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Mediating role of the weight-adjusted-waist index in the association between sedentary behavior and depression: A cross-sectional study

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ABSTRACT

Background: Sedentary behavior and obesity are established risk factors for depression. The weight-adjusted-waist index (WWI) is a more accurate obesity measure than body mass index (BMI) or waist circumference (WC). This study aims to investigate if WWI mediates the effect of sedentary behavior on depression.
Methods: Data on daily sitting times, WWI and depression symptoms assessed by the Patient Health Questionnaire-9 (PHQ-9) scores were analyzed for this study. WWI was calculated as WC divided by the square root of body weight. Depression was defined as a PHQ-9 score ≥ 10. We used weighted logistic regression and restricted cubic splines (RCS) to examine the linear and nonlinear effects of daily sitting time and WWI on depression. Mediation analysis was performed to determine if WWI mediates the relationship between daily sitting time and depression. Gender-stratified analysis was also conducted.
Results: The study included 26,508 participants. Adjusted analyses showed positive associations of both daily sitting time (OR = 1.035, 95 % CI 1.015–1.056) and WWI (OR = 1.345, 95 % CI 1.226–1.476) with depression. Sitting > 8 h/day conferred higher depression risk versus < 4 h/day (OR = 1.268, 95 % CI 1.086–1.481). Similarly, the highest WWI quartile (Q4) had significantly greater risk than the lowest (Q1) (OR = 1.791, 95 % CI 1.429–2.245). WWI significantly mediated the sitting–depression relationship (proportion mediated: 0.075, 95 % CI 0.062–0.212, P < 0.001).
Conclusion: Sedentary behavior and WWI both elevate depression likelihood. Furthermore, WWI partially mediates the effect of sedentary behavior on depression, and this mediation effect is independent of gender.

Introduction

Depression is a common mental disorder characterized by symptoms such as low mood, lack of energy, and insomnia [1]. The prevalence rate of depression is approximately 6 % [2]. Depression can lead to a decrease in quality of life, disability, and even suicide, imposing a significant burden on individuals, families, and society [3]. The etiology and mechanisms of depression are not fully understood, and current treatments primarily focus on enhancing the transmission of monoamine neurotransmitters, such as SSRIs, but their effectiveness is limited and they have notable side effects [4]. Therefore, studying the inducing factors of depression can provide important clinical value for its prevention and early intervention.

Sedentary behavior refers to any activity performed while awake in a sitting, reclining, or lying posture, with an energy expenditure of no more than 1.5 metabolic equivalents (METs) [5]. Sedentary behavior is prevalent in daily life, especially among students, researchers, office workers, and drivers. It increases the risk of diseases such as obesity and depression [6–8]. The weight-adjusted-waist index (WWI), first proposed by Park et al. in 2018, is a more accurate indicator of obesity than body mass index (BMI) and waist circumference (WC) [9,10]. Research has demonstrated a positive association between WWI and the likelihood of depression [11], as well as an association between obesity and an increased risk of depression [12]. However, it remains unclear whether obesity directly contributes to increase the risk of depression due to prolonged sedentary behavior.

Therefore, we investigated the mediating role of WWI in the relationship between sedentary behavior and depression.

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Methods

Participants

Participants were recruited from NHANES, a cross-sectional study targeting individuals in the United States which was conducted from 2007 to 2008 and 2017–2018. All data are available on the Centers for Disease Control and Prevention (CDC) website. Written informed consent was obtained from all participants at the time of recruitment.

From 2007–2008 and 2017–2018, a total of 35,162 participants were enrolled in NHANES. First, we excluded participants who were missing data on various covariates (n = 3582). Then we excluded pregnant participants (n = 311) and those who had not disclosed information regarding depression (n = 2004), daily sitting time (n = 133) and WWI (n = 795). Finally, we divided participants into two groups based on whether or not there was a record of depression: those "with depression" (n = 2390) and those "without depression" (n = 24,118). More details of the participants being screened were shown in Fig. 1.

Definition of depression

The Patient Health Questionnaire-9 (PHQ-9) is a brief self-report used to assess depressive symptoms in primary care and research settings, with a well-established factor structure, reliability, and validity. The PHQ-9 score ranges from 0 to 27, with higher scores indicating greater severity of depressive symptoms. A PHQ-9 score of ≥ 10 is recommended as the binary threshold for defining the presence of depressive symptoms, with a sensitivity and specificity of 88 % for screening major depressive disorder [13].

Definition of daily sitting time

In our study, the exposure variable is daily sitting time, which is measured via the question "How much time do you usually spend sitting (or reclining) on a typical day?" Daily sitting time refers to wake time spent sitting or reclining at work, at home, or at school, including time spent sitting at a desk, sitting with friends, traveling by ar, bus, or train, reading, playing cards, watching television, or using a computer. Daily sitting time is considered a continuous variable or divided into four categories: less than four hours per day, four to six hours per day, six to eight hours per day, and more than eight hours per day. In subsequent analyses, less than four hours per day is defined as the reference group [14].

Assessment of weight-adjusted-waist index (WWI)

WWI is an anthropometric index used to assess obesity, with weight and body measurements collected by certified health technicians at mobile examination centers. The formula for calculating WWI is WC (cm) divided by the square root of body weight (kg).

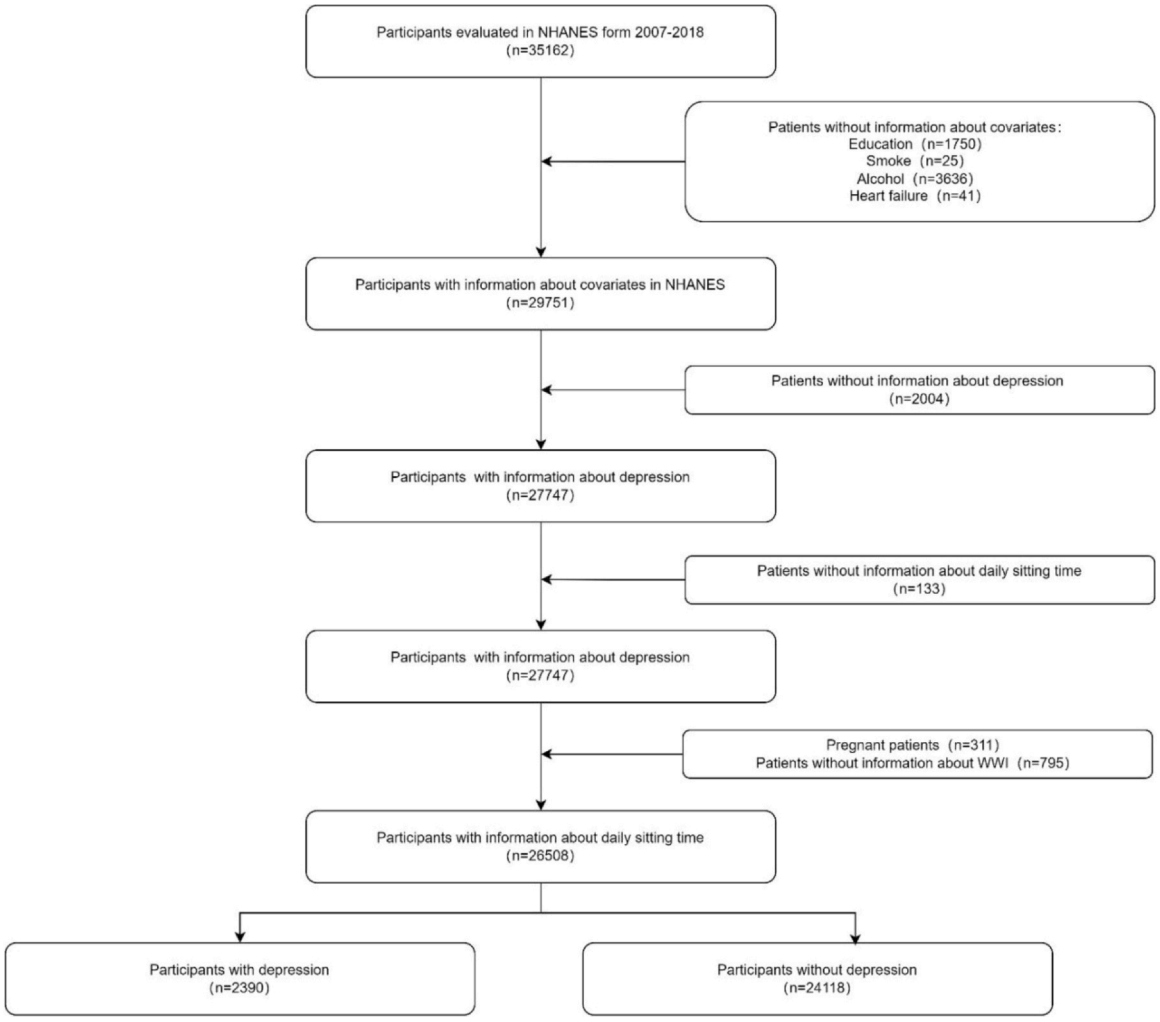

Fig. 1. Flowchart of the screening process of eligible participants from the National Health and Nutrition Examination Survey 2007–2018.

Table 1
Weighted baseline characteristics of participants.

Characteristics	Without depression N = 24118	With depression N = 2390	*P*
Age, mean (median [IQR])	47.88(33.00,61.00)	47.00(34.00,58.00)	0.053
Gender (%)			
Male	12230 (50.1)	870 (36.0)	< 0.001
Female	11905 (49.9)	1520 (64.0)	
Education (%)			
Below high school	5312 (13.9)	838 (25.1)	< 0.001
High School or above	18806 (86.1)	1552 (74.9)	
Race (%)			
Mexican American	3603 (8.3)	358 (8.0)	0.001
Non-Hispanic White	10224 (68.3)	1019 (63.8)	
Non-Hispanic Black	5115 (10.6)	496 (12.7)	
Other	5176 (12.8)	517 (15.6)	
Smoke			
Never	13783 (57.3)	967 (38.2)	< 0.001
Former	5923 (25.3)	535 (22.5)	
Smoke now	4412 (17.4)	888 (39.3)	
Alcohol			
Yes	1672 (13.5)	116 (9.4)	< 0.001
No	14388 (86.5)	1475 (90.6)	
Heart failure			
Yes	773 (2.4)	179 (6.1)	< 0.001
No	23345 (97.6)	2211 (93.9)	
Hypertension			
Yes	10982 (40.4)	1283 (49.4)	< 0.001
No	13136 (59.6)	1107 (50.6)	
Diabetes			
Yes	4210 (13.0)	598 (19.5)	< 0.001
No	19908 (87.0)	1792 (80.5)	
Liver disease			
Yes	881 (3.3)	215 (8.2)	< 0.001
No	23237 (96.7)	2175 (91.8)	

Note: Continuous variables are presented as median (IQR), % for categorical variables.

Participants are required to remove their shoes and clothing to ensure accurate weight measurements. WC is determined by placing a tape measure at the intersection of the (vertical) right midaxillary line and a horizontal line drawn above the highest lateral edge of the right iliac bone [11].

Covariates

Demographic information was collected for NHANES through household interviews and included age, gender, race, level of education, smoking habits and alcohol consumption. Participants' education levels were classified as "below high school" or "high school and above." Participants were grouped based on their smoking habits as "never smoking" (having smoked fewer than 100 cigarettes in their lifetime), "formerly smoking" (having smoked more than 100 cigarettes in their lifetime but not currently smoking) and "currently smoking" (having smoked more than 100 cigarettes in their lifetime and currently smoking) [15]. Hypertension was defined as having a systolic blood pressure (SBP) of ≥ 140 mmHg or a diastolic blood pressure (DBP) of ≥ 90 mmHg across four measurements, or if participants self-reported use of antihypertensive medications in the questionnaire [15]. Diabetes was determined as having blood glucose levels of FBG ≥ 126 mg/dL or HbA1c ≥ 6.5 % on an empty stomach, or if participants self-reported use of antidiabetic medications in the questionnaire [15]. Heart failure and liver disease were identified based on self-reported information.

Statistical methods

All analyses were conducted using R (version 3.6.3), with weights applied to account for the complex sampling design of NHANES. Chi-square test and Wilcoxon rank-sum test were used to assess the demographic characteristics of participants with depression. Daily sitting time was treated as continuous variable or a categorical variable. WWI was treated as both a continuous variable or a categorical variable based on quartiles (Q1, Q2, Q3, Q4). Multivariable weighted logistic regression was used to assess associations between daily sitting time, WWI, and depression, as well as to calculate odds ratios (ORs) and 95 % confidence intervals (CIs). "Age", "gender", "education" (level of education), "race", "smoking" (smoking habits), "alcohol" (alcohol consumption), "heart failure", "hypertension", "diabetes", and "liver disease" were covariates. Sensitivity analysis was performed using restricted cubic splines (RCS). Mediation analysis was further employed to clarify the mediating effect of WWI on the relationship between daily sitting time and depression.

Results

Baseline characteristics of participants

Among the 26,508 individuals who met the inclusion criteria, 13,083 were men and 13,425 were women. Based on their PHQ-9 results, 2390 participants were identified as having depression. As shown in Table 1, participants with depression are more likely to be younger, female, have a lower level of education, smoke and drink alcohol. They are also more likely to suffer from heart failure, hypertension, liver disease and diabetes.

Association between daily sitting time and depression

Table 2 shows the linear relationship between daily sitting time and depression. After adjusting for covariates, each additional hour of daily sitting time increases the risk of depression by 3.5 % (OR = 1.035, [95 % CI 1.015–1.056]). Further analysis reveals that, compared to those with less than four hours of daily sitting time, individuals with more than eight hours of daily sitting time have a 26.8 % higher risk of depression (OR = 1.268, [95 % CI 1.086–1.481]). Table 3 illustrates that, stratified by gender, every additional hour of daily sitting time increases the risk of depression by 3.9 % (OR = 1.039, [95 % CI 1.002–1.078]) for men and 3.3 % (OR = 1.033, [95 % CI 1.009–1.057]) for women.

Association between WWI and depression

Table 4 shows the relationship between WWI and depression. After adjusting for covariates, each unit increase in WWI is associated with a 34.5 % increase in the risk of depression (OR = 1.345,

Table 2
Weighted multivariate regression analysis of the relationship between Daily sitting time and Depression.

Characteristics	Model 1 OR/β (95 % CI)	*P*	Model 2 OR/β (95 % CI)	*P*	Model 3 OR/β (95 % CI)	*P*	Model 4 OR/β (95 % CI)	*P*
Continuous	1.019 (0.999–1.040)	0.061	1.036 (1.016–1.058)	< 0.001	1.041 (1.021–1.061)	< 0.001	1.035 (1.015–1.056)	< 0.001
< 4 h	Ref.		Ref.		Ref.		Ref.	
4–6 h	0.948 (0.807–1.115)	0.516	1.021 (0.866–1.205)	0.800	1.009 (0.856–1.190)	0.912	0.983 (0.834–1.160)	0.842
6–8 h	0.973 (0.822–1.153)	0.752	1.093 (0.925–1.292)	0.293	1.081 (0.913–1.281)	0.361	1.041 (0.874–1.241)	0.646
> 8 h	1.122 (0.966–1.302)	0.129	1.289 (1.109–1.499)	0.001	1.332 (1.143–1.552)	< 0.001	1.268 (1.086–1.481)	0.003

Model 1: Non-adjusted.
Model 2: Age + Gender + Education + Race.
Model 3: Age + Gender + Education + Race + Alcohol + Smoke.
Model 4: Age + Gender + Education + Race + Alcohol + Smoke + Heart failure + Diabetes + Liver condition + Hypertension.

Table 3
Weighted Multivariate Regression Analysis of Daily Sitting Time and Depression Stratified by Gender.

Characteristics	Model 1 OR/β (95 % CI)	*P*	Model 2 OR/β (95 % CI)	*P*	Model 3 OR/β (95 % CI)	*P*	Model 4 OR/β (95 % CI)	*P*
Male (continuous)	1.023 (0.985–1.062)	0.232	1.035 (0.999–1.073)	0.059	1.044 (1.007–1.083)	0.020	1.039 (1.002–1.078)	0.040
< 4 h	Ref.		Ref.		Ref.		Ref.	
4–6 h	0.982 (0.790–1.221)	0.871	1.032 (0.831–1.281)	0.773	1.015 (0.820–1.257)	0.887	0.982 (0.790–1.221)	0.871
6–8 h	0.973 (0.722–1.312)	0.856	1.067 (0.799–1.425)	0.658	1.103 (0.826–1.473)	0.501	1.061 (0.788–1.427)	0.694
> 8 h	1.118 (0.844–1.481)	0.432	1.237 (0.939–1.629)	0.129	1.327 (1.003–1.755)	0.047	1.272 (0.959–1.686)	0.094
Female(continuous)	1.020 (0.996–1.045)	0.095	1.037 (1.014–1.062)	0.002	1.038 (1.014–1.062)	0.002	1.033 (1.009–1.057)	0.007
< 4 h	Ref.		Ref.		Ref.		Ref.	
4–6 h	0.981 (0.783–1.228)	0.866	1.106 (0.879–1.390)	0.386	1.064 (0.847–1.337)	0.589	1.027 (0.811–1.300)	0.826
6–8 h	1.133 (0.938–1.367)	0.193	1.316 (1.089–1.590)	0.005	1.329 (1.100–1.605)	0.004	1.265 (1.045–1.531)	0.016
> 8 h	0.925 (0.744–1.151)	0.482	1.015 (0.813–1.268)	0.892	1.003 (0.807–1.246)	0.981	0.968 (0.775–1.209)	0.769

Model 1: Non-adjusted.
Model 2: Age + Gender + Education + Race.
Model 3: Age + Gender + Education + Race + Alcohol + Smoke.
Model 4: Age + Gender + Education + Race + Alcohol + Smoke + Heart failure + Diabetes + Liver condition + Hypertension.

95 % CI [1.226–1.476]). Conducting further analysis, we grouped the population into WWI quartiles (Q1: < 10.411, Q2: 10.411–10.968, Q3: 10.968–11.544, Q4: > 11.544). Compared to the population in the first quartile (Q1), that in the fourth quartile (Q4) has a 79.1 % increased risk of depression (OR = 1.791, 95 % CI [1.429–2.245]). As shown in Table 5, after stratifying by gender, each unit increase in WWI as a continuous variable is associated with a 31.9 % increase in the risk of depression for men (OR = 1.319, 95 % CI [1.109–1.569]) and a 33.9 % increase for women (OR = 1.339, 95 % CI [1.211–1.480]). Grouping the male population by WWI quartiles (Q1: < 10.289, Q2: 10.289–10.824, Q3: 10.824–11.357, Q4: > 11.357) shows that men in the fourth quartile (Q4) have a 48.5 % higher risk of depression compared to those in the first quartile (Q1) (OR = 1.485, 95 % CI [1.066–2.069]). Grouping the female population by WWI quartiles (Q1: < 10.540, Q2: 10.540–11.123, Q3: 11.123–11.723, Q4: > 11.723) demonstrates that women in Q3 and Q4 respectively have 34.7 % (OR = 1.347, 95 % CI [1.040–1.744]) and 76.2 % (OR = 1.762, 95 % CI [1.383–2.245]) higher risks of depression compared to those in Q1.

The nonlinear relationship between daily sitting time, WWI and depression

Fig. 2 illustrates that both daily sitting time as well as WWI have a linear relationship with depression, with no evidence of a non-linear relationship. After stratifying by gender, the linear relationship between daily sitting time and depression persists, with no nonlinear relationship observed. However, in the male population, one can observe there is a nonlinear relationship—in the form of an inverted L-shape ($P = 0.0101$)—between WWI and depression after stratifying by gender. No nonlinear relationship is observed in the female population.

The relationship between WWI-mediated daily sitting time and depression

We further explored the potential of WWI in mediating the relationship between daily sitting time and depression. As can be seen

Table 4
Weighted Multivariate Regression Analysis of WWI and Depression.

Characteristics	Model 1 OR/β (95 % CI)	*P*	Model 2 OR/β (95 % CI)	*P*	Model 3 OR/β (95 % CI)	*P*	Model 4 OR/β (95 % CI)	*P*
Continuous	1.449 (1.351–1.555)	< 0.001	1.528 (1.406–1.661)	< 0.001	1.472 (1.352–1.602)	< 0.001	1.345 (1.226–1.476)	< 0.001
Q1	Ref.		Ref.		Ref.		Ref.	
Q2	1.137 (0.927–1.393)	0.214	1.237 (0.999–1.533)	0.051	1.173 (0.949–1.449)	0.138	1.114 (0.898–1.382)	0.320
Q3	1.285 (1.068–1.547)	0.008	1.444 (1.177–1.771)	< 0.001	1.330 (1.080–1.638)	0.008	1.206 (0.969–1.501)	0.093
Q4	2.131 (1.786–2.542)	< 0.001	2.392 (1.938–2.952)	< 0.001	2.159 (1.751–2.661)	< 0.001	1.791 (1.429–2.245)	< 0.001

Model 1: Non-adjusted.
Model 2: Age + Gender + Education + Race.
Model 3: Age + Gender + Education + Race + Alcohol + Smoke.
Model 4: Age + Gender + Education + Race + Alcohol + Smoke + Heart failure + Diabetes + Liver condition + Hypertension.

Table 5
Weighted Multivariate Regression Analysis of WWI and Depression Stratified by Gender.

Characteristics	Model 1 OR/β (95 % CI)	*P*	Model 2 OR/β (95 % CI)	*P*	Model 3 OR/β (95 % CI)	*P*	Model 4 OR/β (95 % CI)	*P*
Male (continuous)	1.270 (1.127–1.446)	< 0.001	1.441 (1.230–1.687)	< 0.001	1.407 (1.206–1.643)	< 0.001	1.319 (1.109–1.569)	0.002
Q1	Ref.		Ref.		Ref.		Ref.	
Q2	1.002 (0.713–1.410)	0.989	1.121 (0.786–1.599)	0.523	1.118 (0.780–1.602)	0.539	1.081 (0.749–1.560)	0.673
Q3	1.226 (0.930–1.615)	0.146	1.404 (1.039–1.898)	0.028	1.351 (1.001–1.824)	0.049	1.242 (0.909–1.695)	0.171
Q4	1.473 (1.138–1.907)	0.004	1.787 (1.306–2.445)	< 0.001	1.704 (1.255–2.313)	< 0.001	1.485 (1.066–2.069)	0.020
Female (continuous)	1.412 (1.297–1.538)	< 0.001	1.563 (1.422–1.718)	< 0.001	1.488 (1.348–1.643)	< 0.001	1.339 (1.211–1.480)	< 0.001
Q1	Ref.		Ref.		Ref.		Ref.	
Q2	1.108 (0.898–1.369)	0.335	1.203 (0.964–1.502)	0.101	1.109 (0.886–1.389)	0.981	1.051 (0.840–1.316)	0.657
Q3	1.474 (1.164–1.865)	< 0.001	1.709 (1.325–2.204)	< 0.001	1.506 (1.168–1.941)	< 0.001	1.347 (1.040–1.744)	0.025
Q4	2.066 (1.679–2.541)	< 0.001	2.527 (1.995–3.201)	< 0.001	2.211 (1.741–2.809)	< 0.001	1.762 (1.383–2.245)	< 0.001

Model 1: Non-adjusted.
Model 2: Age + Gender + Education + Race.
Model 3: Age + Gender + Education + Race + Alcohol + Smoke.
Model 4: Age + Gender + Education + Race + Alcohol + Smoke + Heart failure + Diabetes + Liver condition + Hypertension.

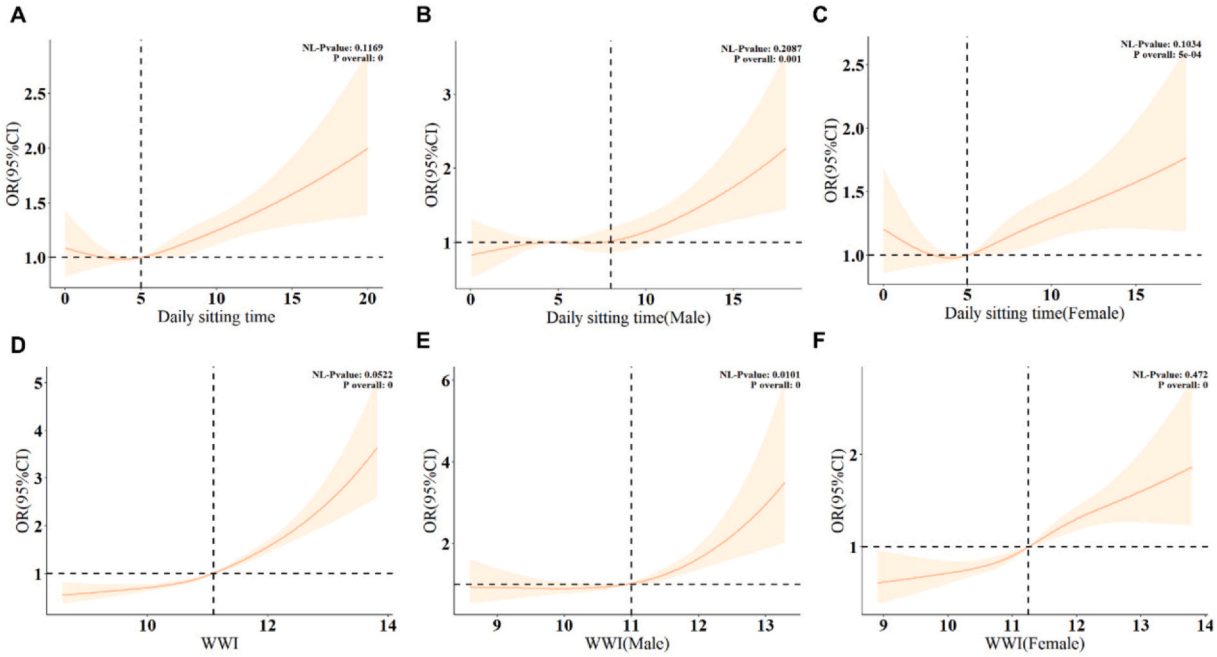

Fig. 2. RCS Curves of associations between daily sitting time, WWI and depression. Note: All models were adjusted for "age", "gender", "education", "race", "smoking", "alcohol", "heart failure", "hypertension", "diabetes", and "liver disease". A: Nonlinear relationship between daily sitting time and depression; B: Nonlinear relationship between daily sitting time and depression in the male population; C: Nonlinear relationship between daily sitting time and depression in the female population; D: Nonlinear relationship between WWI and depression; E: Nonlinear relationship between WWI and depression in the male population; F: Nonlinear relationship between WWI and depression in the female population.

in Table 6 and Fig. 3 (A), after we adjusted for confounding factors, WWI significantly mediated the effect of daily sitting time on depression (mediation proportion: 0.0745 [0.062,0.212], $P < 0.001$). As Table 7 and Fig. 3 (B and C) demonstrates, after stratifying by gender and adjusting for confounding factors, WWI significantly mediated the effect of daily sitting time on depression among both male and female populations (male mediation proportion: 0.0659 [0.0283, 0.3151], $P = 0.004$; female mediation proportion: 0.0515 [0.049, 0.254], $P = 0.002$).

Discussion

Several studies have explored the relationship between sedentary behavior and depression, indicating that sedentary behavior increases the risk of depression [16–18]. Yet it is still unclear what the underlying mechanisms for this are. It is well known that sedentary behavior can lead to obesity [19] and that obesity is a potential causative factor for depression [20]. That suggests that obesity may be a key factor mediating the relationship between sedentary behavior and depression. WWI, as an emerging indicator for assessing obesity, is more accurate than BMI and WC [21]. Therefore, this cross-sectional study aims to determine the impact of sedentary behavior and WWI on depression in American adults, and whether the effect of sedentary behavior on depression is mediated by WWI.

First, the results of our research indicate a positive linear correlation between sedentary behavior and depressive symptoms. Multiple studies across different populations have shown that sedentary behavior can lead to depression [22–24]. An increase in sedentary behavior means a reduction in time spent on physical activity (PA), which is a protective factor against depression [25]. Studies have demonstrated that post-PA levels of norepinephrine and serotonin are elevated, which potentially has a similar effect to antidepressants [26]. However, other studies have found that mentally active sedentary behavior is not related to depressive symptoms [27]. Therefore, further investigation into the potential mechanisms of this association is needed.

We have also found significant differences in the linear impact of daily sitting time on depression between men and women after conducting a stratified analysis by gender. This is inconsistent with

Table 6
Weighted Analysis of the Relationship of Daily Sitting Time on Depression Mediated by WWI.

	ACME				ADE				Total effect				Proportion mediated			
	Estimate	95 %CI Lower	95 %CI Upper	*P*	Estimate	95 %CI Lower	95 %CI Upper	*P*	Estimate	95 %CI Lower	95 %CI Upper	*P*	Estimate	95 %CI Lower	95 %CI Upper	*P*
Model 1	0.000128	0.000131	0.000327	< 0.001	0.001240	0.000147	0.001900	0.040	0.001445	0.000291	0.002151	0.026	0.147065	0.077465	0.662587	0.026
Model 2	0.000337	0.000277	0.000486	< 0.001	0.001968	0.000919	0.002533	< 0.001	0.002305	0.001312	0.002908	< 0.001	0.146382	0.111150	0.314819	< 0.001
Model 3	0.000287	0.000247	0.000442	< 0.001	0.002308	0.001106	0.002685	< 0.001	0.002596	0.001471	0.003023	< 0.001	0.110665	0.094490	0.257090	< 0.001
Model 4	0.000176	0.000143	0.000299	< 0.001	0.002189	0.000905	0.002544	< 0.001	0.002365	0.001121	0.002732	< 0.001	0.074568	0.061720	0.211520	< 0.001

Model 1: Non-adjusted.
Model 2: Age + Gender + Education + Race.
Model 3: Age + Gender + Education + Race + Alcohol + Smoke.
Model 4: Age + Gender + Education + Race + Alcohol + Smoke + Heart failure + Diabetes + Liver condition + Hypertension.

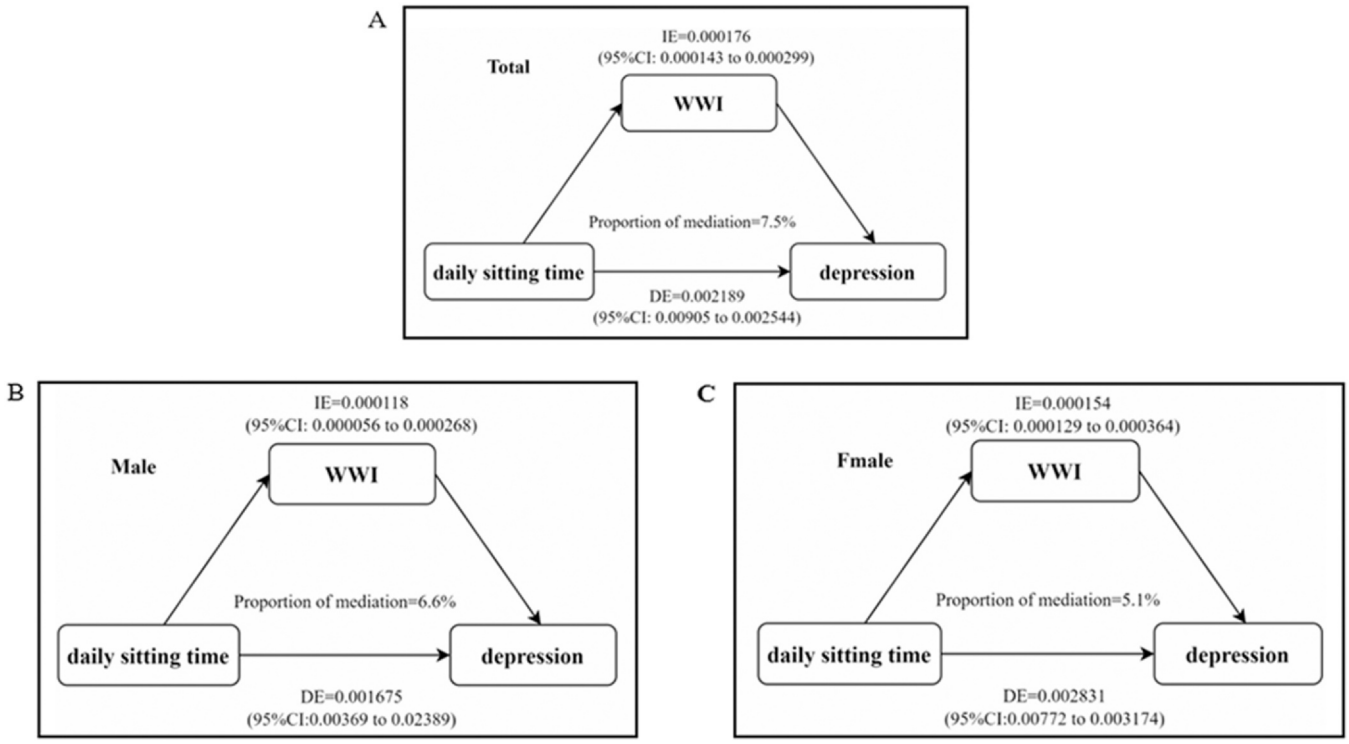

Fig. 3. WWI partially mediates the effect of daily sitting time on depression: analyses in the total population(Upper module), male subsample(Lower-left module), and female subsample(Lower-right module). Note: Adjusted by "Age", "Education", "Race", "Alcohol", "Smoke", "Heart failure", "diabetes", "Liver condition", "Hypertension".

the results of previous meta-analyses, which found that the impact of sedentary behavior on depression was significant in women, but not evident in men [17]. We speculate that this may be related to the insufficient sample size of the male population in the study. Women are twice as likely to suffer from depression than men, making it harder to collect male patients with depression than female patients [28]. Sex hormones (testosterone, estrogen, progesterone) may be one of the reasons accounting for this difference [29]. RCS results indicate that there is no significant nonlinear relationship between sedentary behavior and depression in the overall population as well as specifically in the male and female population. However, while the association significantly increased after five hours in the overall and female population, it only increased significantly in the male population after eight hours. This may be because men and women have different mechanisms for coping with depressive moods; women tend to internalize and reflect on their condition, while men tend to engage in externalizing or distracting activities [30]. This also confirms the previous statement that mentally active sedentary behavior does not lead to depression. However, prolonged sedentary behavior can still exacerbate depressive symptoms.

Second, our results show that WWI is linearly correlated with the risk of depression, with a stronger association in women (OR = 1.92). Additionally, RCS analysis indicates a nonlinear relationship between WWI and depression in men, exhibiting an inverted L-shape with a significant increase when WWI > 11, whereas no nonlinear relationship exists in women. Multiple studies have shown that obesity is significantly associated with depression [31,32], and the differences in gender have also been confirmed [33–35]. The biological mechanisms linking obesity and depression may involve genetic factors, the hypothalamic-pituitary-adrenal (HPA) axis, immune-inflammatory activation, neuroendocrine regulators related to energy metabolism, gut microbiota and central mechanisms [36]. However, although WWI has a stronger association with depression than either WC or BMI, previous studies have primarily used BMI and WC as the main indicators of obesity [37]. Therefore, WWI can serve as a biological predictor of depression, aiding clinicians in developing appropriate prevention and treatment strategies.

Finally, WWI partially mediates the effect of sedentary behavior on depression (approximately 7.5 %). Sedentary behavior is closely related to inflammation, primarily characterized by elevated C-reactive protein and IL-6 levels [38]. The fundamental cause of obesity is the long-term energy imbalance between excessive calorie intake and insufficient calorie expenditure [39]. It is well known that sedentary behavior leads to obesity [40]. Obesity and depression share key inflammatory mechanisms. People with obesity are in a state of chronic inflammation, with elevated plasma levels of C-reactive protein, IL-6, and TNF-α. Peripheral inflammatory factors may affect the synthesis of monoamine neurotransmitters through endocrine pathways, excessively activating the central HPA axis and exacerbating depressive symptoms [41]. Inflammation may be the key mechanism linking sedentary behavior, obesity, and depression. Depression can moreover contribute to the development of obesity [42]; at the same time, a low mood means that depressive patients tend to reduce physical activity and increase sedentary behavior, forming a vicious cycle. Therefore, early interventions, including increasing physical activity duration and reducing overweight, may exert their potential effects through involvement in inhibiting chronic inflammation, which is crucial for alleviating depressive symptoms and breaking this vicious cycle.

This study has several limitations. First, as a cross-sectional study, it cannot determine causality. Second, self-reported data on depressive symptoms, sedentary behavior, and WWI may have recall bias and reporting bias, potentially affecting the accuracy of the results. Furthermore, other potential confounding factors may not have been adjusted for. Future longitudinal studies are needed to explore the causal relationships and mechanisms between sedentary behavior, WWI, and depression.

Table 7
Weighted Analysis of the Gender-Stratified Relationship Between Daily Sitting Time, WWI, and Depression.

		ACME				ADE				Total effect				Proportion mediated			
		Estimate	95 %CI Lower	95 % CI Upper	P	Estimate	95 %CI Lower	95 %CI Upper	P	Estimate	95 %CI Lower	95 %CI Upper	P	Estimate	95 %CI Lower	95 %CI Upper	P
Male	Model 1	0.000173	0.000073	0.000285	< 0.001	0.000939	0.000495	0.001969	0.170	0.001076	0.000315	0.002151	0.120	0.126725	1.088110	1.076230	0.120
	Model 2	0.000220	0.000127	0.000371	< 0.001	0.001195	0.000131	0.002238	0.046	0.001415	0.000317	0.002453	0.024	0.155339	0.061397	0.596445	0.024
	Model 3	0.000167	0.000112	0.000346	< 0.001	0.001689	0.000494	0.002449	0.010	0.001856	0.000759	0.002657	0.004	0.090111	0.053134	0.330621	0.004
	Model 4	0.000118	0.000056	0.000268	< 0.001	0.001675	0.000369	0.002389	0.022	0.001794	0.000508	0.002520	0.012	0.065905	0.028304	0.315082	0.012
Female	Model 1	0.000174	0.000204	0.000307	0.028	0.000306	0.000194	0.001920	0.058	0.002094	0.000699	0.002939	0.040	0.083244	0.030170	0.445850	0.068
	Model 2	0.000379	0.000299	0.000657	0.003	0.000982	0.003366	0.002	0.003	0.003184	0.001420	0.003850	< 0.001	0.119022	0.096574	0.336134	< 0.001
	Model 3	0.000302	0.000250	0.000572	< 0.001	0.003011	0.000956	0.003325	0.002	0.003313	0.001340	0.003730	< 0.001	0.091111	0.085005	0.305456	< 0.001
	Model 4	0.000154	0.000129	0.000364	< 0.001	0.002831	0.000772	0.003174	0.008	0.002985	0.000982	0.003415	0.002	0.051470	0.049447	0.253556	0.002

Model 1: Non-adjusted.
Model 2: Age + Gender + Education + Race.
Model 3: Age + Gender + Education + Race + Alcohol + Smoke.
Model 4: Age + Gender + Education + Race + Alcohol + Smoke + Heart failure + Diabetes + Liver condition + Hypertension.

Conclusion

Our study shows that sedentary behavior and WWI are significantly positively correlated with the risk of depression. WWI partially mediates the effect of sedentary behavior on depression, and this effect is independent of gender.

CRediT authorship contribution statement

X.L. and W.J. conceptualized the project, developed the methodology, performed formal analysis, and wrote the original draft. Z.L. handled software development and data curation. P.Z. conducted formal analysis and created visualizations. Z.X. was responsible for validation. F.L. contributed to the investigation. W.Z. acquired funding. H.Z. provided supervision. L.L. managed writing, review and editing, project administration, and also acquired funding. All authors have read and approved the final version of the manuscript.

Consent for publication

Not applicable.

Ethics approval and consent to participate

The National Center for Health Statistics (NCHS) Research Ethics Review Board approved the NHANES survey protocol. All participants signed a written informed consent form. In addition, all information in the NHANES database is available to the public, and thus our research ethics review was exempt.

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Data availability

The datasets generated during the current study are available in database (https://www.cdc.gov/nchs/nhanes/).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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