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SCIENTIFIC INVESTIGATIONS

Sleep Apnea Is Associated with Hearing Impairment: The Hispanic Community Health Study/Study of Latinos

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Study Objective: Sleep apnea (SA) may promote hearing impairment (HI) through ischemia and inflammation of the cochlea. Our objective was to assess an independent association between SA and HI in the Hispanic Community Health Study/Study of Latinos (HCHS/SOL) participants.

Methods: We used data from the HCHS/SOL, a multicenter population-based study of self- identifying Hispanic/Latinos 18- to 74-y-old adults from four US urban communities. We performed home SA testing and in-clinic audiometry testing in all participants. SA was defined as an apnea-hypopnea index (AHI) ≥ 15 events/h. HI was defined as a mean hearing threshold > 25 dB hearing level in either ear at the frequencies: 3,000 to 8,000 Hz for high-frequency HI (HF-HI) and 500 to 2,000 Hz for low-frequency HI (LF-HI). Combined-frequency HI (CF-HI) was defined as both conditions present, and Any-HI was considered as HI in either low or high frequencies.

Results: Of 13,967 participants, 9.9% had SA and 32.3% had Any-HI. Adjusted for risk factors for HI, those with SA had a 30% higher odds of Any-HI (95% confidence interval [CI] = 8% to 57%), 26% higher odds of HF-HI (CI = 3% to 55%), 127% higher odds of LF-HI (CI = 21% to 326%), and 29% higher odds of CF-HI (CI = 0% to 65%). A dose-response association was observed between AHI severity and Any-HI (versus no SA, OR for AHI ≥ 15 and < 30 = 1.22, CI = 0.96 to 1.54, and OR for AHI ≥ 30 = 1.46, CI = 1.11 to 1.91, p = 0.002).

Conclusion: SA is associated with HF-HI and LF-HI, independent of snoring and other confounders.

Commentary: A commentary on this article appears in this issue on page 641.

Keywords: sleep apnea, hearing impairment

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INTRODUCTION

Sleep apnea (SA) is exceedingly prevalent in the United States, especially among populations such as Hispanics[1] who have a high prevalence of obesity.[2] We recently reported the prevalence of mild, moderate, and severe SA in the US Hispanic/Latino population to be 25.8% (apnea-hypopnea index [AHI] ≥ 5), 9.8% (AHI ≥ 15), and 3.9% (AHI ≥ 30), respectively[1]. SA has been associated with numerous cardiovascular conditions including hypertension,[3] coronary heart disease,[4,5] cardiac arrhythmias,[6] heart failure,[7,8] stroke[9] and sudden death.[10] SA may also be associated with inflammatory and ischemic phenomena that may increase risk of hearing impairment (HI).[11,12]

HI is a highly prevalent condition in adults, and is associated with poor quality of life, impaired activities of daily living,[13] and increased health care costs.[14] The estimated prevalence of HI in the United States between 2001–2008 using data from the National Health and Nutrition Examination Survey (NHANES) has been reported to be 20.3% in persons age 12 y or older.[15] Though HI prevalence did not differ between Hispanics/Latinos and non-Hispanic whites at any age group, the Hispanics/Latinos represented in NHANES are predominately Mexican American. According to the Hispanic Health and Nutrition Examination Surveys (HHANES), the prevalence of HI varied by country of origin; HI prevalence was as high as 46.3% among Mexican Americans and as low as 23.1% in Puerto Rican men age 55–74 y.[16] Although there are a number of well-established risk factors for HI, including age, sex, lower socioeconomic status, and cardiovascular risk factors,[16] identification of new modifiable risk factors may provide further opportunities to prevent HI and alleviate the effects of HI on quality of life, cognitive function, and emotional and social

BRIEF SUMMARY

Current Knowledge/Study Rationale: Sleep apnea may be associated with hearing impairment via vascular insufficiency of cochlea. Few studies have examined the relationship between sleep apnea SA and hearing impairment, but results have been inconsistent.

Study Impact: This is a large population-based study, which showed a strong and independent association between sleep apnea and hearing impairment. Further studies are needed to elucidate the mechanism linking SA with HI, and to assess the effect of SA therapy on HI.

well-being.[13,17–19] Only a few studies examining the link between SA and HI have been conducted, and results are inconsistent.[20,21] Moreover, no prior large, population-based studies have obtained standardized objective measures of both hearing and sleep as well as potential confounding variables.[17,18]

Using data from the largest study of US Hispanics/Latinos to date with standardized SA and audiometry testing, we examined the association between SA and HI.

METHODS

Study Population

The Hispanic Community Health Study/Study of Latinos (HCHS/SOL) is a multicenter, population-based study of 16,415 self- identified Hispanic/Latino 18- to 74-y-old adults from four US urban communities (Bronx, NY; Chicago, IL; San Diego, CA; Miami, FL). Detailed methods on sampling and study design have been published elsewhere.[22,23] Participants were recruited using a stratified two-stage probability sampling design between 2008 and 2011 from defined geographical areas (census block groups) to provide a representative sample of the target population. Informed consent was obtained from all study participants and the study was approved by the institutional review board at study affiliated centers.

Protocol and Measurement

Each participant completed a study visit including interviewer-administered questionnaires in English or Spanish based on the participant's language preference, anthropometric measurements, seated blood pressure, an inventory of currently used medications, blood tests including fasting glucose, lipid levels and hemoglobin A1C, home SA testing, and audiometric testing. Detailed protocols are available online. http://www.cscc.unc.edu/hchs/

Sleep Apnea Measures

SA was assessed using a portable SA monitoring device (ARES Unicorder 5.2; B-Alert, Carlsbad, CA).[24] The SA monitor measured overnight oxygen saturation (using a transcutaneous oximeter), airflow (using nasal cannula and pressure transducer), and head position and movement.[24] Certified polysomnologists scored sleep records to identify periods of sleep and annotated each respiratory event that was associated with oxyhemoglobin desaturation at a centralized sleep reading center. The majority of the sleep studies (84.4%) were rated as "excellent" quality with ≥ 3.8 h of interpretable data, and 5.8% of the studies were of insufficient quality with less than 30 min of recorded data. The interscorer and intrascorer reliability were high. The AHI measured by the sleep monitor in the study and by polysomnography, the gold standard, has been previously reported as having good agreement.[25] Detailed methods on sleep study measures have been published previously.[3]

Audiometric Measures

All participants underwent otoscopy and audiometric testing along with a detailed staff-administered, hearing-related history questionnaire that captured symptoms of HI, ear surgery, and noise exposure. Technicians were trained and certified by the EpiSense Audiometry Reading (EAR) Center at the University of Wisconsin. The EAR Center supervised all data collection and interpretation of audiometry studies. Pure-tone audiometry was conducted to determine the participant's hearing thresholds using GSI-61 clinical audiometer (Grason-Stadler, Inc., Madison, WI) equipped with TDH-50P and insert earphones (E-A-Rtone 3A, Cabot Safety Corp., Indianapolis, IN) that were calibrated annually according to American National Standards Institute standards.[26] Hearing thresholds were measured by pure-tone air (500, 1,000, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz) and bone conduction (500, 2,000 and 4,000 Hz) audiometry using a modified Hughson-Westlake procedure in sound-treated booths according to the guidelines of the American Speech-Language-Hearing Association.[27]

Definitions

Sleep-Related Variables

Respiratory events were defined as a 50% or more reduction in airflow lasting at least 10 sec. Apneas were not distinguished from hypopneas because a thermistor was not available. Each respiratory event was manually identified and linked to its level of desaturation, and artifact was manually edited on an epoch-by-epoch basis. We required events to be linked to a ≥ 3% desaturation in accordance with current recommended hypopnea scoring criteria from the American Academy of Sleep Medicine.[28,29] We defined SA as AHI ≥ 15 events/h. SA severity was defined as: mild or no SA (0 ≤ AHI < 15), moderate SA (15 ≤ AHI < 30), and severe SA (AHI ≥ 30). Interscorer and intrascorer reliability estimates for the AHI remained high over the course of the study (intraclass correlation coefficients > 0.99). Snoring was assessed by a single-item question that read: "How often do you snore now?" Snoring was defined when a participants self-reported snoring one or more times a week.

Hearing Impairment-Related Variables

Consistent with NHANES,[30] we considered HI to be present when the mean hearing threshold was greater than 25 dB hearing level in either ear at the frequencies of interest: 3,000, 4,000, 6,000, and 8,000 Hz for high-frequency HI (HF-HI) and 500, 1,000, and 2,000 Hz for low-frequency HI (LF-HI). HI was defined both as a binary variable (presence or absence of Any-HI including HF-HI and or LF-HI) and as a four-level variable: (1) no HI, (2) HF-HI only, (3) LF-HI only, and (4) combined hearing impairment (CF-HI) defined as both HF-LI and LF-HI. Conductive hearing loss was considered present when the air-bone gap was greater than 15 dB hearing level at 500, 2,000, or 4,000 Hz in either ear. Other hearing-related variables were defined using self-report, including history of ear surgery, hearing aid use, military service, firearms use, and personal earphone use in the past 7 days.

Covariates

Other covariates of interest included the following socio-demographic characteristics: age (18–29, 30–39, 40–49, 50–59, 60–69, and 70–74 y), sex, Hispanic/Latino national background (Dominican, Central American, Cuban, Mexican, Puerto

Rican, or South American), and income (< $20,000, ≥ $20,000, and missing). Hypertension was defined as systolic or diastolic blood pressure greater than or equal to 140/90 mmHg, or current use of antihypertensive medications. Diabetes mellitus was defined as fasting glucose was greater than or equal to 126 mg/dL, or nonfasting glucose greater than or equal to 200 mg/dL, or hemoglobin A1C greater than or equal to 6.5%, or current diabetes medication use. Dyslipidemia was present when low-density lipoprotein (LDL) cholesterol was greater than or equal to 160 mg/dL, or high-density lipoprotein (HDL) cholesterol was less than or equal to 40 mg/dL, or triglycerides were greater than or equal to 200 mg/dL. History of coronary heart disease (CHD) was considered present if participant self-reported diagnosis of angina, myocardial infarction or cardiac procedures such as angioplasty, stent placement or coronary artery bypass graft surgery. History of stroke was self-reported.

Statistical Analysis

Participants with data from SA and audiometry testing were included in the analysis. We calculated age-and-sex adjusted mean hearing thresholds by each sound frequency using survey linear regression with predicted marginal effects stratified by SA status. We assessed differences in mean hearing threshold using survey linear regression. Using survey logistic regression models, we quantified the association between SA and any HI as an odds ratio (OR) with 95% confidence interval (CI). To assess the association between SA and type of HI, we used survey multinomial logistic regression models. We tested for dose-response associations by examining linear trend tests for the presence of HI across categories of SA severity defined by AHI. Each analysis included adjustment for potential confounders that were identified *a priori*: age, sex, body mass index (BMI), Hispanic/Latino background, clinical center, hypertension, diabetes, dyslipidemia, cigarette use, alcohol use, history of CHD, history of ear surgery, military service, firearms use, and personal earphone use in the past 7 days. Because snoring, a frequent correlate of SA, may independently be associated with HI,[26] self-reported snoring was also included as an adjustment variable. We included conductive HI in main analyses, but in sensitivity analyses we found that the main results were not appreciably different after exclusion of participants with conductive hearing loss. Interaction analyses examined whether the association between SA and HI was consistent across sex and age group using first-order interaction terms. These interactions were not significant; therefore, results were not stratified by age or sex. All tests were two-sided with the level of statistical significance defined as $p < 0.05$. All values in tables, except subgroup n, were weighted to account for probability sampling design and non-response using SAS-Callable SUDAAN version 11.0, Research Triangle Park, NC.

RESULTS

Among 16,415 participants in HCHS/SOL, 2,448 (15%) were excluded including 9 who were older than 74 y when data collection was completed, 738 others who had incomplete audiometry data, and 1,701 others who had incomplete SA data. This left a study sample of 13,967 participants including 8,399 females with mean age of 46 y (standard deviation = 14).

Hearing Impairment

HF-HI was the most prevalent form of HI (21.5%). An additional 9.7% of participants had CF-HI, whereas LF-HI alone was relatively uncommon (1.0%). Detailed description of HI prevalence in the HCHS/SOL has been published elsewhere.[31] Briefly, compared with those without HI, those with HI were significantly more likely to be older and male, and had lower income and greater noise exposure (data not shown).

Sleep Apnea and Hearing Impairment

Prevalence of SA ranged from below 10% in participants younger than 50 y, to more than one-quarter of 60- to 74-y-old participants (**Table 1**). The distribution of SA by other sociodemographic characteristics and hearing-related variables are presented in **Table 1**.

The age- and sex-adjusted prevalence of SA was significantly higher in participants with any HI compared to those without HI (11.1% versus 8.7%, **Table 1**). In multivariable adjusted analyses that controlled for additional potential confounding variables, SA was associated with a 30% increase in the odds of Any-HI (OR = 1.30, CI = 1.08, 1.57). Compared with the reference group of participants without SA, individuals with SA had a 26% increased odds of having HF-HI, 29% increased odds of having CF-HI and 127% increased odds of having LF-HI (**Table 2**).

After adjustment for age and sex, as compared to the non-SA group, persons with SA had significantly higher mean hearing thresholds in the worst ear at all sound frequencies of interest (**Figure 1**).

As expected, compared to nonsnorers, snorers had a higher prevalence of SA (respectively 5.4% versus 13.3%, **Table 1**). Snoring was not associated with Any-HI or HI in the low or high frequencies. In multivariable analyses, adjustment for snoring status did not appreciable change the association between SA and HI.

Sleep Apnea Severity and Hearing Impairment

In the study population, 6.0% had moderate SA and 3.9% had severe SA (**Table 1**). The OR for Any-HI increased monotonically across categories of SA severity (p for linear trend = 0.002, **Table 2**). The OR for HF-HI also displayed a significant stepwise increase in risk across severity categories (p for linear trend = 0.006, **Table 3**). For less common types of HI, limited sample size precluded our ability to estimate the associations across the range of SA severity. We examined the relationship between nadir oxygen saturation (SpO_2) and severity of HI. In unadjusted analyses, lower nadir SpO_2 was associated with an increased prevalence of HI (**Table S1**, supplemental material).

We also assessed the dose-response relationship between sleep apnea severity and hearing impairment by examining hearing impairment severity. We found that in unadjusted and adjusted analyses, increasing sleep apnea severity was associated with increased odds of hearing impairment severity;

Table 1—Age-and-sex adjusted prevalence of sleep apnea and sleep apnea severity by sociodemographic characteristics.

		SA Severity		
Characteristic	**Subgroup n**	**Moderate or Severe**	**Moderate**	**Severe**
Overall [a]	13,967	9.9 (9.1, 10.7)	6.0 (5.4, 6.6)	3.9 (3.5, 4.4)
Sociodemographic characteristic				
Age [b]				
18–29	2,189	2.2 (1.5, 3.1)	1.1 (0.7, 1.8)	1.1 (0.6,1.9)
30–39	2,030	5.2 (4.2, 6.4)	2.7 (2.0, 3.6)	2.5 (1.9, 3.4)
40–49	3,627	9.7 (8.4,11.2)	5.6 (4.7, 6.9)	4.1 (3.3, 5.0)
50–59	3,744	16.3 (14.7,18.1)	10.5 (9.1,12.1)	5.8 (4.9, 6.9)
60–69	1,971	25.5 (22.2,29.2)	15.7 (12.9, 18.9)	9.8 (8.0, 12.0)
70–74	406	25.4 (19.4, 32.5)	17.1 (12.5, 23.0)	8.2 (4.9, 13.4)
Sex [c]				
Women	8,399	6.2 (5.4, 7.0)	4.3 (3.6, 5.0)	1.9 (1.6, 2.3)
Men	5,568	14.2 (13.0, 15.6)	8.0 (7.1, 9.0)	6.3 (5.5, 7.1)
Hispanic background				
Dominican	1,179	10.1 (8.0,12.6	6.8 (5.0, 9.2)	3.3 (2.3, 4.7)
Central American	1,449	9.5 (7.6,11.8	5.6 (4.3, 7.3)	3.9 (2.8, 5.3)
Cuban	1,881	10.6 (9.2,12.2)	6.4 (5.3, 7.7)	4.2 (3.5, 5.2)
Mexican	5,982	9.8 (8.6,11.2)	5.6 (4.8, 6.5)	4.2 (3.4, 5.1)
Puerto Rican	2,157	9.8 (8.0,12.0)	4.3 (4.8, 8.2)	3.5 (2.8, 4.4)
South American	902	7.7 (6.1, 9.8)	4.5 (3.2, 6.3)	3.3 (2.2, 4.7)
Field center				
Bronx	3,174	9.4 (7.9,11.1)	6.0 (4.8, 7.4)	3.4 (2.8, 4.1)
Chicago	3,716	10.4 (9.1,11.7)	7.1 (6.0, 8.3)	3.3 (2.7, 4.1)
Miami	3,276	10.1 (8.9,11.5)	6.0 (5.0, 7.1)	4.2 (3.5, 4.9)
San Diego	3,801	9.9 (8.4, 11.6)	5.4 (4.5, 6.5)	4.5 (3.6, 5.6)
Income				
< $20k	6,073	9.6 (8.6,10.7)	5.9 (5.1, 6.8)	3.7 (3.2, 4.3)
≥ $20k	6,745	10.5 (9.3, 11.8)	6.3 (5.4, 7.4)	4.2 (3.5, 4.9)
Missing	1,149	8.0 (6.2, 10.4)	4.6 (3.4, 6.3)	3.4 (2.1, 5.4)
Self-reported snoring				
Yes	7,470	13.3 (12.1, 14.6)	7.6 (6.8, 8.5)	5.7 (5.0, 6.5)
No	6,438	5.4 (4.7, 6.3)	3.9 (3.2, 4.7)	1.6 (1.2, 2.0)
Hearing-related variables				
HI				
Any	5,439	11.1 (10.0, 12.4)	6.5 (5.6, 7.4)	4.7 (4.0, 5.5)
None	8,528	8.7 (7.7, 9.7)	5.5 (4.7, 6.5)	3.2 (2.7, 3.8)
Type of HI				
LF-HI	145	18.0 (11.4, 27.2)	11.1 (5.8, 2.3)	6.9 (3.4, 13.3)
CF-HI	1,644	10.6 (9.0, 12.5)	6.6 (5.3, 8.1)	4.0 (3.0, 5.4)
HF-HI	3,650	11.1 (9.8, 12.5)	6.2 (5.3, 7.4)	4.9 (4.1, 5.8)
History of ear surgery				
Yes	182	10.6 (6.6, 16.7)	7.3 (4.1, 12.8)	3.2 (1.4, 7.3)
No	13,760	9.9 (9.1, 10.7)	6.0 (5.4, 6.6)	3.9 (3.5, 4.4)
Military service				
Yes	1,307	9.4 (8.0, 11.0)	5.6 (4.5, 7.1)	3.7 (3.0, 4.6)
No	12,634	9.9 (9.1, 10.9)	6.1 (5.5, 6.7)	3.9 (3.4, 4.4)
Gun use				
Yes	3,186	10.6 (9.4, 11.9)	5.9 (4.9, 7.0)	4.6 (3.9, 5.4)
No	10,757	9.5 (8.6, 10.5)	6.1 (5.4, 6.8)	3.4 (3.0, 4.0)
Earphone use				
Yes	3,013	8.8 (7.4, 10.3)	5.8 (4.7, 7.3)	3.0 (2.3, 3.9)
No	10,924	10.1 (9.3, 10.9)	6.0 (5.4, 6.7)	4.1 (3.6, 4.6)
Conductive hearing loss				
Yes	2,880	9.0 (7.8, 10.4)	5.3 (4.4, 6.3)	3.7 (2.8, 4.8)
No	11,075	10.2 (9.3, 11.1)	6.2 (5.5, 7.0)	4.0 (3.5, 4.5)

All values, except subgroup n, are weighted to account for complex survey design. Values are presented as % (95% CI). SA definition: moderate sleep apnea (15 ≤ AHI < 30), severe sleep apnea (AHI ≥ 30). [a] Unadjusted. [b] Adjusted for sex only. [c] Adjusted for age only. AHI, apnea-hypopnea index; CF-HI, combination frequency hearing impairment; HF-HI, high-frequency hearing impairment; LF-HI, low-frequency hearing impairment; SA, sleep apnea.

Table 2—Adjusted odds ratios of hearing impairment by sleep apnea.

		Any-HI vs. no HI	HF-HI vs. no HI	CF-HI vs. no HI	LF HI vs. no HI
Model 1	SA				
	Mild or no SA	Ref	Ref	Ref	Ref
	Moderate or severe SA	**1.31 (1.10, 1.55)**	**1.30 (1.07, 1.57)**	1.24 (0.99, 1.56)	**2.29 (1.22, 4.32)**
Model 2	SA				
	Mild or no SA	Ref	Ref	Ref	Ref
	Moderate or severe SA	**1.30 (1.08, 1.57)**	**1.26 (1.03, 1.55)**	**1.29 (1.00, 1.65)**	**2.27 (1.21, 4.26)**

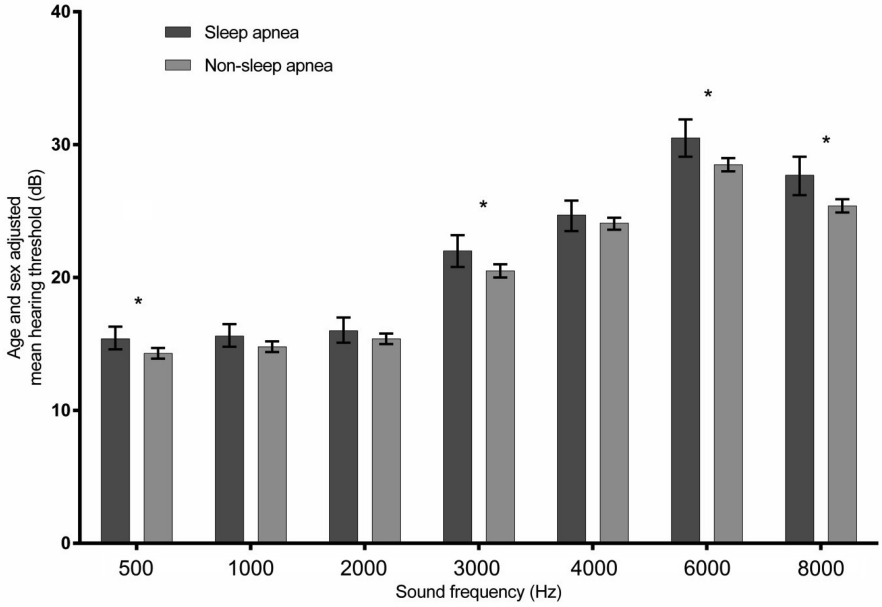
All numbers values are weighted to account for complex survey design. Values are presented as OR (95% CI). Bold values indicate significant at $p < 0.05$. Sleep apnea defined as apnea-hypopnea index ≥ 15 at oxygen desaturation at 3%. Model 1 adjusts for age, sex and Hispanic background. Model 2 adjusts for age, sex, Hispanic background, clinical center, income, hypertension, diabetes mellitus, dyslipidemia, body mass index, cigarette use, alcohol use, and history of congestive heart disease or stroke, conductive hearing loss, history of ear surgery, history of military service, gun use, earphone use in past 7 days, and self-reported snoring. CI, confidence interval; CF-HI, combination frequency hearing impairment; HF-HI, high-frequency hearing impairment; HI, hearing impairment; LF-HI, low-frequency hearing impairment; OR, odds ratio; SA, sleep apnea.

Table 3—Adjusted odds ratios of hearing impairment by severity of sleep apnea.

		Any-HI vs. no HI	HF-HI vs. no HI	CF-HI vs. no HI	LF HI vs. no HI
Model 1	SA severity[a]				
	Mild or no SA	Ref	Ref	Ref	Ref
	Moderate SA	1.21 (0.97, 1.52)	1.16 (0.91, 1.49)	1.21 (0.89, 1.64)	**2.41 (1.07, 5.42)**
	Severe SA	**1.48 (1.14, 1.92)**	**1.54 (1.17, 2.02)**	1.28 (0.88, 1.87)	2.02 (0.95, 4.29)
	p for linear trend	< 0.001	0.002	0.07	0.005
Model 2	SA severity[a]				
	Mild or no SA	Ref	Ref	Ref	Ref
	Moderate SA	1.22 (0.96, 1.54)	1.15 (0.89, 1.48)	1.28 (0.93, 1.76)	**2.38 (1.07, 5.28)**
	Severe SA	**1.46 (1.11, 1.91)**	**1.48 (1.11, 1.97)**	1.30 (0.87, 1.94)	2.02 (0.91, 4.51)
	p for linear trend	0.002	0.006	0.06	0.01

All numbers values are weighted to account for complex survey design. Values are presented as OR (95% CI). Bold values indicate significant at $p < 0.01$. Model 1 adjusts for age, sex and Hispanic background. Model 2 adjusts for age, sex, Hispanic background, clinical center, income, hypertension, diabetes mellitus, dyslipidemia, body mass index, cigarette use, alcohol use, and history of CHD or stroke, conductive hearing loss, history of ear surgery, history of military service, gun use, earphone use in past 7 days, and self-reported snoring. [a]Mild sleep apnea or no sleep apnea (0 ≤ AHI < 15), moderate sleep apnea (15 ≤ AHI < 30), severe sleep apnea (AHI ≥ 30). AHI, apnea-hypopnea index; CF-HI, combination frequency hearing impairment; CI, confidence interval; HF-HI, high-frequency hearing impairment; HI, hearing impairment; LF-HI, low-frequency hearing impairment; OR, odds ratio; SA, sleep apnea.

Figure 1—Age- and sex-adjusted mean hearing thresholds at various sound frequencies in the worst ear by sleep apnea status.



All numbers values are weighted to account for complex survey design. *Age and sex-adjusted mean hearing threshold statistically significantly different at $p < 0.05$.

however this association reached statistical significance only in the severe groups of SA and HI (**Table S2**, supplemental material).

DISCUSSION

We showed presence of SA to be significantly associated with HI in a population-based study of Hispanic/Latino adults. Presence of SA and increased SA severity (defined by AHI) were associated with increased likelihood of HI in both high and low frequency ranges. Although analyses of subtypes of HI produced effect estimates with wide confidence intervals, our findings suggested a slightly stronger association of SA with HI in the low frequency range as compared with HI in the high frequency range. At the same time, the mean hearing threshold was higher at each sound frequency of interest in persons with SA compared to those without SA. The association between SA and HI was present across a wide range of age (18 to 74 y) and was consistent among men and women. Both sleep and hearing were measured using standardized protocols in our population-based study, and findings persisted after adjustment for an array of potential confounding variables.

A number of biologically plausible mechanisms may explain the association between SA and HI. A growing body of evidence suggests that SA is associated with vascular inflammation and endothelial dysfunction via intermittent hypoxia.[32,33] In the current study, we found that nadir oxygen saturation (SpO_2) recorded during the sleep study was inversely associated with severity of HI. There was a dose-response relationship observed between nadir SpO_2 and severity of HI where decreasing nadir SpO_2 was associated with increasing HI severity, supporting hypoxic injury as a linking mechanism between SA and HI. We also found that more severe SA was associated with more severe HI. This suggests a dose response relationship as well between SI and HI. However, statistical significance was not reached in less severe categories of both SA and HI. Future studies with larger sample size within each category of SA and HI severity are needed to draw definitive conclusions regarding a potentially causal association between SA and HI.

Among other mechanisms linking SA and HI is change in sympathetic tone. SA may lead to alteration of cerebral blood flow directly or via change in sympathetic tone in response to hypoxia and hypercarbia.[34] The cochlea is especially vulnerable anatomically to ischemia and vascular inflammation as it is supplied by an end artery.[35,36] Arteries feeding the stria vascularis, the capillary rich network in lateral wall of cochlea, are relatively sparse at the apex as compared to the base. Therefore, the hair cells in the cochlea at the apex that respond to the low-frequency sounds may be more susceptible to ischemia.[35]

Prior studies of the association between SA and HI have had conflicting results. In a hospital-based convenience sample of 224 adults aged 50 y or older, Hwang et al.[20] did not find differences in peripheral auditory function between patients with and without obstructive SA. Hwang et al. used a low threshold of AHI $\geq$ 5 to define SA, and peripheral auditory function was assessed by mean hearing threshold of pure tone audiometry (PTA) at low (250, 500, and 1,000 Hz) and high (2,000, 4,000, and 8,000 Hz) frequencies. Another report by Sheu et al.[21] was a population-based case-control study that used an insurance database to identify those with SA and sudden sensorineural hearing loss (SSNHL). Sheu et al. reported that men (but not women) with SSNHL were more likely to have SA than those without SSNHL (OR 1.48; 95% CI 1.02–2.16).[21] In the current study, we found a consistent association between SA and HI within sizable subgroups of men and women. Comparisons between our study and those previously reported are difficult because of differences in the approaches to defining SA and HI.

Snoring is the most common and well-recognized symptom of SA. Several prior studies that have assessed the association between snoring and HI have found mixed results.[29,30] In the current study, we found that self-reported snoring was not associated with HI, nor did adjustment for self-reported snoring appreciably change the association between SA and HI. In one of the earliest studies of hearing loss among snorers, Prazic[37] reported varying degrees of hearing loss in 17 snorers although this study lacked information on SA. In a subsequent study, Hoffstein et al.[38] prospectively evaluated 219 patients who were referred to a sleep disorder center for the evaluation of SA and found no significant association between snoring and HI. A limitation of prior studies, including ours, has been use of self-report to define snoring. Objective sound measurement may help improve the ability to quantify the intensity and duration of noise from snoring, although such measurements are difficult to standardize.

Strengths and Limitations

Our study used data from the HCHS/SOL, which is the largest study of US Hispanic/Latino adults to date. Although SA was measured objectively using highly reliable approaches for scoring, the sleep studies did not record electroencephalogram data, precluding assessment of arousal or sleep stage disturbances. Our home SA testing approach also may modestly underestimate SA severity, therefore potentially biasing our results to the null. Although our study included only Hispanic/Latino adults, who have higher prevalence of SA and HI, we believe that it is possible to generalize our study findings to non-Hispanic populations. Due to the cross-sectional study design, causality cannot be proven, although we controlled for a variety of medical history and noise exposure variables that may have acted as confounding variables. Last, although SA and HI were measured objectively and the data collection staff was unaware of study hypotheses, self-reporting of health conditions such as snoring and HI-related risk factors (e.g., noise exposure) may be subject to recall or reporting bias.

HI is a highly prevalent condition in the US. With a large aging population, the burden of HI is likely to increase; therefore, identifying modifiable risk factors for HI is important. In our study, presence of SA was associated with HI in US Hispanic/Latinos. Further studies are needed to elucidate the mechanisms involved in the association between SA and HI, and to assess the effect of SA therapy on HI. The strong and independent association between SA and HI might identify individuals with SA as a group at increased risk for HI, suggesting new efforts at increasing awareness of this risk among patients and providers.

ABBREVIATIONS

AHI, apnea-hypopnea index
CF-HI, combined frequency hearing impairment
HCHS, Hispanic Community Health Study
HF-HI, high frequency hearing impairment
HI, hearing impairment
LF-HI, low frequency hearing impairment
SA, sleep apnea
SOL, Study of Latinos

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