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Association of habitual sleep duration with abnormal bowel symptoms: a cross-sectional study of the 2005–2010 national health and nutrition examination survey

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Abstract

Objectives Nowadays, few studies have examined the relationships between sleep duration and abnormal gut health. In this study, we used data from the National Health and Nutrition Examination Survey (NHANES) to investigate the correlations between habitual sleep duration and abnormal bowel symptoms in adults.

Methods This study included 11,533 participants aged ≥ 20 years from the NHANES conducted during 2005–2010. Chronic constipation and chronic diarrhea were defined based on the Bristol Stool Form Scale (BSFS) and frequency of bowel movements. Sleep duration was assessed based on the self-report questionnaire and classified into three groups: short sleep duration (< 7 h), normal sleep duration (7–9 h), and long sleep duration (> 9 h). Weighted data were calculated according to analytical guidelines. Logistic regression models and restricted cubic spline curves (RCS) were used to assess and describe the association between sleep duration and chronic diarrhea and constipation. Univariate and stratified analyses were also performed.

Results There were 949 (7.27%) adults aged 20 years and older with chronic diarrhea and 1120 (8.94%) adults with constipation among the 11,533 individuals. A positive association was found between short sleep duration and chronic constipation, with a multivariate-adjusted OR of 1.32 (95% CI: 1.05–1.66). Additionally, long sleep duration was significantly associated with an increased risk of chronic diarrhea (OR: 1.75, 95% CI: 1.08–2.84, $P = 0.026$). The RCS models revealed a statistically significant nonlinear association (P for non-linearity < 0.05) between sleep duration and chronic diarrhea. Furthermore, obesity was found to modify the association between sleep duration and chronic diarrhea and constipation (p for interaction = 0.044).

Conclusions This study suggests that both long and short sleep durations are associated with a higher risk of chronic diarrhea and constipation in the general population. Furthermore, a non-linear association between sleep duration and these conditions persists even after adjusting for case complexities.

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Keywords Habitual sleep duration, Diarrhea, Constipation, NHANES, Obesity

Introduction

Sleep is a fundamental physiological component for humans [1], encompassing both sleep quantity and sleep quality. It has been found to have an influence on multiple functions, leading to various manifestations. Several studies have explored the associations between sleep quantity, sleep quality, and somatic and mental disorders in adults. These studies suggest that both short sleep duration and poor sleep quality are linked to conditions such as chronic pain, obsessive-compulsive disorder, and psychiatric disorders [2]. Lao et al. [3] examined the negative associations between short sleep duration and quality and an increased risk of coronary heart disease. Additionally, they found that better sleep quality in women was related to a lower level of BMI, while for men, a sleep duration of 7 h or more was more associated with a higher BMI compared to a 5-hour sleep duration [4]. Previous studies [5, 6] have also shown that sleep duration and difficulty in maintaining sleep are associated with the risk of type 2 diabetes and the development of chronic kidney disease.

The gastrointestinal tract plays a pivotal role in the body's overall functioning, as it is in constant contact with dietary elements and a diverse range of gut microorganisms [7, 8]. Abnormalities in intestinal health, such as chronic constipation and diarrhea, are closely associated with alterations and imbalances in the intestinal microbiota. This microbiota interacts with host functions and has been linked to an increased risk of sleep problems [9]. Recent studies have indicated a correlation between sleep dysfunction and an increase in proinflammatory cytokines (e.g., tumor necrosis factor-α, interleukin-1 and interleukin-6) [10, 11], which have significant implications for gastrointestinal disease characterized by inflammation, such as gastroesophageal reflux disease [12], irritable bowel syndrome [13], chronic liver disease [14], inflammatory bowel disease [15], colorectal cancer [16] and chronic diseases [17]. Moreover, circadian rhythm dysfunction [18] and hormone disruption [14, 19], which are secondary consequences of sleep dysfunction, may contribute to the development of gastrointestinal disease. Previous studies have identified notable alterations in the composition, diversity, and metabolic function of the gut microbiota in individuals with insomnia compared to a healthy population [20]. The final stage of digestion, bowel function, plays a pivotal role in this process. Alterations in bowel movement frequency are considered a significant outward indicator of functional bowel disorders [21].

To date, few studies have examined the relationship between sleep duration and abnormal gut health. In this study, we utilized data from the National Health and Nutrition Examination Survey (NHANES) to investigate the correlation between habitual sleep duration and abnormal bowel symptoms in adults.

Methods

Study design and data source

The NHANES is conducted by the National Center for Health Statistics (NCHS) at the Centers for Disease Control and Prevention (CDC). Data were collected in May from the multiple cycles of the United States cross-sectional Continuous NHANES from 2005 to 2010 in this study. The number of participants in the analysis for the association of sleep duration with abnormal bowel health, chronic constipation and chronic diarrhea were 11,533, 10,616, and 10,495, respectively. The inclusion criteria were as follows: (1) available Bowel Health Questionnaire data; (2) available Sleep duration data. The exclusion criteria were as follows: (1) Missing or incomplete data on age, gender, race, education, marital status, and poverty income ratio (PIR), Body mass index (BMI), smoking status, alcohol status, and physical activity; (2) Missing or incomplete data on diabetes, cardiovascular diseases (coronary heart disease (CHD), congestive heart failure (HF), angina, stroke, or myocardial infarction), hypertension or cancer/malignancy, and the detailed sample exclusion criteria are shown in Fig. 1, and written consent was obtained from all surveyed individuals. The study was approved by the Ethics Committee and Institutional Review Board of the First Affiliated Hospital of Jinan University and conducted in May 2023.

Bowel Health Questionnaire

Chronic constipation and chronic diarrhea were defined based on the Bristol Stool Form Scale (BSFS) and frequency of bowel movements [22, 23] in the bowel health questionnaire. Chronic constipation was defined as a usual or most common stool of BSFS type 1 (separate hard lumps, like nuts) or type 2 (sausage-like, but lumpy), or bowel movements less than 3 times a week. Chronic diarrhea was defined as a usual or most common stool of BSFS type 6 (fluffy pieces with ragged edges, a mushy stool) or type 7 (watery, no solid pieces), or bowel movements more than three times a day. No bowel symptoms were composed of having BSFS type 3, type 4, type 5, or other bowel movements. Abnormal bowel health was defined of chronic constipation or chronic diarrhea.

Sleep duration

Sleep duration was assessed based on the self-report question "How much sleep do you usually get at night

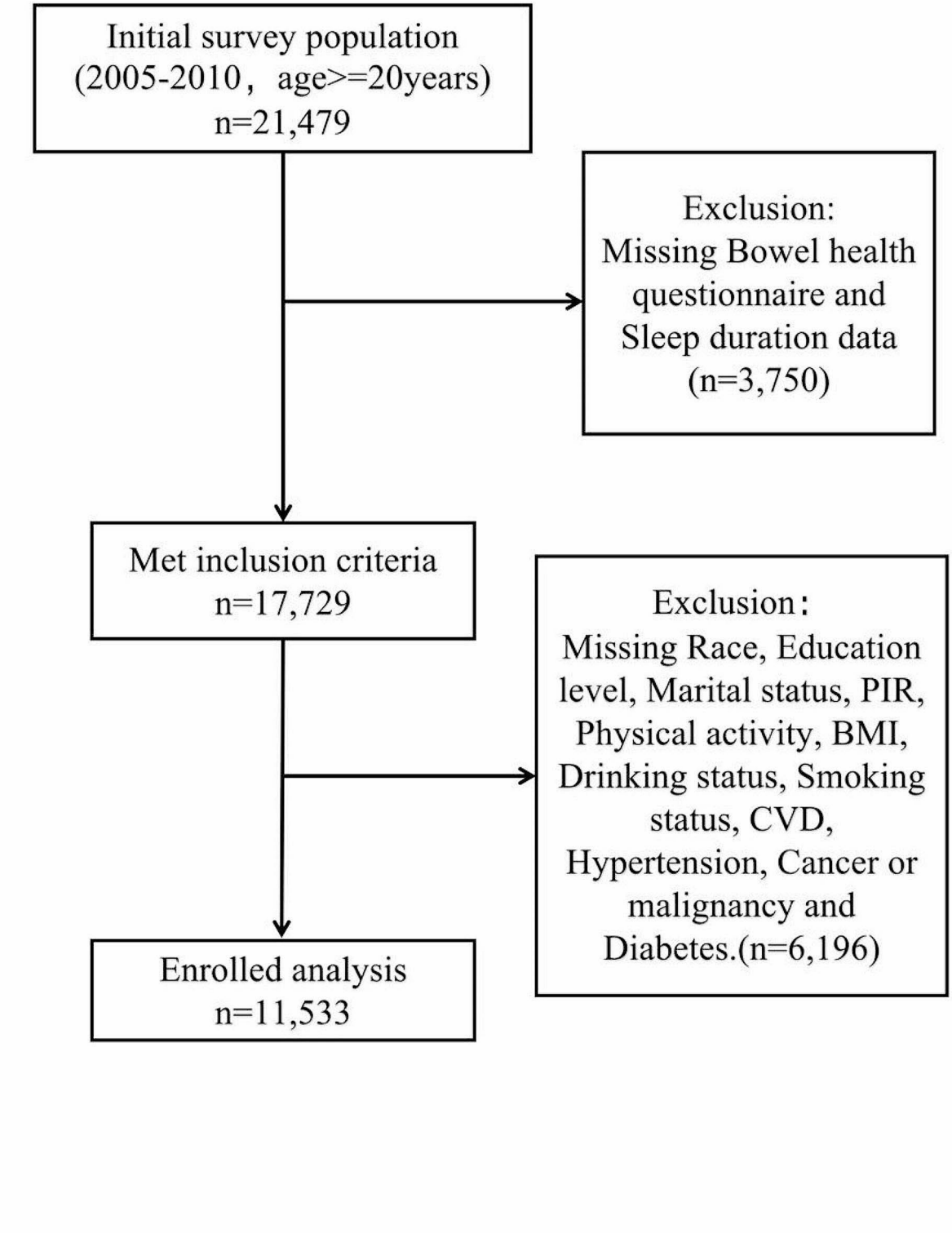

Fig. 1 Flow chart of participants included

on weekdays or workdays?" in the NHANES questionnaire (Range 0∼12 h/day, Integer). The sleep duration was classified and presented in 3 groups: short sleep duration < 7 h, normal sleep duration 7–9 h, long sleep duration > 9 h [24]. Sleep duration was analyzed as both a continuous and categorical variable.

Covariates

Potential confounders were assessed: age, gender, education, marital status, and PIR were self-reported by participants in a household interview. BMI classifications were non-obese (BMI < 30 kg/m^2), and obese (BMI ≥ 30 kg/m^2). Race was reclassified into non-Hispanic white, non-Hispanic black, Mexican American, and non-Hispanic/other races. Participants were divided into three categories for marital status (married or living with partner/widowed or divorced or separated/never married) and four categories for education level (Less than 11th grade/High school graduate or GED or equivalent/Some college or AA degree/College graduate or above). Physical activity was divided into vigorous, moderate, and light on the basis of whether participating in any moderate-intensity sports, fitness, or recreational activities caused changes in the respiratory or heart rate. Smoking status was determined by the questions "Have you smoked at least 100 cigarettes in your entire life?" and alcohol status was assessed by the question "In any one year, have you had at least 12 drinks of any type of alcoholic beverage?" (yes/no). Chronic diseases were assessed by the self-reported medical history, including diabetes, cardiovascular diseases (CHD, HF, angina, stroke, or myocardial infarction), hypertension, and cancer or malignancy by asking participants "Have you ever been told by a doctor or health professional that you have __?".

Statistical analysis

NHANES is characterized by the complex, multistage, stratified, and cluster-sampling design (including oversampling of certain subgroups), and administered by the National Center for Health Statistics (NCHS) of the Centers for Disease Control on Prevention (CDC). We combined the MEC examination weights for the analysis. Through the NHANES database analysis guide (2005–2010), the following formula was used for calculating the weights: WTMEC6YR = 1/3*WTMEC2YR. Continuous variables were represented by mean ± standard deviation, and categorical variables were expressed as percentage. The difference for baseline demographics and characteristics was compared using the sampling weight adjusted T test or analysis of variance (ANOVA) for continuous variables and Rao-Scott chi-square test for categorical variables. Multivariate logistic regression was performed to examine the associations between sleep duration and abnormal bowel health. We constructed three models: (1) model I included no adjustment; (2) model II adjusted for age (years), gender and race; (3) model III adjusted for age(year), gender, race, education level, marital status, poverty-income ratio, smoking status, drinking status, hypertension, diabetes, CVD, cancer, and physical activity. "Forestplot" in R (version 4.0.2) was used to generate the forest plots. We performed univariate and stratified analyses and interaction test to identify independent effects between sleep duration and abnormal bowel symptoms. A restricted cubic spline (RCS) model was carried out to explore the potential association between sleep duration and chronic diarrhea, constipation after adjusting for all variables. The effect value was expressed as the odds ratios (ORs) and 95% confidence intervals (CIs). A two-sided probability value of $p < 0.05$ was considered significant in all analyses. All statistical analyses were conducted using the statistical software R (version 3.6.1, https://www.r-project.org/).

Results

Baseline characteristics

The baseline characteristics of the participants in the bowel health survey are presented in Table 1. A total of 11,533 participants were included in the analysis, including 2,037 (7.6%) participants with bowel symptoms, with an average age of 46.30 ± 16.35 years, and 9,496 (92.4%) participants without bowel symptoms. Compared to the non-case group, participants with bowel symptoms were more likely to be female, non-Hispanic White, married or living with partners, and have lower education levels. They also had middle to high incomes, engaged in much more physical activity, and had lower rates of traditional risk factors such as diabetes, cancer, and cardiovascular disease (CVD). Particularly, patients with chronic diarrhea had a lower prevalence of chronic diseases such as CVD, cancer, and diabetes, and the difference was statistically significant ($p < 0.05$). However, chronic constipation did not show a significant difference with respect to these factors.

Associations of sleep duration with abnormal bowel symptoms in different models

Figure 2 presents the associations between different sleep duration groups and abnormal bowel symptoms, based on three logistic regression models for abnormal bowel symptoms. Overall, individuals with short and long sleep durations had higher odds of experiencing abnormal bowel symptoms by 28% (OR = 1.28, 95% CI = 1.12–1.48) and 100% (OR = 2.00, 95% CI = 1.49–2.67), respectively, compared to those with normal sleep duration. Individuals with short sleep duration were found to be more susceptible to chronic constipation and chronic diarrhea compared to those with normal sleep duration, with OR of 1.35 (95% CI = 1.14–1.59) and 1.21 (95%

Table 1 Weighted demographics and characteristics of participants by abnormal bowel symptoms

Variables		Abnormal bowel health (*n* = 11533)		*P*	Chronic Constipation (*n* = 10,616)	*P*	Chronic Diarrhea (*n* = 10,495)	*P*
Total (*n*)		No (*n* = 9496)	Yes (*n* = 2037)		Yes (*n* = 1120)		Yes (*n* = 949)	
Age(years) ($\bar{x} \pm s$)		45.966±16.077	46.301±16.352	0.502	43.960±16.647	0.002	49.06±15.52	< 0.001
Gender (%)	Male	5285(54.246)	804(35.859)	< 0.001	364 (27.286)	< 0.001	449(45.924)	0.007
	Female	4211(45.754)	1233(64.141)		756(72.714)		500(54.076)	
Obesity (%)	< 30	5981(65.021)	1264(65.557)	0.733	761(71.682)	0.003	519(57.620)	< 0.001
	≥ 30	3461(34.979)	761(34.443)		353(28.318)		424(42.380)	
Race (%)	Mexican American	1592(7.381)	373(8.636)	< 0.001	179(7.801)	< 0.001	201(9.731)	0.030
	Other Hispanic/ Other Race	1060(8.571)	251(9.564)		144(10.019)		107(8.704)	
	Non-Hispanic White	5081(74.617)	940(68.173)		511(66.635)		446(70.341)	
	Non-Hispanic Black	1763(9.431)	473(13.627)		289(15.545)		195(11.224)	
Education level (%)	Less than 11th grade	2289(15.676)	676(22.408)	< 0.001	336(20.818)	< 0.001	350(24.291)	< 0.001
	High school graduate/GED or equivalent	2257(23.556)	508(26.736)		303(28.874)		216(24.603)	
	Some college or AA degree	2799(31.730)	529(28.753)		305(30.320)		229(27.013)	
	College graduate or above	2151(29.037)	324(22.103)		172(19.987)		154(24.094)	
Marital status (%)	Married/ Living with partner	5981(66.171)	1192(62.470)	0.003	634(60.251)	0.005	576(65.157)	0.021
	Widowed/ Divorced/ Separated	1995(17.422)	503(21.333)		267(21.550)		245(21.238)	
	Never married	1520(16.407)	342(16.197)		219(18.198)		128(13.604)	
Sleep duration (%)	< 7 h	3650(35.483)	875(40.738)	< 0.001	503(42.073)	< 0.001	388(39.044)	0.001
	7–9 h	5654(62.769)	1081(56.143)		573(55.119)		523(57.300)	
	> 9 h	192(1.748)	81(3.120)		44(2.808)		38(3.656)	
Poverty-Income Ratio (PIR) (%)	≤ 1.30	1677(11.379)	504(16.703)	< 0.001	279(17.776)	< 0.001	237(15.908)	0.003
	1.31–3.49	3806(33.133)	881(38.068)		493(39.697)		400(35.589)	
	≥ 3.50	4013(55.488)	652(45.228)		348(42.527)		312(48.503)	
Smoking status (%)	No	4506(48.908)	982(48.866)	0.976	581(53.560)	0.014	418(42.853)	0.002
	Yes	4990(51.092)	1055(51.134)		539(46.440)		531(57.147)	
Drinking status (%)	No	7854(84.275)	1663 (83.203)	0.364	949(87.629)	0.015	737(77.529)	< 0.001
	Yes	1642(15.725)	374(16.797)		171(12.371)		212(22.471)	
Hypertension (%)	No	6361(70.930)	1321(69.121)	0.098	794 (73.410)	0.011	549(64.172)	< 0.001
	Yes	3135(29.070)	716(30.879)		326 (26.590)		400(35.828)	
Diabetes (%)	No	8548(92.993)	1787(91.289)	0.019	1012(93.361)	0.477	800(88.677)	< 0.001
	Yes	948(7.007)	250(8.711)		108(6.639)		149(11.323)	
CVD (%)	No	857(92.833)	1785(90.601)	0.009	993(91.973)	0.606	821(89.001)	0.001
	Yes	920(7.167)	252(9.399)		127(8.027)		128(10.999)	
Cancer or Malignancy (%)	No	8619(91.352)	1818(89.279)	0.017	1013(89.938)	0.350	833(88.030)	0.003
	Yes	877(8.648)	219(10.721)		107(10.062)		116(11.970)	
Vigorous work activity (%)	Vigorous	3428(50.131)	601(43.887)	0.001	334(43.594)	0.026	271(43.740)	0.017
	Moderate	1986(26.810)	418(26.935)		241(28.401)		190(26.109)	
	Inactive	2077(23.059)	522(29.178)		281(28.005)		249(30.151)	

*: $p < 0.05$

CI = 1.01–1.44), respectively. Similarly, individuals with long sleep duration also had higher odds of experiencing chronic constipation and chronic diarrhea, with ORs of 1.83 (95% CI = 1.24–2.70) and 2.29 (95% CI = 1.58–3.32), respectively. When adjusting for age, gender, and race, consistent results were found: short sleep duration was associated with a 36% higher odds of chronic constipation (OR = 1.36, 95% CI = 1.12–1.64) and a 21% higher odds of chronic diarrhea (OR = 1.21, 95% CI = 1.01–1.46), while long sleep duration was associated with a 68% higher odds of chronic constipation (OR = 1.68, 95% CI = 1.16–2.43) and a 117% higher odds of chronic diarrhea (OR = 2.17, 95% CI = 1.51–3.13). Furthermore, after adjusting for all variables (Model III) listed in Fig. 2, the multivariate-adjusted OR with a 95% CI for chronic constipation was 1.32 (1.05–1.66) in the short sleep duration

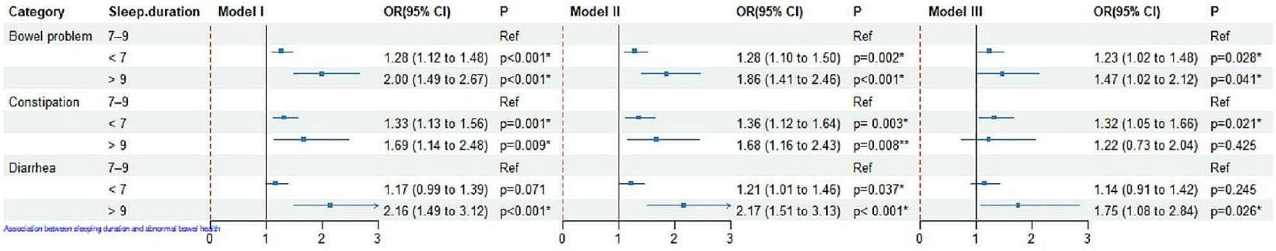

Fig. 2 Weighted association between sleep duration and abnormal bowel health
Data are presented as odds ratios, 95% confidence intervals, and P-value
Model I adjust for: None
Model II adjust for: Age (years), Gender, Race
Model III adjust for: Age (years), Gender, Race, Education level, Marital status, PIR, Physical activity, BMI, Drinking status, Smoking status, CVD, Hypertension, Cancer or malignancy and Diabetes
*: $p < 0.05$

group. However, there was no significant association found between participants with long sleep duration and chronic constipation symptoms ($P=0.425$). For chronic diarrhea, we found a significant association between long sleep duration and the presence of this symptom compared to those with normal sleep duration (OR=1.75, 95% CI=1.08–2.84, $P=0.026$). However, the short sleep duration group did not show a significant association ($P=0.245$).

Effect size of sleep duration on abnormal bowel health in prespecified and exploratory subgroups

As shown in Fig. 3. Interaction tests were performed to assess the robustness of the association between sleep duration and abnormal bowel health. We found that there were interaction effects between obesity and sleep duration on abnormal bowel health ($p=0.044$) (Fig. 3). No significant interaction effects were observed in other subpopulations (all p for interaction>0.05). Notably, both obese individuals with short sleep duration and those with long sleep duration showed a positive association with abnormal bowel symptoms ($p<0.05$).

Weighted association between sleep duration and chronic diarrhea, constipation

After adjusting for all potential confounders, we observed a non-linear relationship between sleep duration and chronic diarrhea and constipation (P for non-linearity<0.05; Fig. 4).

Discussion

In this study, we examined the associations between habitual sleep duration and chronic diarrhea and constipation in adults. We found that individuals with sleep durations of less than 7 h per day had a higher risk of chronic constipation compared to those with normal sleep duration. Additionally, sleep durations of more than 9 h per day were associated with a higher risk of chronic diarrhea. Furthermore, we observed a non-linear association between sleep duration and both chronic constipation and chronic diarrhea after adjusting for all potential confounders.

Several studies have provided evidence that functional gastrointestinal disorders have an influence in the duration and quality of sleep [25–27]. Additionally, sleep quality has been found to have a negative influence on gastrointestinal functions [28, 29]. While few reports have focused on the association between sleep duration and abnormal bowel health, especially chronic diarrhea, our work found similar significance to prior studies. For instance, short sleep duration per day was associated with a higher risk of chronic constipation [30, 31], and subjective sleep problems were significantly related to gastrointestinal dysfunctions [32], these findings support the validity of the present study. Several potential mechanisms could explain the observed relationship between sleep duration and chronic constipation, diarrhea. Firstly, short sleep duration may increase the risk of chronic constipation by lowering the contraction of skeletal muscle [33]. In fact, long-term insufficient or poor-quality sleep could lead to lower muscle mass [34, 35] and rates of muscle protein synthesis [36]. An unexplored

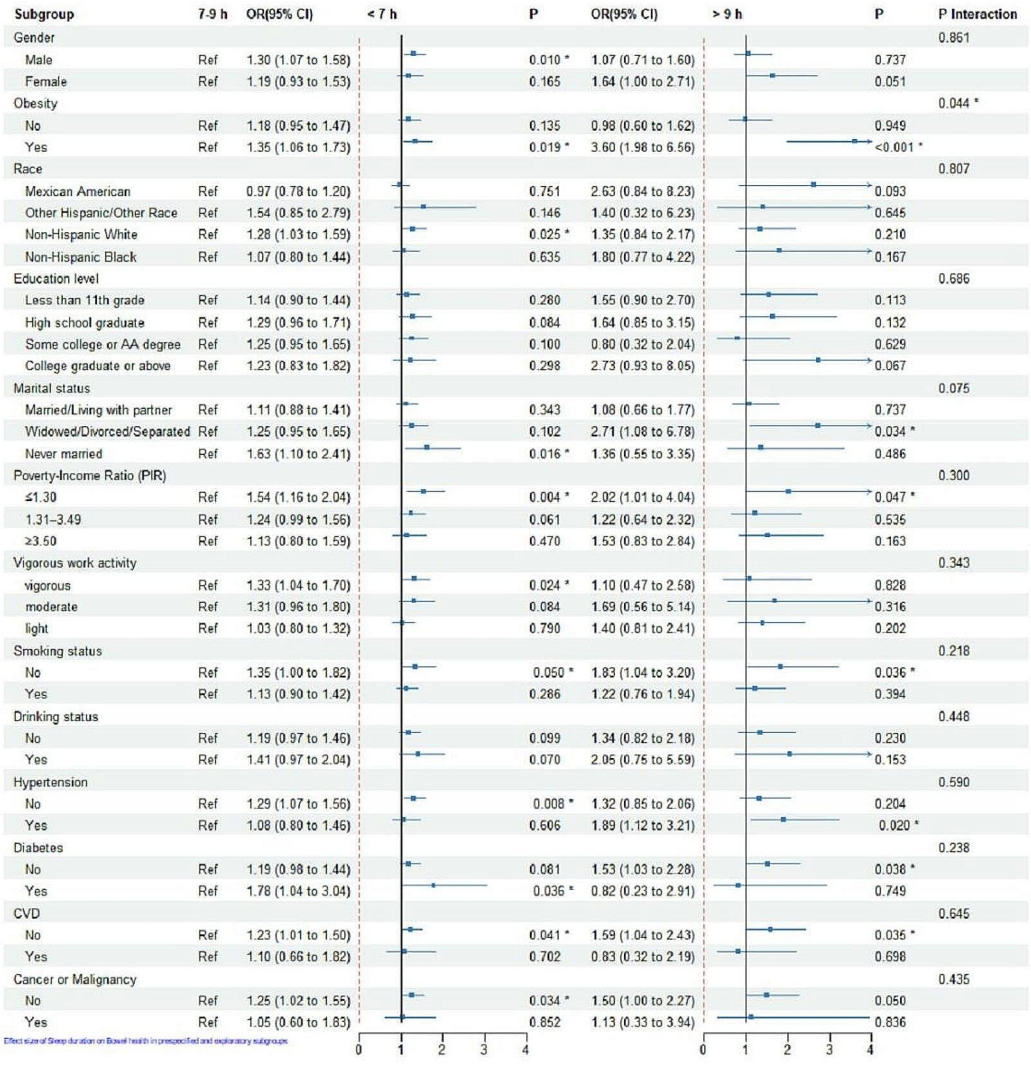

Fig. 3 The forest plot shows the weighted effect size of sleep duration on abnormal bowel health in prespecified and exploratory subgroups
Each stratification adjusted for all factors (Age, Gender, Race, Education level, Marital status, PIR, Physical activity, BMI, Drinking status, Smoking status, CVD, Hypertension, Cancer or malignancy and Diabetes) except the stratification factor itself
*: $p < 0.05$

hypothesis indicated that sleep disturbances may cause dysfunction of the anal sphincter and enhance pelvic floor muscle tone, thereby aggravated constipation [28]. Secondly, the mechanism of inflammatory cytokine and gut microbiota should be noted. In mice, sleep has been shown to change immune response [37] and the diversity in gut microbiota [38]. For example, sleep deprivation can lead to increased secretion of pro-inflammatory cytokines, activation of inflammatory-related signaling pathways [39] and reduced diversity of gut bacteria [40]. These immune changes resulting from insufficient sleep may increase susceptibility to infection. Additionally, higher risks of emotional disorders have been associated with significantly insufficient sleep time [41], which have all been found to be positively correlated with constipation severity [28]. Also, it should be highlighted that we observed an interesting relationship where sleep duration of >9 h per day was correlated with an increased risk of chronic diarrhea. Recent studies have provided some perspectives on this, such as Mantua et al. suggesting that inflammation levels may play a role in the relationship between sleep and diarrhea, particularly in infectious diarrhea [42], then evidence of emotional disorders has also supported the relationship [41]. There

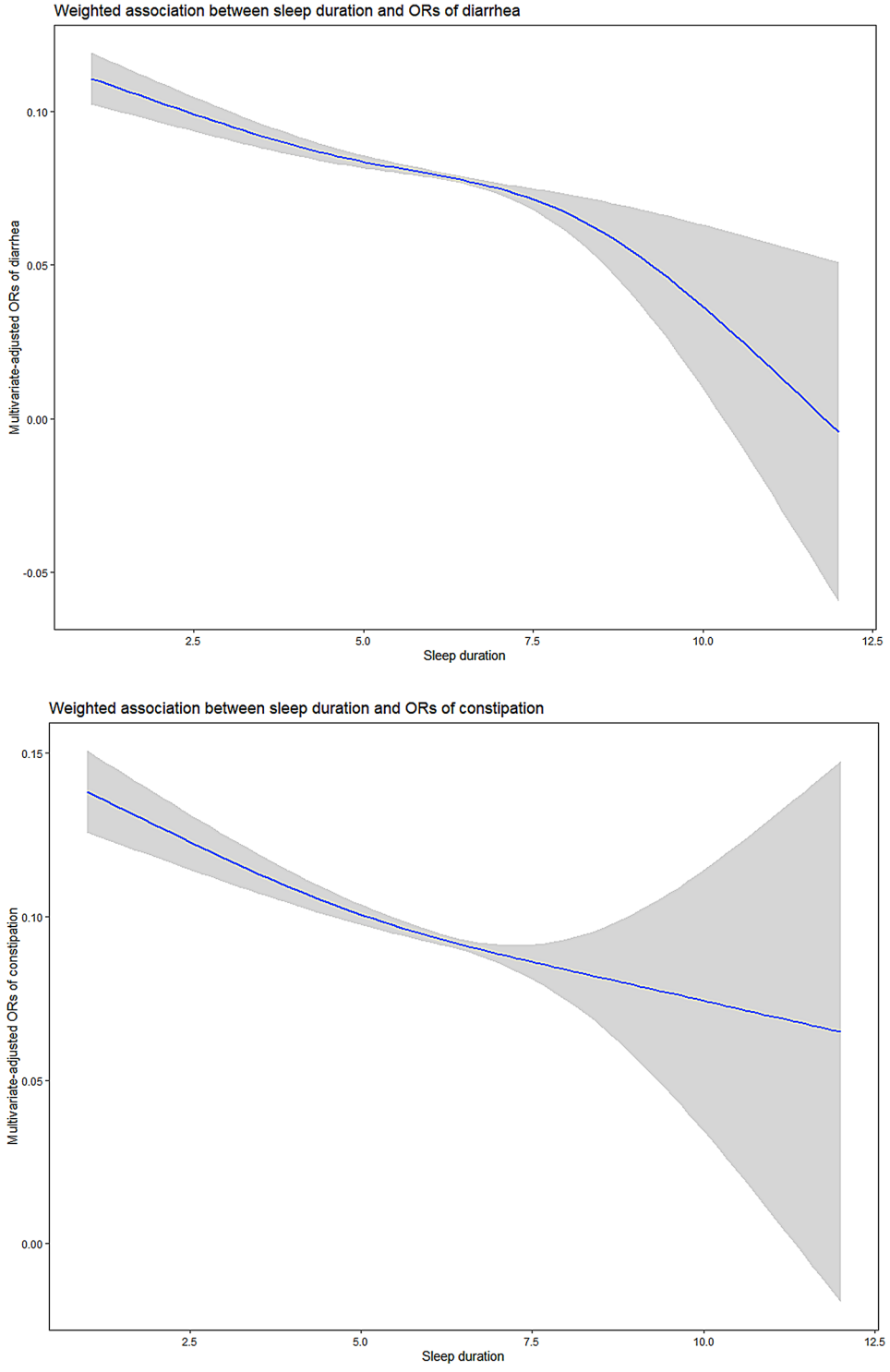

Fig. 4 Weighted relationship between sleep duration and risk of chronic diarrhea, constipation. *p for non-linearity < 0.05

was a bidirectional and complicated association between functional gastrointestinal disorders and sleep disorders, thus further scientific explanations need to be explored in longitudinal studies. This study found significant associations between habitual sleep duration and abnormal gastrointestinal health.

Our findings can provide suggestive evidence for adults with unhealthy sleep duration, especially those with chronic diseases [43]. Furthermore, this study was

the first, to our knowledge, to investigate the association between different sleep durations and chronic constipation and diarrhea in adults. Our findings reveal a potential health concern, showing that obesity may be significantly related to the correlations between habitual sleep duration and chronic diarrhea and constipation. The positive association was statistically significant in obese individuals with short or long sleep duration, rather than in non-obese individuals. This can be explained by the 24-hour circadian rhythms and circadian clock [44].

And several limitations were inevitable in this study. Firstly, self-reported sleep questionnaires in NHANES included no assessment for insomnia or other specific sleep disorders (e.g., restless leg syndrome, sleep apnea) that may have an impact on sleep duration. Secondly, although the study sample size was sufficient, the cross-sectional design of the study prevented the estimation of directional associations between sleep duration and abnormal bowel health. Despite these limitations, this study provided valuable population-based evidence on the association between habitual sleep duration and gastrointestinal disorders in adults.

Conclusions

In conclusion, this study suggested that both long and short sleep durations were associated with a higher risk of chronic diarrhea and constipation in the general population. Furthermore, a non-linear association persisted even after adjusting for case complexities.

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Not applicable.

Author contributions
Guimei Zhang, Sisi Wang and Ping Ma proposed the theme of this study, performed methodology and formal analysis, completed the writing of the original draft, who contributed equally to this work, Tuzhi Wang and Xizhe Sun were responsible for investigation and validation, also coordinated all works. Xiaotao Zhang, Hongyao Li conducted data collection and visualization. Jiyang Pan supervised and checked the manuscript writing, arranged funding acquisition. All authors provided final approval for manuscript submission and agreed to be accountable for the accuracy and integrity of the data.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participation.
The study analyzed data downloaded from the National Health and Nutrition Examination Survey public database. The National Center for Health Statistics Ethics Review Committee granted ethics approval. The methods involved in this study were conducted in accordance with relevant guidelines and regulations (Declaration of Helsinki). All individuals provided written informed consent before participating in the study. Details are available at https://www.cdc.gov/nchs/nhanes/irba98.htm. The current study was deemed exempt from further review because the data used are deidentified and publicly accessible.

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