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Unraveling the relationship between sleep behaviors and physical activity in the United States: insights from 2015 to 2020 NHANES data

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Abstract

Background Physical activity is an important component of metabolic health. However, little is known about the impact of specific types/intensities of physical activity on sleep health, especially among ethnically diverse populations. We examined the association of various sleep behaviors with moderate to vigorous work/recreational activity.

Methods Self-reported data from the National Health and Nutrition Examination Survey 2015–2020 were cross-sectionally analyzed for a sample of 11,039 participants in the United States (U.S.). Weighted univariate logistic regressions determined unadjusted associations, while weighted multivariable regression models adjusting for age, sex, ethnicity, BMI categories, and socio-economic status assessed the multivariable associations with moderate and vigorous work/recreational activity. Stratified analyses were performed to determine across-group differences by ethnicity and BMI categories.

Results Of 11,039 adults (mean age 41 years), 50.7% were female, 59.8% were Non-Hispanic White, 17.8% Hispanic/Latino, 12% Non-Hispanic Black, 6.3% Non-Hispanic Asian, and 4.1% other/multiple ethnicities. Moderate work activity increased the odds of short sleep duration [aOR = 1.42; 95% CI: 1.22, 1.65], snoring [aOR = 1.45; 95% CI: 1.21, 1.73], breath cessation [aOR = 1.37; 95% CI: 1.18, 1.59], and daytime sleepiness [aOR = 1.63; 95% CI: 1.39, 1.91]. Vigorous recreational activity reduced the odds of short sleep duration [aOR = 0.81; 95% CI: 0.71, 0.94] and trouble sleeping [aOR = 0.83; 95% CI: 0.73, 0.96]**.** Stratified analyses indicated significant ethnicity-based differences in the odds of sleep behaviors across physical activity groups and increased odds of poor sleep behaviors among participants who were underweight, overweight or had obesity.

Conclusion Work-related activity was significantly associated with suboptimal sleep behaviors while recreational activity was associated with favorable sleep behaviors. These associations were more pronounced among certain ethnic groups. Further longitudinal investigation is needed to examine the mechanism driving the relationship between sleep behaviors and physical activity.

Keywords Work activity, Recreational activity, Physical activity intensity, Sleep disorders, Ethnicity

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Background

Sleep health, a multi-dimensional pattern of sleep-wakefulness adapted to individual, social, and environmental demands, is a key lifestyle factor that impacts the physical and mental well-being of adults globally [1, 2]. Sleep behaviors are commonly thought to include insomnia, daytime napping, [3] daytime sleepiness, sleep apnea, [4] sleep duration, sleep medication use, [5] sleep continuity or efficiency, and sleep quality or satisfaction [6]. Sleep quality and duration affect human physiology, influencing the risk for chronic illnesses and metabolic disorders [7]. Sleep health has also been directly linked to a person's productivity at work/school, affecting their cognitive function and decision-making [8, 9]. According to the American Academy of Sleep Medicine (AASM) and the Sleep Research Society (SRS), adults are encouraged to get at least 7 h of sleep each night to facilitate physiological/mental recovery and foster optimal health [10, 11]. Despite the documented benefits of having adequate sleep, more than one-third of the American population fail to meet the recommended sleep guidelines [12]. While a multitude of lifestyle and physiological determinants of sleep health have been scientifically examined over the last decade, there is a dearth of recent evidence regarding the relationship of sleep behaviors with specific types and intensity of physical activity.

According to the World Health Organization (WHO), physical activity includes any bodily movements produced by skeletal muscles that require energy expenditure [13]. Such activity may occur during leisure time, transport to and from places, or as part of a person's work [13]. The intensity of physical activity is an important aspect to consider, especially in the context of physiological health. Based on guidelines by the Centers for Disease Control and Prevention (CDC), activity expending between 3.0 and 6.0 METs or 3.5–7 kcal/min is considered moderate activity; this includes activities like brisk walking, roller skating, or hiking at a leisurely pace [14]. Vigorous activity includes activities like walking, jogging, or rock climbing that expends greater than 6 METs or more than 7 kcal/min [14, 15]. The duration of physical activity is also a well-established determinant of overall health that protects against a variety of health conditions like obesity, type II diabetes, cardiovascular diseases, and degenerative neurological disorders [16]. Current guidelines recommend a minimum of 150 to 300 min of moderate-intensity or 75 to 150 min of vigorous-intensity aerobic activity per week for adults [17]. Unfortunately, only 51% of American adults meet these recommendations [17, 18]. The effects of physical activity on sleep quality are gaining attention in the scientific community. Prior literature has demonstrated that regular physical activity enhances sleep quality/duration and alleviates sleep disorders such as insomnia, daytime sleepiness, and sleep apnea [4, 19].

The type and intensity of physical activity in the context of various sleep behaviors is crucial, given its lasting impact on the health outcomes of adults across different ethnic groups. Current evidence suggests significant disparities in both physical activity levels and sleep health among ethnic minorities. For instance, non-Hispanic Black, non-Hispanic Asians, and Hispanic individuals are less likely to engage in sufficient physical activity compared to non-Hispanic whites [20]. Additionally these ethnic minorities tend to have a higher prevalence of sleep disorders such as obstructive sleep apnea and insomnia; [21] studies suggest that non-Hispanic Black adults experience the most significant deficit in sleep duration and sleep efficiency [20, 22] and are five times more likely than non-Hispanic Whites to have short sleep duration, adjusting for various demographic features. Similar findings have been observed among Hispanics and Asian populations [23]. Therefore, understanding these nuanced relationships between physical activity, sleep behaviors, and ethnicity could potentially lead to more effective, culturally tailored interventions to improve physical activity and sleep health across various ethnic groups.

Much of the existing literature regarding the relationship between physical activity and sleep behaviors are based on data collected over a decade ago, limited in their generalizability to ethnically diverse populations, and do not examine the influence of type and intensity of physical activity on various sleep behaviors. Therefore, this cross-sectional study aims to examine the association of sleep behaviors with moderate and vigorous work and recreational activity in an ethnically and metabolically diverse sample of adults in the U.S. Ethnicity was chosen as a key stratification variable due to substantial evidence of ethnic disparities in both physical activity and sleep health.

Methods

Study data an population

This study cross-sectionally analyzed data collected by the National Health and Nutrition Examination Survey (NHANES) between 2015 and 2020. A complex 3-step weighting method was created by NHANES for each survey cycle to represent the U.S non-institutional, civilian population [24]. Participants were recruited by NHANES through a multistage, representative sampling approach that involved the random selection of primary and secondary sampling units, followed by the recruitment of households and individuals to participate in comprehensive health examinations and interviews [24]. NHANES face-to-face household interviews were

conducted by trained interviewers using the Computer-Assisted Personal Interview system to gather information on demographics, medical conditions, and prescription medication use. In contrast, physical examinations, including anthropometric measures, and the collection of all biospecimens were conducted by trained NHANES personnel in Mobile Examination Centers [24].

Our study included a sample of NHANES participants between the ages of 18 and 65 years. From the overall NHANES study population (N = 25,531), individuals who were younger than 18 or older than 65 (N = 13,387), refused to respond to questions or could not recall relevant information or had missing data regarding sleep behaviors or physical activity (N = 1105) were excluded from our analysis. Therefore, the final unweighted analytical sample included 11,039 adults. The Institutional Review Board at the University of Texas Health Science Center ruled this study to be exempt from review because of the use of publicly available, deidentified data for analysis. All participants provided informed consent before participating in the NHANES study.

Assessment of physical activity frequency and intensity

The type and intensity of physical activity during a typical week were self-reported by participants via NHANES questionnaires. Participants were asked whether they engaged in moderate and/or vigorous physical work (i.e., carrying light loads, paid/unpaid work, household chores, and yard work) or recreational activities (i.e., running, swimming, volleyball, and basketball) each week. Moderate work activity (MWA) and recreational activity (MRA) were defined as any task that caused a small increase in breathing or heart rate for at least 10 min continuously, whereas vigorous work activity (VWA) and recreational activity (VRA) included tasks that caused large increases in breathing or heart rate lasting for at least 10 min continuously. For our study, each type of activity for both moderate and vigorous intensity levels was treated as separate binary variables (1 = yes, 2 = no).

Assessment of sleep behaviors

Sleep behaviors were assessed by NHANES through a series of questions regarding (1) sleep duration ("Number of hours you usually sleep on weekdays or workdays"), (2) frequency of snoring ("In the past 12 months, how often did you snore while you were sleeping?"), (3) snorting, gasping, or experiencing breathing cessation ("In the past 12 months, how often did you snort, gasp, or stop breathing while sleeping?"), (4) trouble sleeping ("Ever told a doctor you had trouble sleeping"), and (5) feeling excessively sleepy during the day ("In the past month, how often did you feel excessively or overly sleepy during the day?"). NHANES-captured responses for snoring, gasping/breath cessation, and trouble sleeping were recorded as 'never' (0 times/week), 'rarely' (1–2 nights/week), 'occasionally' (3–4 nights/week), and 'frequently' (≥ 5 nights/week) [25]. For our analysis, we categorized responses of 'never' as not having the behavior (0 = No) and responses of 'rarely', 'occasionally', or 'frequently' as having the behavior (1 = yes). We also created a short-sleep duration variable, where participants reporting < 7 h of sleep per day were considered to have short sleep duration (1 = yes) while those reporting ≥ 7 h of sleep per day were not (0 = No). For daytime sleepiness, participants who never experienced it (monthly) were treated as not having daytime sleepiness (0 = no), while those reporting this experience ≥ 1 times per month were considered to have daytime sleepiness (1 = yes).

Assessment of body measures and demographics

Participants' body measurements (including height and weight) were collected during physical examinations conducted by NHANES personnel in Mobile Examination Centers [26]. Based on these measurements, body mass index (BMI) was generated by NHANES as weight in kilograms divided by height in meters squared (kg/m^2) and rounded to one decimal place [26]. Using standardized BMI cut-offs provided by the Centers for Disease Control and Prevention (CDC), [27] we created the following BMI categories: underweight (BMI < 18.5), normal weight (BMI 18.5–24.9), overweight (BMI 25–29.9), obesity (BMI ≥ 30). Additional demographic information regarding participants' age, sex, ethnicity, and socio-economic status (SES) were collected at participants' homes by trained NHANES interviewers using Computer-Assisted Personal Interview (CAPI). In this study, family income to poverty ratio was considered a proxy indicator of SES [28].

Statistical analysis

NHANES datasets (demographics, sleep disorders, physical activity, body measurements) from 2015 to 2020 were merged based on participant ID. Participant demographics were expressed as mean (SE) for continuous variables and frequencies with weighted percentages for categorical variables. All bivariate associations between sleep behaviors and physical activity measures were assessed using weighted univariate logistic regression models. Multivariable associations between sleep behaviors and physical activity measures were determined using weighted multivariable logistic regression models. The applied NHANES MEC weights accounted for the clustered and stratified NHANES sampling design. These logistic regression models were further adjusted for age, sex, weight categories, ethnicity, and SES; these covariates were selected a priori, based on literature from

previous studies. A sensitivity analyses was performed to test for random effects between sampling clusters. However, no significant random effects were detected. All analyses were conducted in SAS Studio version 9.4 (SAS Institute, Cary, NC) and R Studio.

Results

A total of 11,039 adults were included in this analysis. Participants had a mean age of 41 years; 50.7% were female, 59.8% non-Hispanic White (NHW), 17.8% Hispanic/Latino, 12% non-Hispanic Black (NHB), and 6.3% non-Hispanic Asian (NHA). Additionally, 88.6% of participants had a high school, General Educational Development (GED), or associate-level education and above (Table 1). Based on NHANES-generated BMI (mean = 29.5 kg/m^2), 40.2% of participants had obesity and 30.2% were overweight. Regarding physical activity, 28% engaged in VWA, 34.4% in VRA, 49% in MWA, and 49.5% in MRA (Table 2). Self-reported data regarding sleep behaviors indicated that 22.7% had < 7 h of sleep per night (mean duration = 7.6 h, SE = 0.02), 27.9% had trouble sleeping, 43.2% snored ≥ 3 nights per week, 11.3% experienced breathing cessation ≥ 3 nights per week, and 86.7% experienced daytime sleepiness ≥ 1 time per month (Table 2).

Table 1 Distribution of participant demographic characteristics (N = 11, 039)

Characteristics	Mean (SD)	N (%) [a]
Age	41.0 (0.2)	
Body Mass Index (BMI)	29.5 (0.2)	
Gender		
Male		5007 (49.3)
Female		5408 (50.7)
Ethnicity		
Hispanic/Latino		2825 (17.8)
Non-Hispanic White		3032 (59.8)
Non-Hispanic Black		2645 (12.0)
Non-Hispanic Asian		1412 (6.3)
Other		501 (4.1)
Education		
Below High School		1818 (11.3)
High School, GED, Associated Degree		5394 (55.5)
College Graduate or Above		2559 (33.1)
Weight categories		
Underweight		197 (1.8)
Normal Weight		2760 (27.7)
Overweight		3109 (30.2)
Obesity		4220 (40.2)

[a] Unweighted frequency (weighted column %) reported

Table 2 Distribution of participants' sleep behaviors and physical activity levels (N = 11, 039)

Characteristics	N (%)[a]
Work activity	
Moderate	4565 (49.0)
Vigorous	2697 (28.0)
Recreational activity	
Moderate	4509 (49.5)
Vigorous	3173 (34.4)
Sleep duration	
< 7 h/night	2605 (22.7)
≥ 7 h/night	7810 (77.3)
Snoring	
Never	2947 (27.6)
Rarely (1–2 nights/week)	2798 (29.1)
Occasionally (3–4 nights/week)	1874 (18.0)
Frequently (≥ 5 nights/week)	2796 (25.2)
Trouble sleeping	
Yes	2642 (27.9)
No	7773 (72.1)
Breath cessation	
Never	7807 (75.2)
Rarely (1–2 nights/week)	1401 (13.5)
Occasionally (3–4 nights/week)	638 (6.2)
Frequently (≥ 5 nights/week)	569 (5.1)
Daytime sleepiness	
Never	1773 (13.3)
Rarely (1 time/month)	2491 (24.0)
Sometimes (2–4 times/month)	3491 (35.1)
Often (5–15 times/month)	1849 (19.6)
Almost Always (16–30 times/month)	811 (8.1)

[a] Unweighted frequency (weighted column %) reported

Results from the bivariate and multivariable analysis are presented in Table 3. Briefly, we observed that MWA significantly increased the odds of short sleep duration [aOR = 1.42; 95% CI: 1.22, 1.65], snoring [aOR = 1.45; 95% CI: 1.21, 1.73], breath cessation [aOR = 1.37; 95% CI:1.18, 1.59], and daytime sleepiness [aOR = 1.63; 95% CI:1.39, 1.91] ($p < 0.05$ for all) after adjusting for age, gender, BMI, ethnicity, and family income to poverty ratio. Additionally, VWA increased the odds of short sleep duration by 72% [aOR = 1.72, 95% CI:1.43, 2.08], the odds of snoring by 42% [aOR = 1.42; 95% CI: 1.21, 1.66], the odds of breath cessation by 31% [aOR = 1.31; 95% CI: 1.13, 1.53], and the odds of daytime sleepiness by 21% [aOR = 1.21; 95% CI: 1.03, 1.41] ($p < 0.05$ for all). However, the association between VWA and trouble sleeping was not statistically significant after adjustment (Table 3). Furthermore, engaging in VRA was associated with 19% lower odds of short sleep duration [aOR = 0.81; 95% CI: 0.71, 0.94]

Table 3 Crude and adjusted associations between sleep behaviors and type and intensity of physical activity

	Work activity		Recreational activity	
	Moderate OR (95% CI)	Vigorous OR (95% CI)	Moderate OR (95% CI)	Vigorous OR (95% CI)
Short sleep duration				
Unadjusted	1.39 (1.21, 1.59)*	1.74 (1.50, 2.03)*	0.83 (0.74, 0.92)*	0.87 (0.71, 0.92)*
Adjusted[a]	1.42 (1.22, 1.65)*	1.72 (1.43, 2.08)*	0.90 (0.78, 1.03)	0.81 (0.71, 0.94)*
Snoring				
Unadjusted	1.43 (1.25, 1.64)*	1.51 (1.30, 1.75)*	0.94 (0.81, 1.10)	0.73 (0.63, 0.85)*
Adjusted[a]	1.45 (1.21, 1.73)*	1.42 (1.21, 1.66)*	1.03 (0.89, 1.20)	0.98 (0.73, 1.08)
Trouble sleeping				
Unadjusted	1.13 (0.96, 1.32)	1.00 (0.85, 1.18)	1.00 (0.89, 1.13)	0.62 (0.54, 0.72)*
Adjusted[a]	1.07 (0.91, 1.26)	1.01 (0.85, 1.21)	1.05 (0.93, 1.18)	0.83 (0.73, 0.96)*
Breath cessation				
Unadjusted	1.46 (1.29, 1.66)*	1.45 (1.26, 1.68)*	0.91 (0.78, 1.05)	0.71 (0.60, 0.84)*
Adjusted[a]	1.37 (1.18, 1.59)*	1.31 (1.13, 1.53)*	1.01 (0.84, 1.22)	0.84 (0.70, 1.01)
Daytime sleepiness				
Unadjusted	1.87 (1.61, 2.17)*	1.29 (1.12, 1.49)*	0.54 (0.46, 0.62)*	0.98 (0.84, 1.13)
Adjusted[a]	1.63 (1.39, 1.91)*	1.21 (1.03, 1.41)*	1.04 (0.85, 1.27)	0.87 (0.71, 1.06)

*$p < 0.05$, statistically significant, *OR* odds ratios, *CI* confidence intervals

[a] ORs adjusted for age, gender, BMI, ethnicity, and family income to poverty ratio

and 17% lower odds of experiencing trouble sleeping [aOR = 0.83; 95% CI: 0.73, 0.96], respectively. The associations between VRA and snoring and breath cessation were not statistically significant after adjustment and no significant associations were noted between MRA and sleep behaviors after adjustment (Table 3).

Although the interaction analysis found no significant effect measure modification by ethnicity, the stratified analysis highlighted important ethnicity-based findings regarding sleep behaviors and physical activity (Table 4). Among those engaging in MWA, we consistently observed higher odds of all sleep behaviors among NHB, with the highest odds being for daytime sleepiness [aOR = 1.69; 95% CI: 1.36, 2.11]; NHW also had increased odds of all sleep behaviors, except trouble sleeping, and Hispanics had the highest odds of snoring among those engaging in MWA [aOR = 1.52; 95% CI: 1.18, 1.95] (Table 4). Among those engaging in VWA, the highest odds of short sleep duration were observed among Hispanics [aOR = 1.48; 95% CI: 1.16, 1.89], highest odds of snoring among NHA [aOR = 1.89; 95% CI: 1.20, 2.96], and highest odds of breath cessation among NHW [1.40; 95% CI: 1.10, 1.83]. NHA were the only ethnic group with significantly higher odds of trouble sleeping [aOR = 1.63; 95% CI: 1.04, 2.54]. No significant associations were observed between VWA and daytime sleepiness across any ethnic group.

When examining recreational activity, we observed a 31% reduction in the odds of short sleep duration among NHA engaging in MRA, and NHW engaging in VRA, respectively. MRA was also associated with a decreased odds of snoring among those belonging to other or multiple races, while VRA was associated with a decreased odds of trouble sleeping among NHW, breath cessation among NHB and NHA, and daytime sleepiness among NHW (Table 4). MRA was also associated with elevated odds of snoring among NHA [aOR = 1.63; 95% CI: 1.22, 2.17], trouble sleeping among Hispanics [aOR = 1.30; 95% CI: 1.01, 1.70] and NHB [aOR = 1.21; 95% CI: 1.01, 1.45], and daytime sleepiness among NHB [aOR = 1.31; 95% CI: 1.00, 1.71] and NHA [aOR = 1.31; 95% CI: 1.02, 1.68]. VRA was also associated with higher odds of snoring [aOR = 1.59; 95% CI: 1.16, 2.17] and daytime sleepiness [aOR = 1.64; 95% CI: 1.29, 2.10] among NHA. No significant association was observed between MRA and breath cessation across any ethnic group (Table 4).

When stratified by BMI categories and adjusted for age, sex, ethnicity, family income to poverty ratio, we observed a decreased odds of trouble sleeping [aOR = 0.72; 95% CI: 0.52, 0.99] and breath cessation [aOR = 0.75; 95% CI: 0.57, 0.98] among individuals who were overweight and engaged in VRA. Interestingly, underweight individuals engaging in MRA had over three times the odds of experiencing breath cessation compared to those not engaging in MRA [aOR = 3.09; 95% CI: 1.24, 7.69]. MWA and VWA were also significantly associated with short sleep duration, snoring, trouble sleeping, breath cessation, and daytime sleepiness among various BMI categories (Table 5).

Table 4 Adjusted associations between physical activity type and intensity and sleep behaviors, stratified by ethnicity

	Work activity		Recreational activity	
	Moderate OR (95% CI)	**Vigorous OR (95% CI)**	**Moderate OR (95% CI)**	**Vigorous OR (95% CI)**
Short sleep duration				
Hispanic/Latino	1.15 (0.93, 1.43)	1.48 (1.16, 1.89)*	0.96 (0.77, 1.19)	1.16 (0.92, 1.46)
Non-Hispanic White	1.52(1.21, 1.91)*	1.91 (0.92, 1.06)	0.90 (0.72, 1.14)	0.68 (0.54, 0.86)*
Non-Hispanic Black	1.43 (1.19, 1.72)*	1.43 (1.11, 1.85)*	0.88 (0.71, 1.08)	1.06 (0.86, 1.31)
Non-Hispanic Asian	1.25 (0.96, 1.63)	1.46 (0.85, 2.51)	0.69 (0.49, 0.98)*	0.86 (0.62, 1.29)
Other	1.59 (0.90, 2.83)	1.54 (0.80, 2.96)	0.87 (0.45, 1.70)	0.76 (0.36, 1.59)
Snoring				
Hispanic/Latino	1.52 (1.18, 1.95)*	1.67 (1.26, 2.17)*	0.90 (0.73, 1.11)	0.84 (0.61, 1.15)
Non-Hispanic White	1.43 (1.10, 1.86)*	1.44 (1.12, 1.84)*	1.10 (0.88, 1.37)	0.90 (0.71, 1.14)
Non-Hispanic Black	1.44 (1.17, 1.77)*	1.16 (0.92, 1.46)	0.89 (0.72, 1.11)	0.88 (0.70, 1.10)
Non-Hispanic Asian	1.38 (1.01, 1.88)*	1.89 (1.20, 2.96)*	1.63 (1.22, 2.17)*	1.59 (1.16, 2.17)*
Other	1.70 (0.90, 3.22)	1.31 (0.69, 2.49)	0.46 (0.23, 0.90)*	1.10 (0.60, 2.00)
Trouble sleeping				
Hispanic/Latino	1.12 (0.83, 1.52)	1.00 (0.76, 1.33)	1.30 (1.01, 1.70)*	1.02 (0.80, 1.31)
Non-Hispanic White	1.10 (0.83, 1.24)	1.02 (0.81, 1.29)	0.97 (0.81, 1.17)	0.70 (0.57, 0.85)*
Non-Hispanic Black	1.44 (1.15, 1.81)*	1.01 (0.83, 1.29)	1.21 (1.01, 1.45)*	0.87 (0.72, 1.06)
Non-Hispanic Asian	1.21 (0.84, 1.74)	1.63 (1.04, 2.54)*	1.03 (0.78, 1.35)	1.06 (0.70, 1.60)
Other	0.90 (0.47, 1.73)	0.77 (0.43, 1.37)	0.86 (0.55, 1.37)	1.09 (0.47, 2.53)
Breath cessation				
Hispanic/Latino	1.50 (1.20, 1.87)*	1.33 (1.05, 1.69)*	0.93 (0.76, 1.14)	0.87 (0.68, 1.11)
Non-Hispanic White	1.40 (1.15, 1.70)*	1.40 (1.10, 1.83)*	1.06 (0.79, 1.42)	0.84 (0.65, 1.08)
Non-Hispanic Black	1.11 (0.89, 1.39)	1.15 (0.91, 1.40)	0.92 (0.69, 1.21)	0.93 (0.72, 1.20)
Non-Hispanic Asian	1.13 (0.78, 1.64)	1.35 (0.76, 2.41)	0.99 (0.75, 1.32)	0.67 (0.48, 0.94)*
Other	1.47 (0.84, 2.56)	0.59 (0.32, 1.10)	0.91 (0.51, 1.60)	0.40 (0.19, 0.84)*
Daytime sleepiness				
Hispanic/Latino	1.66 (1.27, 2.18)*	1.17 (0.89, 1.53)	1.21 (0.95, 1.54)	1.09 (0.80, 1.49)
Non-Hispanic White	1.66 (1.31, 2.09)*	1.24 (0.98, 1.58)	1.11 (0.79, 1.55)	0.67 (0.50, 0.90)*
Non-Hispanic Black	1.69 (1.36, 2.11)*	1.26 (0.95, 1.68)	1.31 (1.00, 1.71)*	0.96 (0.75, 1.24)
Non-Hispanic Asian	1.27 (0.93, 1.75)	0.86 (0.63, 1.15)	1.31 (1.02, 1.68)*	1.64 (1.29, 2.10)*
Other	2.00 (0.87, 4.60)	1.55 (0.57, 4.25)	0.60 (0.24, 1.49)	1.21 (0.38, 3.84)

*$p < 0.05$, statistically significant, *OR* odds ratios, *CI* confidence intervals, ORs adjusted for age, gender, BMI, and family income to poverty ratio

Discussion

The study highlights important findings regarding the impact of physical activity on sleep behaviors by ethnicity and BMI groups. Briefly, MWA and VWA were associated a higher odds of adverse sleep behaviors such as short sleep duration, snoring, breath cessation, and daytime sleepiness; these associated were statistically significant among specific ethnic groups, especially among non-Hispanic Blacks, Hispanics, and non-Hispanic Asians. In contrast, MRA and VRA significantly reduced the odds of short sleep duration and snoring, further substantiating the benefits of weekly recreational activity on sleep health.

When examining work activity, findings from our study suggested significantly higher odds of shorter sleep duration, snoring, breath cessation and daytime sleepiness among participants who reported engaging in VWA or MWA. Evidence from recent studies concurred with our findings, demonstrating that high-intensity physical activity (especially those associated with long/night shifts) could have adverse impacts on overall health and contribute to fatigue, exhaustion, and poor sleep outcomes [5, 29]. Some studies also noted a 15% increase in the likelihood of experiencing disordered sleep associated with moderate-to-vigorous work activity [1] and increased odds of sleep disturbances, difficulty falling asleep, shortened sleep durations, and poor sleep quality [5, 30, 31]. While our study did not examine the influence of occupation-related responsibilities, work hours, and workplace conditions on work-related activity and sleep

Table 5 Adjusted associations between physical activity type and intensity and sleep behaviors stratified by weight categories

	Work activity		Recreational activity	
	Moderate OR (95% CI)	Vigorous OR (95% CI)	Moderate OR (95% CI)	Vigorous OR (95% CI)
Short sleep duration				
Underweight	2.25 (0.66, 7.75)	3.81 (0.77, 18.8)	2.79 (0.91, 8.53)	1.43 (0.47, 4.29)
Normal weight	1.37 (1.00, 1.89)	2.05 (1.34, 3.15)*	0.81 (0.61, 1.07)	0.57 (0.44, 0.74)*
Overweight	1.63 (1.26, 2.12)*	1.81 (1.27, 2.58)*	0.91 (0.71, 1.17)	0.84 (0.65, 1.08)
Obesity	1.31 (1.03, 1.66)*	1.49 (1.18, 1.88)*	0.90 (0.73, 1.10)	1.00 (0.74, 1.34)
Snoring				
Underweight	1.57 (0.60, 4.07)	1.29 (0.39, 4.22)	1.56 (0.62, 3.93)	1.15 (0.45, 2.96)
Normal weight	1.64 (1.19, 2.26)*	1.25 (0.92, 1.71)	0.82 (0.65, 1.03)	0.80 (0.65, 0.98)*
Overweight	1.47 (1.10, 1.97)*	1.71 (1.24, 2.37)*	1.08 (0.83, 1.40)	0.81 (0.58, 1.14)
Obesity	1.25 (0.93, 1.67)	1.45 (1.09, 1.93)*	1.20 (0.92, 1.57)	1.12 (0.78, 1.63)
Trouble sleeping				
Underweight	1.04 (0.30, 3.60)	0.62 (0.11, 3.51)	1.15 (0.36, 3.69)	1.78 (0.46, 6.94)
Normal weight	1.25 (0.93, 1.69)	1.26 (0.87, 1.82)	1.04 (0.79, 1.36)	0.83 (0.61, 1.13)
Overweight	1.36 (1.01, 1.85)*	1.05 (0.77, 1.44)	1.01 (0.77, 1.34)	0.72 (0.52, 0.99)*
Obesity	0.86 (0.70, 1.01)	0.89 (0.72, 1.10)	1.08 (0.88, 1.31)	0.87 (0.68, 1.10)
Breath cessation				
Underweight	1.13 (0.39, 3.31)	1.68 (0.48, 5.91)	3.09 (1.24, 7.69)*	0.84 (0.21, 3.35)
Normal weight	1.63 (1.17, 2.26)*	1.49 (1.05, 2.11)*	0.81 (0.54, 1.20)	0.71 (0.48, 1.04)
Overweight	1.20 (0.97, 1.71)	1.59 (1.16, 2.17)*	0.96 (0.76, 1.22)	0.75 (0.57, 0.98)*
Obesity	1.33 (1.09, 1.62)*	1.08 (0.80, 1.47)	1.09 (0.89, 1.35)	1.01 (0.82, 1.24)
Daytime sleepiness				
Underweight	1.31 (0.32, 5.43)	0.85 (0.14, 5.28)	0.43 (0.16, 1.12)	0.96 (0.19, 4.69)
Normal weight	2.26 (1.52, 3.36)*	1.45 (0.92, 2.29)	1.36 (0.99, 1.87)	1.05 (0.74, 1.49)
Overweight	1.75 (1.26, 2.41)*	1.06 (0.80, 1.40)	0.95 (0.66, 1.37)	0.79 (0.55, 1.13)
Obesity	1.20 (0.89, 1.63)	1.19 (0.83, 1.69)	0.93 (0.67, 1.29)	0.72 (0.50, 1.04)

*$p < 0.05$, statistically significant, *OR* odds ratios, *CI* confidence intervals, ORs adjusted for age, gender, ethnicity, and family income to poverty ratio

behaviors, we hypothesize that the physiological effects of the labor-related demands along with the impact of long work duration and overnight work schedules on sleep cycles may be driving the relationships between work-related physical activity and various sleep behaviors. The findings from our study highlight the strength of these relationships and underscore the need for further prospective longitudinal examination to examine the underlying mechanism driving these associations.

On the other hand, the health benefits of leisure or recreational physical activity have been extensively studied and documented in the literature. Our study found that VRA was associated with lower odds of having short sleep duration and trouble sleeping. This aligns with previous studies that have found regular moderate-to-vigorous recreational physical activity to promote good cardiovascular health, production of beneficial genetic biomarkers, and musculoskeletal fitness, [32–34] which consequently improves functional independence, mobility, glucose homeostasis, bone health, psychological well-being, and overall quality of life [35]. Regular recreational activity also protects against the development of sleep disorders, [1, 36] which further substantiates the findings of our study. Collectively, current and previous evidence reinforces the benefits of moderate-to-vigorous recreational activity on sleep behaviors.

An increasingly important factor to consider in the context of physical activity and sleep behaviors is the role of stress. Excessive stress and elevated cortisol levels are known predictors of poor sleep behaviors [37]. Numerous animal and human studies have provided compelling evidence demonstrating that acute and chronic stress profoundly impacts sleep wellness, is mediated by the hypothalamic–pituitary–adrenal (HPA) axis and sympathetic nervous system, and actively contributes to poor sleep quality and the onset/perpetuation of insomnia [29, 37–39]. Various social and occupational stressors can contribute to this mechanism such as occupation-related pressures, strained familial or spousal relationships, and/or socio-economic disadvantage. The relationship between stress and sleep behaviors can be further mediated by a number of socio-demographic factors such

as gender, substance abuse, alcohol consumption, and immigration status [40–42]. While we were unable to examine the role of stress as a confounder in this study, we believe stress may be an increasingly important driver of the relationship between physical activity and sleep in adults.

Another important factor to consider is ethnicity. Attributed to the differences in physiology and body composition, sleep disorders such as obstructive sleep apnea disproportionately affect individuals of certain ethnicities [43]. In general, studies have found that Non-Hispanic Blacks tend to have a higher likelihood of reporting suboptimal sleep patterns, [44] sleep apnea [OR = 1.78; 95% CI: 1.20, 2.63], reduced sleep quality [OR = 1.57; 95% CI: 1.00, 2.48], daytime sleepiness [OR = 1.89; 95% CI: 1.38, 2.60], and shorter sleep durations, while Hispanics/Latinos have a higher likelihood of experiencing sleep-disordered breathing compared to other ethnicities [23, 45]. These findings align with those from our study, where increased odds of short sleep duration, snoring, trouble sleeping, and daytime sleepiness was observed among non-Hispanic Blacks, and increased odds of snoring, breath cessation, and daytime sleepiness among Hispanics engaging in MWA and VWA. While ethnic differences in physiology and body composition influence sleep behaviors, other social factors that differ by ethnicity such as SES, employment, and occupation also contribute to sleep disorders. In the U.S, ethnicity, SES and health are interconnected on multiple levels, with certain ethnic groups having lower SES compared to others [46]. Individuals with low SES often experience higher levels of chronic stress due to financial instability and job insecurity, which further impacts their overall health and sleep behaviors [47, 48]. Additionally, certain ethnic groups are more highly represented in labor-intensive occupations [49] that are associated with increased physical and mental strain, musculoskeletal pains, chronic pain, and demanding schedules that disrupt sleep [30, 50]. Therefore, applying an ethnicity-based approach to the relationship between physical activity and sleep behaviors is essential to accounting for a broader set of social, economic, and environmental factors outside of biological predisposition that impact sleep health in an ethnically diverse population.

Additionally, metabolic health is an important predictor of sleep health. Multiple studies have indicated a positive association between increased adiposity and sleep disorders, especially obstructive sleep apnea [51–54]. The uneven deposition of adipose tissue around the neck significantly contributes to disordered sleep breathing, such as snoring, gasping for air, or temporary breath cessation due to obstruction [53, 54]. Additionally, longitudinal evidence suggests that obesity-related biochemical compounds such as elevated evening concentrations of cortisol, elevated ghrelin, and decreased leptin are bi-directionally associated with increased loss of sleep and poor sleep quality [52]. The findings from our study align with these observations, where participants with obesity had increased odds of shorter sleep durations, snoring, and breath cessation [53, 54]. Another group of interest in our study was the underweight group, which had significantly higher odds of breath cessation when engaging in moderate recreational activity. Prior studies have demonstrated that underweight individuals may experience reduced lung capacity, weaker respiratory muscles, and higher rates of respiratory complications which could contribute to breath cessation during physical exertion [55, 56]. This could also potentially exacerbate disordered sleep breathing and manifest as breath cessation while asleep. However, further longitudinal research is needed to confirm the mechanism correlating extreme weight categories (i.e., underweight and obesity) to sleep disorders in the context of varying physical activity type and intensity.

This study had many strengths, including being one of the first to provide detailed insights into the association between types and intensities of physical activity and various sleep behaviors, stratified by ethnicity and BMI categories. Additionally, the use of a nationally representative dataset including individuals from ethnically diverse backgrounds in the U.S. improves the external validity and generalizability of the study's results. The study's large sample size provided ample statistical power to detect smaller effects. The complex weighting methodology implemented by NHANES accounted for major selection biases, thus improving the generalizability and external validity of this study's findings.

However, the limitations of this study should also be acknowledged. The cross-sectional design of the NHANES study prevented us from determining the temporality between sleep disorders and physical activity, and from establishing any causal relationships between them. Additionally, the NHANES sleep behavior data was self-reported and primarily indicative of sleep disorders (i.e., obstructive sleep disorder, insomnia), and were not clinically confirmed using a polysomnogram. Similarly, engagement in physical activity was self-reported and not measured objectively using pedometers or accelerometers. Therefore, results from this study should be interpreted with caution in the context of broader physical activity and sleep health outcomes. The analysis was further limited by the availability of covariate data and was unable to account for other potential confounders related to education, marital status, stress, genetics, environment, occupation, and workplace conditions; data on

education attainment and marital status were available only for those above the age of 20 years.

Conclusion

This study provides valuable insight into the complex relationships between work-related physical activity and suboptimal sleep outcomes. Key disparities across ethnicity and BMI groups underscore the potential influence of both physiological and socio-environmental factors on sleep health among an ethnically diverse population. Future prospective studies of longer duration are needed to determine the long-term impacts of various type of physical activity on sleep outcomes and examine additional social and workplace factors that may contribute to the mechanism linking the physical activity and sleep health.

Abbreviations

aOR	Adjusted odds ratio
BMI	Body mass index
CDC	Centers for disease control and prevention
CVD	Cardiovascular disease
GED	General educational development
METs	Metabolic equivalents
MEC	Mobile examination center
MWA	Moderate work activity
MRA	Moderate recreational activity
NHANES	National Health and Nutrition Examination Survey
NHW	Non-Hispanic White
NHB	Non-Hispanic Black
NHA	Non-Hispanic Asian
SCD	Sudden cardiac death
SRS	Sleep research society
U.S	United States
VWA	Vigorous work activity
VRA	Vigorous recreational activity
WHO	World health organization
ANOVA	Analysis of variance
AASM	American Academy of Sleep Medicine
CAPI	Computer-Assisted Personal Interview
HPA	Hypothalamic–pituitary–adrenal

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Author contributions

DE, BS, and SS were involved in the design of the study, analysis, interpretation, writing, critical review, and final approval of the manuscript. FS and EO were involved in the critical review and final approval of the manuscript.

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Availability of data and materials

The dataset analyzed in this study is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The Institutional Review Board at the University of Texas Health Science Center ruled this study to be exempt from review because of the use of publicly available, deidentified data for analysis. All participants provided informed consent before participating in the National Health and Nutrition Examination Survey.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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