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Association of Sleep Characteristics with Tinnitus and Hearing Loss

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Abstract

Objective. The impact of poor sleep on tinnitus has been mainly attributed to central processes. There is an association between sleep disorders and hearing loss, but whether hearing levels mediate the association between sleep disorders and tinnitus is unknown. This study investigates the association between sleep characteristics, tinnitus, and hearing loss.

Study Design. Cross-sectional.

Setting. National Health and Nutrition Examination Survey (NHANES).

Methods. Study cohort includes 9693 adults (≥20 years) from the NHANES 2005 to 2018 who completed audiometric testing and questionnaires on tinnitus and sleep characteristics. Multivariable regression analyses were performed to quantify associations between sleep characteristics, tinnitus, and hearing loss.

Results. In this cohort, 29% (95% confidence interval [CI]: 28%-31%) reported trouble sleeping and 9% (95% CI: 8%-10%) reported being diagnosed with sleep disorders. Negative sleep characteristics (less hours of sleep, diagnosis of a sleep disorder, trouble sleeping, or OSA symptoms) were not associated with audiometry-measured hearing loss in multivariable models adjusted for demographics and comorbidities but were significantly associated with bothersome tinnitus. This association remained significant without substantial attenuation in multivariable models additionally adjusting for hearing levels: sleeping <8 h/day (vs ≥8) (odds ratio [OR]: 1.28 [95% CI: 1.08-1.52]), trouble sleeping (OR: 1.78 [95% CI: 1.45-2.19]), diagnosis of sleep disorders (OR: 1.57 [95% CI: 1.14-2.15]), and report of OSA symptoms (OR: 1.42 [95% CI: 1.08-1.88]).

Conclusion. Negative sleep characteristics were associated with tinnitus while there was no clinically meaningful association between sleep and hearing loss. Our findings suggest that the relationship between poor sleep and tinnitus is likely contributed by central processes without a major role of mediation via the peripheral auditory system.

Keywords

hearing loss, NHANES, sleep, tinnitus

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Tinnitus is a phenomenon of perceiving sound in the absence of external stimuli. There exists significant heterogeneity across tinnitus etiology, severity, and impact, highlighting its multifaceted nature. Due to this heterogeneity, there is no singular mechanism that fully explains tinnitus, nor is there a universally effective treatment. Severe tinnitus can have a negative impact on daily functioning, quality of life, and mental health.[1-5] Tinnitus imposes a significant economic burden on healthcare, with direct and indirect costs in the United States exceeding $15 billion annually.[6] In 2020, more than 2.3 million US veterans received compensation for tinnitus-related claims—for a total cost believed to be more than $2.75 billion.[6-8]

Sleep disorders are strongly linked to tinnitus. Disrupted sleep is a well-established risk factor for worsening the distress caused by tinnitus.[9] Conversely, bothersome tinnitus itself is a risk factor for poor sleep quality, creating a vicious cycle.[10] Prior studies have demonstrated that various negative sleep characteristics are significantly associated with tinnitus. Chronic tinnitus patients are more likely to report insomnia, poor sleep efficiency, and sleep quality.[10-12] Furthermore, insomnia has been associated with tinnitus and some studies have found links between increased intensity of tinnitus and impaired sleep quality.[13,14] Studies have also shown that the prevalence of obstructive sleep apnea (OSA) is higher among tinnitus patients.[15] Given these significant correlations, there have been efforts to understand the mechanistic

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pathways linking tinnitus and sleep disorders and to manage them in conjunction based on shared strategies such as cognitive behavior therapy.[16] Various mechanisms have been proposed to explain these links, mainly via central auditory pathway such as hyperarousal of the sympathetic nervous system in limbic and autonomic brain activities exacerbating the intolerance of tinnitus.[17]

Recently, there has been emerging evidence indicating the association between sleep disorders and hearing loss.[18] Patients with a diagnosis of OSA were found to have higher rates of audiometry-measured hearing loss based on population-based and clinic-based cohorts.[19-22] Ischemic damage to the cochlea secondary to periods of apnea during sleep has been proposed as one of the underlying mechanisms.[23,24] These findings demonstrate the potential role of hearing loss as a mediator of the association between sleep disorders and tinnitus via peripheral auditory pathway. However, no prior studies have investigated the association between sleep-related characteristics and tinnitus with audiometry-measured hearing loss as a potential mediator.

In this study, we examined the association between sleep characteristics, tinnitus, and hearing loss based on a large population-based cohort of US adults. We particularly assessed the role of objectively measured hearing thresholds as a potential mediator of associations between negative sleep characteristics and tinnitus.

Methods

Study Population

The analytic cohort was comprised of 9693 participants from the National Health and Nutrition Examination Survey (NHANES) who were 20 years of age or older and who had complete data on tinnitus, audiometric assessment, sleep, and related demographic characteristics. The NHANES is an ongoing program of studies designed to assess the health, functional, and nutritional status of the noninstitutionalized, civilian US population. Each of the sequential, cross-sectional study cycles in NHANES uses a stratified, multistage probability sampling design to survey a sample of the US population with selective oversampling of low-income individuals, racial minorities, and older adults. Sampling weights allow for analyses that account for the complex survey design and yield results that are generalizable to the US population. NHANES cohorts from 2005 to 2006, 2011 to 2012, 2015 to 2016, and 2017 to 2018 were included excluding cohorts with audiometry data on pediatric participants. The study underwent review by the University of Minnesota Institutional Review Board and was deemed exempt (#00015174).

Sleep-Related Variables

Five sleep-related variables were defined through NHANES: sleep hours as a continuous variable, sleep hours as a binary variable, sleep disorder diagnosis, trouble with sleeping, and OSA symptoms. Participants were asked the number of hours of sleep they usually get at night in integers (SLD010H and SLD012). This served as our sleep hours variable. Because of the recommended sleep duration in young adults, adults, and older adults, we analyzed sleep duration continuously and binarily (≥8 and <8 hours).[25] Participants were asked if they had ever been told by a doctor that they had a sleep disorder (SLQ060) or if they had ever told a doctor that they had trouble sleeping (SLQ050). Positive answers for these questions indicated a "sleep disorder diagnosis" and "trouble with sleeping," respectively. Participants were asked how often they had snored while they slept (SLQ030) and how often they snorted, gasped, or stopped breathing in the past 12 months (SLQ040). Additionally, they were asked how many times they felt excessively or overly sleepy during the day in the past month (SLQ120). Possible answers for all three questions were never, rarely (1-2 times per week), occasionally (3-4 times per week), or frequently (≥5 times per week). Individuals who answered "occasionally" or "frequently" to all three questions were determined to be positive for "obstructive sleep apnea symptoms" in our analysis as in prior literature.[26] Data on OSA symptoms was available in a subset of the cohort (NHANES 2005-2006, 2016-2017, 2017-2018, n = 4651). Sample weights were adjusted for this subgroup analysis for the presence of OSA symptoms to account for the changes in study cohort.

Audiometric Assessment and Tinnitus

Audiometric assessment was performed by trained examiners based on the established NHANES protocols.[27] A trained examiner determined the air conduction hearing threshold for each unaided ear in a sound-isolated room in the mobile examination center. Testing was conducted according to a modified Hughson-Westlake procedure using the automated testing mode of the audiometer (Model AD 226; Interacoustics). Quality assurance and control were established through daily calibration of equipment and monitoring of ambient noise levels using a sound level meter. Thresholds were measured twice at 1 kHz in each ear as an additional quality measure, and audiometry was repeated if there was a greater than 10-dB discrepancy between the threshold measurements. Speech-frequency pure-tone average (PTA) was calculated for each ear based on thresholds at 0.5, 1, 2, and 4 kHz. Audiometry-measured hearing loss was defined as speech-frequency PTA at 25 dB HL or greater in better hearing ear as defined by the World Health Organization.[28] Tinnitus was defined as answering "yes" to the question as in prior literature: In the past 12 months, have you been bothered by ringing, roaring, or buzzing in your ears or head that lasts for 5 minutes or more?[29-31] Sensitivity analyses were performed defining audiometry-measured hearing loss based on high-frequency thresholds (PTA at 3, 4, 6, and 8 kHz as defined in prior study) given the significant association between high-frequency hearing loss and tinnitus.[32]

Other Study Variables

Data on demographics, medical history, noise exposure history, and depression were obtained from interviews. Sex was included as a binary variable. Race/ethnicity was grouped as white (non-Hispanic white), black (non-Hispanic black), Hispanic (Mexican American or other Hispanic), or other. Education was categorized in three groups (<12th grade, high school graduate, or some college or more). Household income was reported in five categories (<$20,000, $20,000-$44,999, $45,000-$74,999, ≥$75,000, unknown). Insurance status was included as a binary variable for analyses and further descriptive categories were provided (none, private insurance, Medicare, Medicaid, or unknown). Medical history variables include smoking (never, former, current), diabetes (based on self-reported diagnosis and/or current use of insulin or other diabetic medications), hypertension (told by physician on two or more visits about hypertension diagnosis), cardiovascular disease (congestive heart failure, coronary artery disease, angina pectoris, or myocardial infarction), and stroke (self-reported history). Occupational noise exposure ("Have you ever had a job where you were exposed to loud noise for five or more hours a week?"—yes or no), and recreational noise exposure ("Outside of a job, have you ever been exposed to very loud noise or music for five or more hours a week?"—yes or no) was also included. Depression was defined by a Patient Health Questionnaire-9 (PHQ-9) score ≥10 as in prior literature.[33]

Statistical Analyses

Complex sampling design was accounted for by using sample weights according to the National Center for Health statistics guidelines in all analyses, except for the data presented in **Table 1**.[34] The population prevalence of the five sleep variables were estimated with 95% confidence intervals (CIs) in the overall cohort, individuals without tinnitus, and individuals with tinnitus. Logistic regression analysis was used to examine the association between the sleep variables and tinnitus. Multivariable regression models were adjusted for age, demographic factors, medical history, and noise exposure sequentially. Linear and logistic regression analyses were used to examine the association between sleep variables and hearing loss as continuous and binary (<25 and ≥25 dB HL) variables, respectively. Statistical significance was set at $P < .05$, two-tailed. All analyses were conducted using Stata software (version 16.1; StataCorp.).

Results

The overall study cohort consisted of 9693 adults who participated in the 2005 to 2018 NHANES (4782 women [49.3%] and 4911 men [50.7%]; mean [SD] age, 51.7 [18.7] years). Unweighted participant characteristics are summarized in **Table 1**. In this representative cohort of US adults, the mean sleep hours were 7.3 (SD 1.5) and 57% [95% CI: 56%-58%] reported sleeping less than 8 hours. 29% [95% CI: 28%-31%] reported trouble sleeping, 9% [95% CI: 8%-10%] reported being diagnosed with sleep disorders, and 22% [95% CI: 20%-24%] reported OSA symptoms. **Figure 1** represents the prevalence of negative sleep characteristics for the overall study cohort and by presence and absence of bothersome tinnitus. The prevalence of sleep disorders, trouble sleeping, and OSA symptoms were higher in adults who reported having bothersome tinnitus.

Table 2 summarizes findings from the univariable and multivariable logistic regression analyses examining the associations between sleep-related variables and tinnitus. Negative sleep characteristics were significantly associated with bothersome tinnitus in the crude model. These associations remained significant across all sleep-variables in multivariable models adjusting for hearing levels, demographics, medical comorbidities, history of noise exposure, and depression (model 3). In these models, sleeping less than 8 hours per night was associated with 28% (95% CI: 8%-52%) increased risk of bothersome tinnitus than sleeping more than 8 hours per night. Reporting trouble with sleeping was associated with 78% (95% CI: 45%-119%) increased risk of bothersome tinnitus. Report of OSA symptoms was associated with 42% (95% CI: 8%-88%) increased risk of bothersome tinnitus.

Table 3 summarizes findings from the univariable and multivariable logistic and linear regression analyses examining the associations between sleep-related variables and audiometry-measured hearing loss. Hearing loss was defined in two ways, as a continuous variable and as a binary variable (speech frequency PTA in better hearing ear <25 vs ≥25 dB HL). When considering hearing loss as a continuous variable, a history of sleep disorder diagnosis and report of trouble with sleeping were associated with increased hearing thresholds in the crude model ($\beta = 2.25$, 95% CI: 0.78-3.73; $\beta = 1.55$, 95% CI: 0.77-2.33). In multivariable models adjusting for demographics, medical comorbidities, and noise exposure, there was no statistically significant association between a history of sleep disorder diagnosis and hearing loss ($\beta = 0.12$, 95% CI: −1.13-1.37). While the association between report of trouble with sleeping and hearing loss remained statistically significant, the effect size remained small without clinically meaningful differences in hearing thresholds ($\beta = -0.69$, 95% CI: −1.37-0). Similarly, there were no significant associations between sleep-related characteristics and hearing loss when hearing loss was defined as a binary variable (<25 vs ≥25 dB HL) in multivariable models. Sensitivity analysis was performed defining hearing loss based on high-frequency thresholds (continuous and binary variables). Findings from the

Table 1. Study Participant Characteristics, NHANES 2005-2018 (n = 9693)

Characteristics	Overall n = 9693	Sleep hours ≥8 hours n = 4112	Sleep hours <8 hours n = 5581	*P* value
Mean age, years (SD)	51.7 (18.7)	52.5 (19.7)	51.1 (17.9)	<.001
Sex, n (%)				
Female	4782 (49.3)	2173 (52.9)	2609 (46.8)	<.001
Race, n (%)				
White	4012 (41.4)	1847 (44.9)	2165 (38.8)	<.001
Black	2185 (22.5)	752 (18.3)	1433 (25.7)	<.001
Hispanic	2213 (22.8)	999 (24.3)	1214 (21.8)	<.001
Other	1283 (13.2)	514 (12.5)	769 (13.8)	<.001
Education, n (%)				
Less than high school	2159 (22.3)	984 (23.9)	1175 (21.0)	.001
High school graduate	2200 (22.7)	948 (23.0)	1252 (22.4)	.001
Some college or more	5334 (55.0)	2180 (53.0)	3154 (56.5)	.001
Income, n (%)				
<$20,000	1811 (18.7)	789 (19.2)	1022 (18.3)	.006
$20,000-$44,999	2500 (25.8)	1095 (26.6)	1405 (25.2)	.006
$45,000-$74,999	1685 (17.4)	692 (16.8)	993 (17.8)	.006
≥$75,000	2292 (23.6)	908 (22.1)	1384 (24.8)	.006
Unknown	1405 (14.5)	628 (15.3)	777 (13.9)	.006
Health insurance, n (%)				
None	1763 (18.2)	749 (18.2)	1014 (18.2)	<.001
Private	3681 (38.0)	1346 (32.7)	2335 (41.8)	<.001
Medicare	2509 (25.9)	1228 (29.9)	1281 (23.0)	<.001
Medicaid	987 (10.2)	472 (11.48)	515 (9.2)	<.001
Unknown	753 (7.8)	317 (7.7)	436 (7.8)	<.001
Smoking, n (%)				
Never	5380 (55.5)	2346 (57.1)	3034 (54.4)	.004
Former	2522 (26.0)	1066 (25.9)	1456 (26.1)	.004
Current	1791 (18.5)	700 (17.0)	1091 (19.5)	.004
Diabetes, n (%)	1498 (15.4)	667 (16.2)	831 (14.9)	.073
Hypertension, n (%)	3570 (36.8)	1509 (36.7)	2061 (36.9)	.815
Cardiovascular disease, n (%)	928 (9.6)	403 (9.8)	525 (9.4)	0.515
Stroke, n (%)	403 (4.2)	191 (4.6)	212 (3.8)	.039
Occupational noise exposure, n (%)	3408 (35.2)	1347 (32.8)	2061 (36.9)	<.001
Recreational noise exposure, n (%)	1308 (13.5)	510 (12.4)	798 (14.3)	.007
Major depressive disorder, n (%)	559 (5.8)	224 (5.5)	335 (6.0)	.247

sensitivity analysis demonstrated no changes in statistical significance, effect size, or directionality of these associations (data not shown).

Figure 2 summarizes the conceptual model for the mediation analysis for the association between poor sleep characteristics and tinnitus with audiometry-measured hearing as a potential mediator. We found no significant association between poor sleep characteristics and audiometry-measured hearing mediating the association between poor sleep characteristics and tinnitus. Multivariable models with or without hearing levels as a covariate (**Table 2**, Model 3 vs Model 4) found no significant shifts in the degree of the associations between sleep-related variables and bothersome tinnitus suggestive of the mediation effect.

Discussion

In this nationally representative sample of US adults, negative sleep characteristics were significantly associated with bothersome tinnitus. Report of bothersome tinnitus was associated with less hours of sleep per night, being diagnosed with sleep disorders, report of trouble with sleeping, and OSA symptoms. Contrarily, there was no significant association between negative sleep characteristics and audiometry-measured hearing loss. Our findings

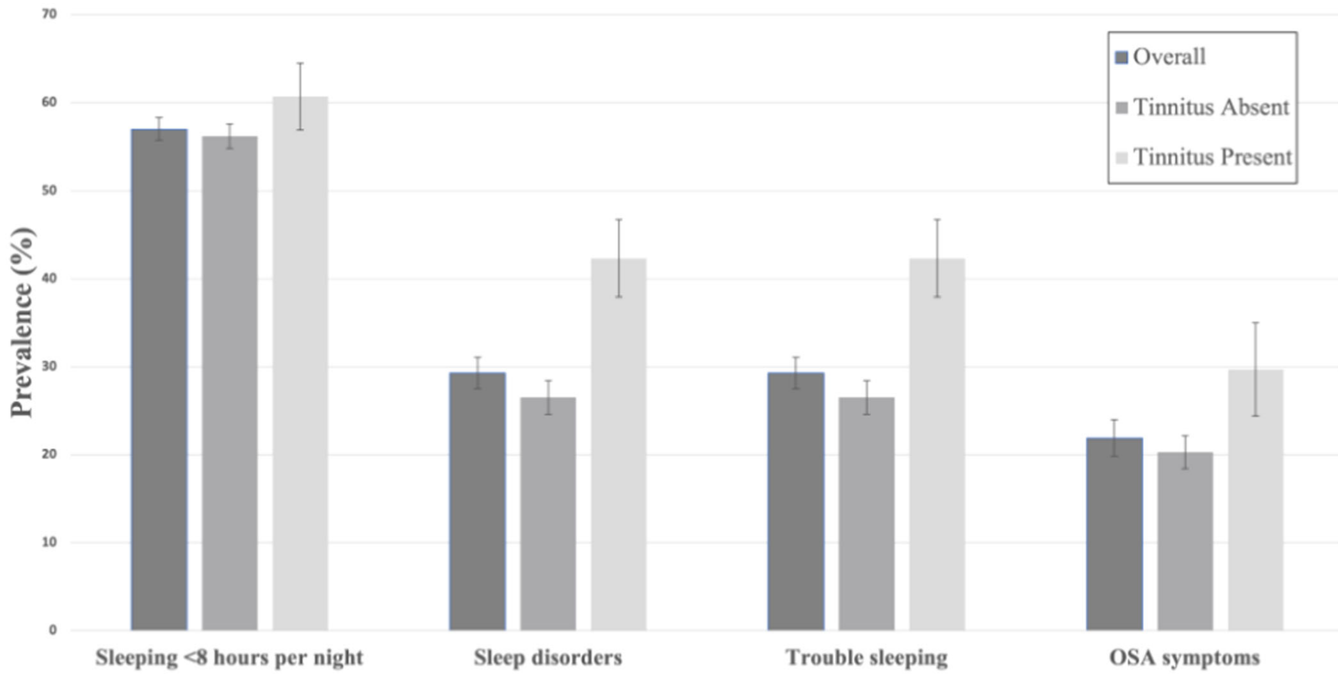

Figure 1. Prevalence of negative sleep characteristics for the overall cohort and by presence of bothersome tinnitus in the past 12 months. *Sleep Hours*: Participants were asked the number of hours of sleep they usually get at night on weekdays or workdays in integers. *Sleep Disorders*: Answering "yes" to "Have you ever been told by a doctor or other health professional that you have a sleeping disorder?" *Trouble Sleeping*: Answering "yes" to "Have you ever told a doctor or other health professional that you have trouble sleeping?" *OSA symptoms*: Answering "occasionally" or "frequently" to all three of the following questions; "In the past 12 months, how often did you snore while you were sleeping?" "In the past 12 months, how often did you snort, gasp, or stop breathing while you were sleeping?" and "In the past month, how often did you feel excessively or overly sleepy during the day?" OSA, obstructive sleep apnea.

suggest no significant role of hearing loss as a mediator contributing to the association between negative sleep characteristics and bothersome tinnitus on a population-level.

Our findings linking negative sleep characteristics to tinnitus are consistent with previous studies and this association has been described extensively.[14,35-38] Contrarily, few epidemiological studies have investigated the association between audiometry-measured hearing loss and sleep characteristics.[39,40] To our knowledge, this is the first population-based study exploring the role of hearing loss as a potential mediator in the association between tinnitus and negative sleep characteristics. Prior studies have found that the reported severity of tinnitus is highly correlated to the severity of sleep disturbance.[41] One proposed hypothesis underlying this association is that severe tinnitus can cause inappropriate activation of the limbic and sympathetic nervous systems.[42] To support this theory, one study investigating four patients who could alter the loudness of their tinnitus showed links between the limbic system and auditory system when measured by Positron Emission Tomography, although an exact mechanism for this has not been revealed.[43] This activation can be associated with the sleep disorder characteristics described in this study and others such as anxiety, depression, and panic disorders which also have a higher prevalence in tinnitus patients.[44-46] Hyperarousal and enhanced activation of the limbic and sympathetic nervous system are likewise implicated in sleep disturbances, as has been shown in various animal models.[17,47,48] The similarities in neural activation in tinnitus and sleep disturbances may reveal implications on clinical treatment options that can target these pathways.

In this cohort, there was no clinically meaningful association between sleep-related variables and audiometry-measured hearing. Several prior cohort studies interestingly have found significant associations between increased sleep duration and subclinical hearing loss. The inconsistent findings may have been contributed by variability in the cohort characteristics. A study based on a cohort of older adults in the US aged 70 years and older found that each additional hour of sleep after 8 hours was associated with a 2.89 dB HL high-frequency PTA.[39] Another study based on a large population-based cohort of adults aged 20 to 79 from Japan demonstrated an association between longer sleep duration and subclinical hearing loss at 1k and 4k Hz.[40] Although an underlying mechanism explaining the association between longer sleep duration and hearing loss has not been identified, some have hypothesized that this may be linked to the cardiovascular effects of increased sleep, particularly diabetes, obesity, and stroke.[49,50] These diseases have also been shown to be associated with HL.[51-53] In our cohort, we did not find any

Table 2. Logistic Regression Analysis Examining the Association Between Sleep Variables and Bothersome Tinnitus

	Odds ratio (95% CI)	*P* value
Sleep hours (continuous)		
Crude model[a]	0.92 (0.87-0.97)	.003
Multivariable model		
Model 1	0.91 (0.86-0.96)	<.001
Model 2	0.91 (0.86-0.95)	<.001
Model 3	0.92 (0.88-0.97)	.002
Model 4	0.93 (0.89-0.98)	.004
Sleep hours (binary; ≥8 h (reference) vs. <8 h)		
Crude model[a]	1.21 (1.02-1.43)	.028
Multivariable model		
Model 1	1.30 (1.10-1.55)	.003
Model 2	1.31 (1.10-1.55)	.002
Model 3	1.28 (1.08-1.52)	.005
Model 4	1.25 (1.05-1.49)	.012
Sleep disorder diagnosis		
Crude model[a]	2.05 (1.56-2.68)	<.001
Multivariable model		
Model 1	1.97 (1.48-2.61)	<.001
Model 2	1.88 (1.40-2.451)	<.001
Model 3	1.57 (1.14-2.15)	.006
Model 4	1.55 (1.13-2.13)	.007
Trouble with sleeping		
Crude model[a]	2.04 (1.69-2.44)	<.001
Multivariable model		
Model 1	1.97 (1.62-2.40)	<.001
Model 2	1.98 (1.63-2.40)	<.001
Model 3	1.78 (1.45-2.19)	<.001
Model 4	1.73 (1.43-2.10)	<.001
Obstructive sleep apnea symptoms		
Crude model[a]	1.66 (1.32-2.09)	<.001
Multivariable model		
Model 1	1.65 (1.28-2.13)	<.001
Model 2	1.57 (1.22-2.04)	.001
Model 3	1.42 (1.08-1.88)	.015
Model 4	1.41 (1.08-1.84)	.013

Model 1: adjusted for age, hearing levels. Model 2: adjusted for age, hearing levels, and other demographic factors (sex, race, education, income, health insurance). Model 3: adjusted for age, hearing levels, demographic factors, medical history (smoking, diabetes, hypertension, cardiovascular disease, stroke), occupational and recreational noise exposure, and depression. Model 4: adjusted for all variables in model 3 except hearing levels (excluding hearing levels as a covariate).
[a]Crude model: unadjusted crude model.

significant association of sleep duration with speech-frequency or high-frequency hearing loss with or without adjusting for cardiovascular diseases. There was no significant role of audiometry-measured hearing as a mediator for the association between sleep-related variables and tinnitus.

A few prior studies have investigated the potential role of treatment for sleep disorders such as OSA on hearing and tinnitus. A meta-analyses of 20 cohort, case-control, and cross-sectional studies that diagnosed OSA by polysomnography or sleep tests and hearing threshold level totaling 33,391 adult patients found that continuous positive airway pressure (CPAP) treatment for OSA did not show improvement in audiometry-measured hearing loss.[54] In contrast, a prior non-randomized, noncontrolled study assessing the impact of CPAP treatment on tinnitus found that the Tinnitus Handicap Inventory scores significantly decreased with CPAP use after 3 months for 14 patients with sleep-disorder breathing and tinnitus symptoms.[55] Multiple studies have shown improvements in depression and anxiety symptoms following CPAP use, which have been heavily linked to tinnitus.[56,57] CPAP treatment for OSA may have positive impact on mitigating bothersome tinnitus. Whether this is due to CPAP's improvement of tinnitus or the noise-masking of a CPAP machine, a known treatment for tinnitus, is unknown. Further studies investigating this and the impact of medical and surgical treatments of OSA on hearing loss and tinnitus are needed to understand their effectiveness.

There are several limitations to this study. First, this is a cross-sectional study, and temporal and causal relationships between the associations are unable to be established in this data. Furthermore, there may be additional confounders and mediators that were not available in this dataset. Examples of these include anxiety, diet, and alcohol consumption. Presence of OSA symptoms were defined by the questionnaire, and data on formal diagnosis of OSA via polysomnography were unavailable. Tinnitus and sleep variables were defined based on self-report without objective measures (eg, tracked sleep hours, polysomnography, or clinical diagnosis from physicians) and are subject to misreporting and recall bias. In a population-based study of middle-aged adults, participants tended to overestimate their sleep duration, especially among those with shorter sleep durations.[58] Furthermore, tinnitus was defined based on a single question in this study, which restricted our ability to assess the associations stratified by the varying degrees of tinnitus severity. Additionally, participants were asked if they had ever been told by a doctor that they had a sleeping disorder so mild or undiagnosed cases may have been missed. Lastly, the sleep-related variables were defined based on categorization from prior studies. The results may have been different based on the questions asked and their response choices. This study utilized various questionnaires on sleep characteristics, and we found generally similar associations of variables across the poor sleep indicators with tinnitus and hearing loss.

Conclusion

The current study used a nationally representative sample of US adults to investigate the association between sleep characteristics, tinnitus, and hearing loss. The objective was

Table 3. Linear and Logistic Regression Analysis Examining the Association Between Sleep Variables and Hearing Loss

	Linear regression HL continuously (dB)		Logistic regression HL binary (<25 vs ≥25 dB)	
	β-coefficients (95% CI)	*P* value	Odds ratio (95% CI)	*P* value
Sleep hours (continuous)				
Crude model[a]	0.23 (−0.06-0.53)	.114	1.05 (1.00-1.11)	.069
Multivariable model				
Model 1	0.15 (−0.04-0.34)	.122	0.97 (0.91-1.03)	.297
Model 2	0.12 (−0.05-0.30)	.170	0.98 (0.92-1.04)	.512
Model 3	0.15 (−0.03-0.33)	.095	0.98 (0.92-1.05)	.631
Sleep hours (binary; ≥8 h (reference) vs <8 h)				
Crude model[a]	−1.26 (−2.03 to −0.49)	**.002**	0.78 (0.67-0.90)	**.001**
Multivariable model				
Model 1	−0.67 (−1.27 to −0.44)	**.036**	1.01 (0.83-1.23)	.11
Model 2	−0.50 (−1.06-0.05)	.073	0.99 (0.82-1.19)	.879
Model 3	−0.53 (−1.08-0.02)	.058	0.98 (0.80-1.18)	.803
Sleep disorder diagnosis				
Crude model[a]	2.25 (0.78-3.73)	**.003**	1.15 (0.83-1.61)	.389
Multivariable model				
Model 1	0.50 (−0.68-1.267)	.398	1.20 (0.80-1.80)	.38
Model 2	0.28 (−0.86-1.42)	.62	1.10 (0.71-1.70)	.658
Model 3	0.12 (−1.13-1.37)	.848	1.08 (0.67-1.74)	.755
Trouble with sleeping				
Crude model[a]	1.55 (0.77-2.33)	**<.001**	1.24 (1.08-1.42)	**.003**
Multivariable model				
Model 1	−0.55 (−1.30-0.20)	.15	1.06 (0.088-1.27)	.549
Model 2	−0.37 (−1.06-0.31)	.278	1.15 (0.95-1.39)	.152
Model 3	−0.69 (−1.37-0.00)	**.049**	1.09 (0.90-1.33)	.348
Obstructive sleep apnea symptoms				
Crude model[a]	0.97 (−0.41-2.35)	.164	1.06 (0.80-1.42)	.68
Multivariable model				
Model 1	0.34 (−0.90-1.58)	.585	1.32 (0.88-1.98)	.177
Model 2	0.18 (−0.89-1.25)	.733	1.26 (0.87-1.83)	.216
Model 3	−0.18 (−1.30-0.93)	.741	1.17 (0.79-1.74)	.429

Model 1: adjusted for age. Model 2: adjusted for age and other demographic factors (sex, race, education, income, health insurance). Model 3: adjusted for age, demographic factors, medical history, and noise exposure. Bold-face values indicate models with $P < .05$.
[a]Crude model: unadjusted crude model.

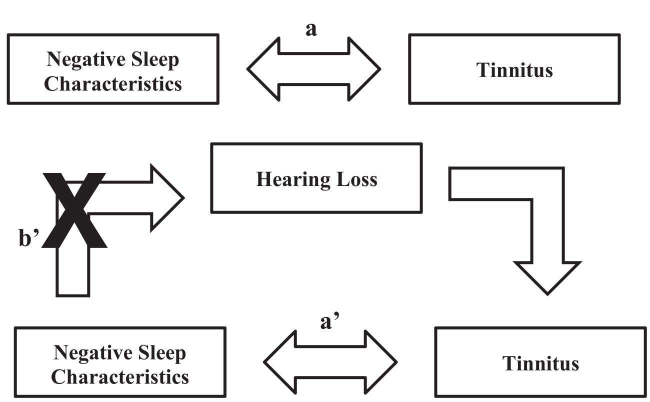

Figure 2. Path diagrams for the association among sleep characteristics, hearing loss, and tinnitus. a/a′: Models in **Table 2**. b′: Models in **Table 3**.

to explore whether hearing levels mediate the association between sleep disorders and tinnitus. Negative sleep characteristics were significantly associated with tinnitus, while no significant role of audiometry-measured hearing as a mediator for the association between sleep variables and tinnitus was discovered. Despite limitations, these findings have future implications in understanding the potential mechanism underlying the association between sleep disorders and tinnitus, along with exploring conjunctive management options for both conditions that are difficult to treat.

Author Contributions

Matthew Awad, study conception and design, acquisition of data and analysis, drafting the manuscript, critical revisions, final approval for submission; **Ibrahim Abdalla**, drafting the manuscript, critical revisions, final approval for submission; **Sebastian Jara**, interpretation of study data, critical revisions, final approval for submission; **Tina C. Huang**, study conception, critical revisions, final approval for submission; **Meredith E. Adams**, study conception, critical revisions, final approval for submission; **Janet S. Choi**, study conception, study design, acquisition of data and analysis, drafting the manuscript, critical revisions, final approval for submission.

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