,076
Metabolic syndrome	349 (14)	640 (25)	989 (19)
Large waist circumference[a]	343 (14)	575 (23)	918 (18)
High triacylglycerol[b]	529 (34)	630 (36)	1,159 (35)
Low HDL[c]	204 (8)	310 (12)	514 (10)
High glucose[d]	634 (40)	913 (49)	1,547 (45)
High BP[e]	610 (25)	1,050 (41)	1,660 (33)
Total daily SB time (h/day)	6.6 (5.6–7.3)	9.4 (8.7–10.6)	8.0 (6.7–9.5)
Breaks (number/day)	89 (78–100)	91 (77–104)	90 (77–102)
MVPA (min/week)	154 (70–286)	82 (29–181)	116 (46–230)

Values for categorical and continuous variables are *n* (%) and median (25–75%), respectively

[a] Frequency missing=57; <8 h 22, ≥8 h 35

[b] Frequency missing=1,761; <8 h 940, ≥8 h 821

[c] Frequency missing=13; <8 h 6, ≥8 h 7

[d] Frequency missing=1,615; <8 h 891, ≥8 h 724

[e] Frequency missing=78; <8 h 34, ≥8 h 44

prevalence of the metabolic syndrome, a large waist circumference, high blood glucose, high BP and less weekly MVPA.

Linearity Our primary hypothesis was that there would be a certain amount of SB (total time and breaks) that, once accumulated, would be related to an increased odds of meeting the criteria for the metabolic syndrome and its components. This hypothesis had two premises: (1) that SB is significantly related to the metabolic syndrome and its components; and (2) that the curves that describe these relationships are non-linear. Regarding the first premise, we found a statistically significant relationship between total time spent in SB (h/day) and the metabolic syndrome and several of its components. The results of the logistic regression models describing these relationships will be presented in the following section. However, we did not find an association between breaks in SB and any of the dependent variables (data not shown). Regarding the second premise, we did not find any evidence for non-linear relationships for total SB time and breaks with the metabolic syndrome and its components. To illustrate this point, we plotted both the linear and natural cubic spline curves describing the relationship between the amount of SB time and OR for the metabolic syndrome (Fig. 1). The *p* value for the linear term describing this relationship was 0.04 and for the non-linear term was 0.50.

Total time spent in SB As previously stated, the total time spent in SB was significantly related to the metabolic syndrome (Table 3). We found an OR of 1.09 (95% CI 1.01, 1.18) for a 1 h increase in daily SB time. However, SB time was not associated with a large waist circumference (OR 1.02; 95% CI 0.93, 1.12). To address our secondary hypothesis, we examined whether associations of SB with the metabolic syndrome and its components were modified by sex, age and MVPA. We did not find evidence of effect modification by these factors for the metabolic syndrome, as depicted in Fig. 2. Nor did we find effect modification by age or sex for any of the components; however, the associations between SB time and several components of the metabolic syndrome appeared to be modified by MVPA level (Table 3). Statistically significant interactions were found between SB and MVPA for triacylglycerol (p=0.04), HDL-cholesterol (p=0.01), fasting blood glucose (p<0.001) and BP (p=0.01). The ORs associated with a 1 h increase in SB time for having high triacylglycerol, low HDL-cholesterol and high fasting blood glucose were only statistically significant for the highest two quartiles of MVPA. That is, there was a 13% (OR 1.13; 95% CI 1.03, 1.23) and 21% (OR 1.21; 95% CI 1.08, 1.35) increased odds of having high

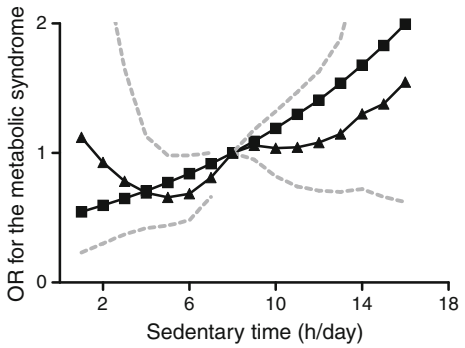

Fig. 1 Associations between daily sedentary time and ORs for the metabolic syndrome using linear (squares) and natural cubic spline (triangles) logistic regression models. Dotted lines indicate the 95% CI for the natural cubic spline model. *p* values for the linear and cubic terms were 0.04 and 0.50, respectively. Both models were adjusted for age, sex, education, family income, race/ethnicity, marital status, current smoking status, monitor wear time and MVPA

Table 3 OR associated with a 1 h/day increase in SB time by MVPA level and in combined sample regardless of MVPA

	<75 min/week	75–149 min/week	150–299 min/week	≥300 min/week	$P_{interaction}$[a]	Combined[b]
Metabolic syndrome	1.07 (0.98, 1.17)	1.02 (0.86, 1.21)	1.14 (1.02, 1.28)	1.15 (1.01, 1.33)	0.29	1.09 (1.01, 1.18)
High waist circumference	0.95 (0.85, 1.07)	1.01 (0.86, 1.19)	1.07 (0.95, 1.20)	1.03 (0.91, 1.16)	0.48	1.02 (0.93, 1.12)
High triacylglycerol	1.05 (0.98, 1.13)	1.08 (0.95, 1.22)	1.13 (1.03, 1.23)	1.21 (1.08, 1.35)	0.04	
Low HDL-cholesterol	0.93 (0.84, 1.03)	1.02 (0.84, 1.23)	1.19 (1.05, 1.34)	1.23 (1.05, 1.44)	0.01	
High fasting glucose	1.04 (0.95, 1.14)	0.90 (0.82, 0.99)	1.06 (0.97, 1.17)	1.13 (1.01, 1.27)	<0.001	
High BP	1.03 (0.93, 1.14)	0.85 (0.74, 0.97)	1.04 (0.91, 1.20)	0.86 (0.76, 0.98)	0.01	

Data are presented as OR (95% CI)

[a] Adjusted for age, sex, education, family income, race/ethnicity, marital status, current smoking status and monitor wear time

[b] Also adjusted for MVPA

triacylglycerol, and a 19% (OR 1.19; 95% CI 1.05, 1.34) and 23% (OR 1.23; 95% CI 1.05, 1.44) increased odds of having low HDL-cholesterol with each hour of SB time for those who accumulated 150–300 and ≥300 min/week of MVPA, respectively. Similarly, we found an increased odds of 13% (OR 1.13; 95% CI 1.01, 1.26) for having high fasting blood glucose with each hour of SB time for those who accumulated ≥300 min/week of MVPA. The pattern describing the relationship between SB time and the odds of having high BP by MVPA level is less consistent. There was a counterintuitive reduction in odds found for the second (OR 0.84; 95% CI 0.73, 0.96) and fourth (OR 0.87; 95% CI 0.77, 0.98) quartiles of MVPA.

Discussion

We examined the dose–response relationship between SB and the metabolic syndrome and its components in a large nationally representative sample of US adults with objectively measured activity data. Our main finding was that total daily time spent in SB was associated with a linear increase in the odds of having the metabolic syndrome, without influence from any tested effect modifiers. This contradicted our hypothesis that there would be a certain threshold of SB necessary to increase the odds of the metabolic syndrome, which would vary by age, sex and amount of MVPA. We also found the total daily amount of SB to be linearly related to increased odds of meeting the criteria for the high triacylglycerol, low HDL-cholesterol and high fasting blood glucose components of the metabolic syndrome. Furthermore, this relationship seemed to be modified by weekly participation in MVPA. Conversely, we did not find evidence for a relationship between breaks in SB and increased odds of meeting the criteria for the metabolic syndrome or any of its components.

We are unaware of other studies involving similar analyses (i.e. which treated both the metabolic syndrome and its components as dichotomous variables), thus making direct comparisons difficult. However, parallels can be drawn with studies that have treated the components as continuous variables. Regarding breaks in SB, we are aware of one study that consistently found significant linear relationships between SB breaks and measures of insulin resistance and lipid variables [15]; however, our study corroborates the findings of most other studies on this subject [16–19], which have not found similar relationships. In the previously mentioned studies, one component of the metabolic syndrome consistently found to be related to SB breaks is waist circumference. We could not confirm a similar statistically significant relationship in the current study. We did, however, find a similar trend, characterised by a 6% reduction in the odds of meeting the criteria for high waist circumference with every 10 breaks, which almost reached significance (OR 0.94; 95% CI 0.85, 1.04).

Findings from the current study extend the body of literature regarding total time spent in SB and markers of cardiometabolic health. Our evidence for a 9% increase in the odds of having the metabolic syndrome with each additional hour of daily SB is consistent with the findings of a previous meta-analytical review on the subject [5], although with a lesser magnitude. This is to be expected, though, because we examined SB as a continuous variable while the review reported differences between the highest and lowest quantiles of SB. When our data was analysed in a similar fashion for comparative purposes, we found a 58% (OR 1.58; 95% CI 1.01, 2.48) increased odds of the metabolic syndrome in the highest quartile of SB (>9.49 h) compared with the lowest (<6.70 h). Our findings regarding the components of the metabolic syndrome in relation to total SB time are also consistent with published reports. Previous studies have demonstrated significant associations between daily SB and triacylglycerol [6, 16, 17], HDL-cholesterol [16, 18] and fasting plasma glucose [17].

The relationships between total SB time and the components of high triacylglycerol, low HDL-cholesterol and high fasting glucose were modified by participation in MVPA. Interestingly, significantly increased odds of meeting the criteria for these components were found only in those in the

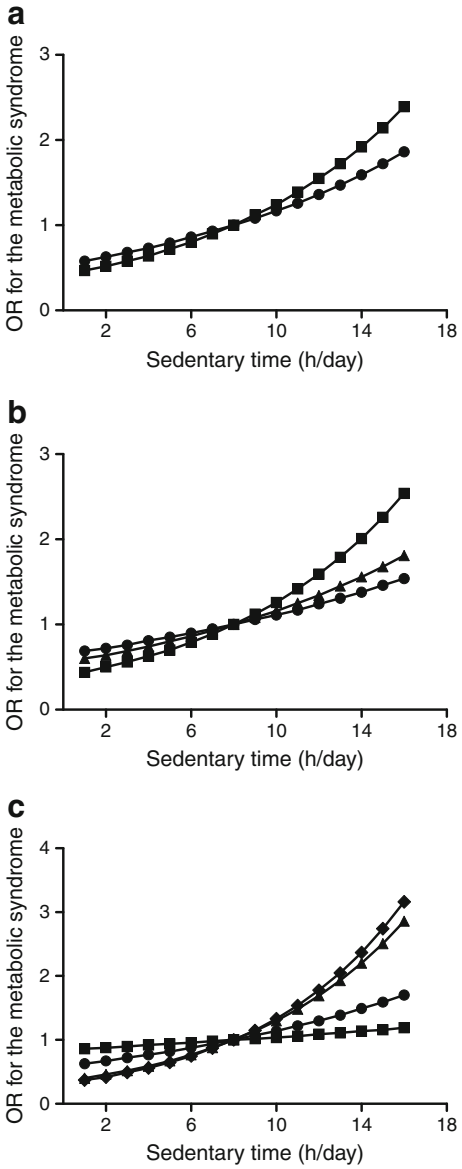

Fig. 2 Associations between daily sedentary time and ORs for the metabolic syndrome by (**a**) sex, (**b**) age and (**c**) MVPA. (**a**) Circles, men; squares, women; *p* value for the interaction between sex and SB = 0.53. (**b**) Circles, 18–39 years; squares, 40–59 years; triangles, ≥60 years; *p* value for the interaction between age and SB = 0.46. (**c**) Circles, <75 min/week; squares, 75–149 min/week; triangles,150–299 min/week; diamonds, ≥300 min/week; *p* value for the interaction between MVPA and SB = 0.28

highest quartiles of MVPA. It is established that regular participation in activity of at least moderate intensity reduces the risk of the metabolic syndrome [20]. Evidence from cross-sectional studies suggests that 120–180 min/week of MVPA is the minimum amount associated with lower rates of the metabolic syndrome [21–23]. Extending these findings to the current study might help explain why only in those with 150 or more min/week of MVPA was there an association with SB. It is conceivable that the lack of adequate MVPA in the lower two quartiles outweighed the effect of varying amounts of SB on the odds of meeting criteria for those components. Meanwhile, in the upper quartiles, attainment of adequate MVPA provided an opportunity for the effect of SB. We also found an effect modification by MVPA on the relationship between total SB and high BP; however, the lack of a linear trend makes us suspect that the association is spurious.

The novelty of SB research means that there is a lack of studies describing the effect of prolonged free-living SB on human physiology. Therefore, any insight into potential mechanisms behind the association between SB and the metabolic syndrome must be gleaned from animal studies or from human studies using more extreme models of SB. For instance, lipoprotein lipase, an enzyme essential for lipoprotein-derived fatty acid uptake [24] and whose dysfunction is associated with dyslipidaemia [25] and hypertension [26], is reduced in both concentration and activity by hindlimb unloading in rats [27]. In addition, the effect of prolonged SB has been demonstrated on muscle GLUT proteins, which are integral for insulin- and exercise-stimulated uptake of plasma glucose. A study of spinal cord injury by Megeney et al found reductions in GLUT content and glucose uptake within 3 days of muscle denervation [28]. Our finding of effect modification by MVPA on the relationship between SB and the components of triacylglycerol, HDL-cholesterol and fasting glucose implies that SB and MVPA may exert their effects through similar pathways for some biomarkers but different pathways for others. This notion is supported in a review of several studies by Hamilton et al [29], who demonstrated that the expression of some genes important for preventing diabetes and other metabolic risks is resistant to being restored after 12 h of inactivity, while the expression of others is not. In particular, a study examining the activity of lipid phosphate phosphatase-1 (LPP1) suggested that gene expression may be suppressed in response to chronic sitting despite participation in 1 h/day of vigorous exercise [30].

This study adds to the body of literature concerning the dose–response relationship between SB and the metabolic syndrome. A major strength of this study is the use of accelerometry data from a large, nationally representative sample of US adults. This enabled the concurrent measurement of SB and MVPA without relying on participant recall. Another strength was our consideration of the interaction between SB and MVPA. Most studies treat MVPA as a confounder and ignore its role as a potential effect modifier. Doing so in the current study would have prevented us from finding that SB is only related to certain metabolic syndrome components in people with higher MVPA. A third major strength of the current study was the decision to fully examine and describe a possible non-linear relationship between SB and the dependent variables, rather than performing transformations or categorising our dependent variables. Although none of the relationships proved to be non-linear, this is not

something we could have detected without investigating the possibility.

This study also has several limitations. One limitation inherent in the use of a hip-mounted accelerometer, such as the ActiGraph, is that its inability to discern sitting from standing still may lead to measurement error in the estimate of time spent in SB. Kozey-Keadle et al found the ActiGraph accelerometer to significantly underestimate sitting time compared with both direct observation [31] and the activPAL [32], a thigh-worn accelerometer that can detect changes in posture; however, the differences were less than 5%. Future studies should aim to verify our findings using similar devices that can differentiate between sitting and standing with higher accuracy. Another limitation of using a hip-mounted accelerometer to measure MVPA is that it does so poorly for certain activities such as cycling and swimming. In contrast, these devices are especially accurate at measuring ambulatory activity, and walking is the most common form of physical activity in US adults [33]. We also deliberately selected an activity count threshold designed to capture daily physical activities of moderate intensity (≥3 metabolic equivalents), thus reducing the likelihood of underestimating the amount of relevant activities. Another unavoidable limitation inherent in the cross-sectional design of the current study is the inability to make causal inferences. It is possible that those with the metabolic syndrome or its components were consequently more sedentary rather than the other way around. Finally, although the current study had a large sample size, limited statistical power to detect the number of multiplicative interactions that were investigated remains a possibility.

Conclusion

We found that total daily time spent in SB, but not breaks in SB, was linearly related with higher odds of the metabolic syndrome in large sample of US adults aged >18 years. This relationship was not modified by sex, age or time spent in MVPA. However, the association between total SB and several components of the metabolic syndrome did differ by the MVPA level. These findings suggest that there is no threshold of SB at which the odds of the metabolic syndrome begin to rise. Future studies should investigate this question prospectively to provide causal evidence for a recommendation to maintain low amounts of total time spent in SB so as to lessen the odds of developing the metabolic syndrome.

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Contribution statement All authors contributed to the design, interpretation of data, and drafting of the article. All authors provided final approval of the version to be published. KPG is the guarantor of this work.

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