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Association of sleep duration and noise exposure with hearing loss among Chinese and American adults: two cross-sectional studies

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ABSTRACT

Objectives To examine the associations of sleep duration (SPD) and noise exposure with hearing loss (HL) among Chinese and American adults.

Design Two cross-sectional studies.

Setting The National Health and Nutrition Examination Survey (2011–2012), and Zhejiang Chinese participants between 1 January 2018 and 1 November 2021.

Participants 3322 adults from the USA and 4452 adults from Zhejiang, China.

Main outcome measures HL was defined as a pure-tone average >20 dB in the better ear at low frequency (500, 1000 and 2000 Hz), speech frequency (500, 1000, 2000 and 4000 Hz) or high frequency (3000, 4000, 6000 and 8000 Hz). Binary logistic regression analysis quantified the associations between SPD, noise exposure (at work or off-work) and HL.

Results SPD ≥8 hours/night had an OR of 0.71 (95% CI 0.59 to 0.84) for high-frequency HL vs. an SPD of 6–8 hours/night among the Chinese participants but had an OR of 1.28 (95% CI 1.03 to 1.58) among American participants. Noise exposure (both at work and off-work) was associated with poorer low-frequency (OR 1.58, 1.43; p<0.05), speech-frequency (OR 1.63, 1.29; p<0.05) and high-frequency (OR 1.37, 1.23; p<0.05) hearing among the Chinese participants; and it was associated with worse high-frequency hearing (OR 1.43, 1.66; p<0.05) among the American participants. The negative relationship between SPD ≥8 hours/night and HL was mainly observed in the Chinese participants with noise exposure (OR <1, p<0.05), and SPD ≥8 hours/night associated with poorer HF hearing was only identified in the American participants without noise exposure (OR >1, p<0.05).

Conclusions Noise exposure was associated with poorer hearing. SPD ≥8 hours/night was negatively associated with HL in the Chinese participants especially when exposed to noise. SPD ≥8 hours/night was related to poorer high-frequency hearing in the American participants when they had no noise exposure.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This is the largest epidemiological study exploring the associated factors of hearing loss outcomes using the Chinese and American participants.
⇒ This is the first study to compare the effects of noise at work, noise off-work and sleep duration on hearing loss.
⇒ The effect of specific sleep duration on hearing loss could not be explored due to the limited information in the questionnaire among the Chinese participants.
⇒ Outcomes of hearing loss were adjusted for covariates and potential factors.

INTRODUCTION

Hearing loss (HL) is the fifth leading cause of disability worldwide, affecting interpersonal communication, physical and mental health and daily life.[1 2] WHO has estimated that approximately 20% of the world population (1.5 billion) suffers from HL. Furthermore, 430 million out of the 1.5 billion currently suffer from disabling HL, which is expected to rise to 700 million by 2050, potentially causing a significant social and economic burden.[3] Potential contributing factors to HL currently include genetic features, infections, noise exposure, age and immune-mediated aspects.[4–8] WHO has estimated that public health measures, such as a healthy individual lifestyle, could prevent half of HL cases. Thus, further attention has been focused on the development of public health programmes that reduce HL morbidity by targeting modifiable risk factors. Previous studies have found that exposure to intense occupational noise potentially results in a shift of hearing threshold or leaves a permanent threshold change, as well as causing alterations in the auditory nerve-output growth functions.[9] However, studies on the effects of non-occupational noise exposure on HL are rare.

Sleep is essential for maintaining environmental homeostasis in humans, including circadian rhythms[10] and hormone levels.[11] Currently, an increasing number of people suffer from sleep disorders, mainly manifested as reduced sleep time.[12] It is reported that 35.7% of Chinese adults have poor sleep quality.[13] Over the past 40 years, Americans self-reported 1.5–2 hours less sleep, the proportion of young adults reporting <7 hours of sleep per night increased from 15.6% in 1960 to 37.1% in 2001–2002.[14] Today, many Americans sleep only 5–6 hours a night.[15] Fewer than half of Americans are getting the National Sleep Foundation guideline-recommended sleep time.[16] Sleep disturbances increase the risk of certain diseases, including obesity,[17] diabetes mellitus (DM),[18] cancer,[19] cardiovascular disease,[20 21] Alzheimer's disease and dementia.[22] Sleep duration (SPD) is also closely associated with the auditory system diseases. However, research on the associations between sleep characteristics and HL is rare. Only three cross-sectional studies have evaluated the associations between sleep disturbance and hearing in adults[23–25]; in a recent analysis, they included 632 older adults (aged >70 years) from the National Health and Nutrition Examination Survey (NHANES) (2005–2006) and found that >8 hours of sleep was associated with a higher threshold of hearing.[25] The small sample size limited the potential to explore the associations between SPD and HL. Additionally, none of these studies included the Chinese population, nor did they consider the potential impact of factors such as noise.

Researchers have observed that noise causes HL primarily by causing damage and death of cochlear hair cells.[26] Additionally, individuals have different outcomes of HL, even when exposed to similar levels of noise,[27] suggesting that individuals have different tolerances for noise exposure intensity. Therefore, our study considers the individual's subjective noise exposure intensity. Judgement replaces objective noise measurements. Given the critical roles of sleep and noise in cell death, we hypothesised that SPD and noise might be associated with HL in adults. To the best of our knowledge, this is the first study to test this hypothesis. In this study, we included American adult participants from the NHANES database (2011–2012) and Chinese participants from Zhejiang, China. We also examined the SPD-HL associations stratified by noise exposure.

METHODS

Study participants

This study obtained data from the NHANES and Zhejiang province, China. Details of the NHANES design and survey methodology have been described previously.[28] Briefly, it is an ongoing, cross-sectional series of health-related surveys performed annually by the National Center for Health Statistics (NCHS), with a complex, multistage probability sampling design to choose a nationally representative sample of Americans.[29] We collected information on demographic characteristics, medical history, sleep habits, noise environment, extensive physical examination and audiometric-exam data from NCHS-trained professionals. Information on 9756 American participants from the NHANES (2011–2012) was extracted. We excluded 6434 participants with missing values, those aged ≤18 years and those with incomplete audiometric-exam data. We subsequently included 3322 US participants from the NHANES in this analysis.

In addition, we collected data on 6643 Zhejiang Chinese participants through a multistage stratified cluster random sampling method between 1 January 2018 and 1 November 2021. They were randomly chosen from seven cities (Hangzhou, Ningbo, Wenzhou, Quzhou, Jiaxing, Huzhou and Lishui) according to geographic location and city population. The inclusion criteria were as follows: (1) local residents who had lived there for at least 1 year and (2) those of Han ethnicity. The exclusion criteria were as follows: (1) participant has been exposed to explosives or suffered a head injury; (2) participants had a diagnosis of HL, otitis media, other ear disorders or a family history of these diseases; (3) participants had a fever or a common infection, such as the influenza, or had taken ototoxic drugs within 1 month prior to the audiometric-exam. A total of 2191 participants with missing values, incomplete audiometric information or those aged ≤18 years were further excluded. There remained 4452 Zhejiang Chinese participants (online supplemental efigure 1).

Audiometric measurements and definition of HL

Audiometric measurements of American participants were performed by a trained examiner in a unique sound booth located at a mobile examination centre. Details of the NHANES audiometric procedures have been described previously.[30] In brief, it was tested on both ears using pure-tone air-conduction audiometry (AD226 audiometer). The trained examiner sent signals to the ear through standard audiometric headphones or inserted earphones at frequencies of 0.5, 1, 2, 3, 4, 6 and 8 kHz across an intensity limit, ranging from −10 to 100 dB at frequencies of 0.5–6 kHz, and −10 to 90 dB at frequencies of 8 kHz. A frequency of 1 kHz was measured twice in both ears to test the reliability of the test. The Chinese participants underwent pure-tone air-conduction audiometry testing (MADSEN Conera audiometer) in a sound-attenuating chamber within a background-noise of 25 dB. The ascending methods in 5 dB steps at each frequency of 0.5, 1, 2, 3, 4, 6 and 8 kHz were used for audiometric measurements. Trained physicians performed all evaluations using standard procedures.

The primary outcome of this study was HL, including low-frequency HL (LFHL), speech-frequency HL (SFHL) and high-frequency HL (HFHL). According to the latest definition by WHO, we defined LFHL as a pure-tone average (PTA) >20 dB in the better ear at 0.5, 1 and 2 kHz; SFHL was defined as a PTA >20 dB in the better ear at 0.5, 1, 2 and 4 kHz; HFHL was defined as a PTA >20 dB in the better ear at 3, 4, 6 and 8 kHz.[31 32]

Assessment of sleep duration and noise exposure

Americans' SPD was collected by asking about the number of sleep hours they usually get at night on weekends or weekdays. The usual nightly SPD of Chinese participants was surveyed with three response options: <6 hours/night, 6–8 hours/night (excluding 8) and ≥8 hours/night.[33] We, therefore, use 6 and 8 as cut-off points to categorise SPD. Non-occupational noise exposure in this analysis included noise at work and off-work (yes or no). Noise at work in Americans: have you ever had a job or combination of jobs where you were exposed to loud sounds or noise for ≥4 hours/day, several days a week? Noise at work in Chinese: has your workplace been affected by loud sounds or noise at least once a week for the past year. Noise off-work in Americans: outside of a job, have you ever been exposed to very loud noise or music for at least ≥10 hours/week? Noise off-work in Chinese: has your living environment been affected by loud noise or music at least once a week for the past year? Loud means you must speak in a raised voice to be heard by someone three feet away when not using hearing protection. Examples are noise from lawnmowers, farm machinery, cars or loud music.

Covariates

Information on covariates included age at the time of assessment (years), sex (female, male) and marital status (unmarried: never married or living with a partner, married and others: divorced or separated or widowed). Education level in the USA was classified as lower (<ninth grade), medium (from ninth grade to college, or associate of arts degree) or higher (college graduate or above). Education level in China was categorised as lower (Junior high school and below), medium (high school) or higher (college and above). Disease history included hypertension (yes, no), DM (yes, no) and hyperlipidemia (yes, no).

Statistical analysis

Descriptive analyses were performed to present the distribution of basic characteristics among participants based on the specific HL type. We conducted Pearson's χ^2 test to analyse unordered categorical variables, and the Wilcoxon rank test was used to analyse ordered categorical variables (such as age classification, online supplemental efigure 2). Sequentially, we used binary logistic regression (BLR) analysis to present the ORs and 95% CIs for the associations between potential factors (SPD, noise at work and noise off-work) and HL outcomes. We adjusted the BLR model for age (years), sex (male or female), marital status (unmarried, married or others) and education level (lower, medium or higher). Considering the complex sampling design of NHANES, we applied 2-year sampling weights in the full model among the Americans. The fully adjusted restricted cubic spline with three knots was used to examine the dose-response associations between SPD and HL among the American participants.

Subgroup analyses were performed to evaluate the heterogeneous results of the sex and age on noise/SPD-HL associations. We examined the associations among prespecified basic subgroups based on sex (male, female) and age (<45, 45–59 and ≥60 years). Multiplicative interactions were conducted to examine the interaction term beta from the logistic models. Notably, we also investigated SPD-HL associations stratified by with or without noise exposure.

Sensitivity analyses were performed to test the robustness of the primary findings. First, we tested linear trends by modelling the number of relatively unfavourable classifications of SPD and noise exposure (considering the number zero as the reference group) as a continuous variable to estimate the ORs of specific HL types. Second, stratified analysis by disease history of hypertension (yes or no), DM (yes or no) and hyperlipidemia (yes or no) were conducted. Third, we reuse 7–8 or 7–9 hours/night as the cut-off points for the US participants according to the National Sleep Foundation's SPD recommendations.[34] We used Stata (V.15.0; StataCorp, College Station, Texas, USA) for the statistical analysis and R (V.4.0.0; R Foundation for Statistical Computing, Vienna, Austria) for the graphs plotting of this study. All p values were two-sided, p values <0.05 were considered statistically significant and the Benjamini-Hochberg procedure with a false discovery rate of 0.12 was performed to adjust for multiple comparisons.[35]

Patient and public involvement

Patients or the public were not involved in the design, conduct, reporting, or dissemination plans of our research.

RESULTS

Basic characteristics of participants by specific HL

Among the 4452 Chinese and 3322 American participants, there were 1778, 2119 and 2690 cases of LFHL, SFHL and HFHL among Chinese adults, and 240, 398 and 1002 cases among the American participants, respectively (table 1). Compared with participants without specific HL, those with HL were older; had a lower education level; tended to be men, married and were more likely to document a history of hyperlipidemia, DM and hypertension (p<0.05, table 1).

Associations of noise exposure and sleep duration with specific types of HL

After adjustment for potential confounders, SPD ≥8 hours/night was negatively associated with HFHL among the Chinese participants (OR 0.71; 95% CI 0.59 to 0.84), but was associated with poorer HF hearing among the Americans (OR 1.28; 95% CI 1.03 to 1.58). Moreover, a U-shaped non-linear dose-response association between SPD and HFHL among Americans was observed (p for non-linearity <0.001) (figure 1). When SPD was between 6 and 8 hours/night, the Americans' HFHL was at a lower level. Compared with those without corresponding noise, the Chinese participants exposed to noise at work or off-work were associated with poorer LF hearing (OR 1.58

Table 1 Basic characteristics of participants with and without specific HL

Characteristics	US NHANES (n=3322)						Chinese (n=4452)					
	LFHL		SFHL		HFHL		LFHL		SFHL		HFHL	
	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Participants, n	3082	240	2924	398	2320	1002	2674	1778	2333	2119	1762	2690
Sex, %												
Male	49.3	50.0	47.6	62.1	44.8	59.8	49.1	51.9	46.8	54.0	44.3	54.1
Female	50.7	50.0	52.4	37.9	55.2	40.2	50.9	48.1	53.2	46.0	55.7	45.9
Age (years)*, %												
19–44	55.5	12.5	58.1	10.6	68.6	14.8	50.9	12.2	56.0	12.8	64.9	16.1
45–59	28.5	34.6	27.8	37.2	23.7	41.1	32.1	30.2	31.2	31.5	27.7	33.8
≥60	16.0	52.9	14.1	52.3	7.7	44.1	17.0	57.6	12.8	55.7	7.4	50.1
Education, %												
Lower	5.6	11.7	5.2	12.3	3.9	11.0	26.9	53.4	23.6	52.8	19.1	49.5
Medium	64.2	75.8	64.2	71.9	63.6	68.6	26.9	24.9	27.0	25.0	27.6	25.1
Higher	30.2	12.5	30.6	15.8	32.5	20.4	46.2	21.7	49.4	22.2	53.3	25.4
Marriage, %												
Unmarried	36.5	15.8	37.2	18.6	41.9	19.1	9.5	1.5	10.7	1.4	13.5	1.6
Married	46.4	52.5	46.0	53.0	44.3	52.6	87.4	93.6	86.5	93.6	84.0	93.7
Other	17.1	31.7	16.8	28.4	13.8	28.3	3.1	4.9	2.8	5.0	2.5	4.7
Hypertension†, %	28.3	47.9	27.4	46.5	22.2	47.0	14.1	38.5	11.7	37.1	9.1	33.5
DM†, %	11.5	25.0	10.9	23.9	8.1	22.6	3.1	8.8	2.3	8.7	1.6	7.8
Hyperlipidemia†, %	28.2	46.7	26.8	49.5	22.4	46.2	2.1	3.4	2.0	3.3	1.6	3.3
Sleep duration (hours/night)*, %												
<6	16.4	19.2	16.2	19.3	15.2	19.7	5.8	9.3	4.9	9.9	4.0	9.3
<8	52.3	50.8	52.4	50.8	53.3	49.1	69.2	62.6	70.4	62.3	69.4	64.7
≥8	31.3	30.0	31.4	29.9	31.3	31.2	25.0	28.1	24.7	27.8	26.6	26.0
Noise at work†, %	24.3	33.3	23.2	37.9	21.1	34.0	34.3	42.5	33.6	42.0	34.2	39.7
Noise off-work†, %	12.3	10.4	11.9	14.3	11.2	14.5	21.5	28.5	21.8	27.1	21.5	26.1

*Means Wilcoxon rank test. The distributions of all variables were significantly different between participants with and those without specific hearing loss (p<0.05) except for sex in LFHL among Chinese and US participants, sleep duration, noise at work and noise off-work in LFHL and SFHL among US participants.
†The column percentages for the binary variable sum to 100, and present the percentages of the 'yes' option. Pearson's χ^2 test was used to analyse all variables except for those indicated.
CHD, coronary heart disease; DM, diabetes mellitus; HFHL, high-frequency hearing loss; HL, hearing loss; LFHL, low-frequency hearing loss; NHANES, National Health and Nutrition Examination Survey; SFHL, speech-frequency hearing loss.

and 1.43, p<0.05), SF hearing (OR 1.63 and 1.29, p<0.05) and HF hearing (OR 1.37 and 1.23, p<0.05); the Americans exposed to noise at work were associated with worse SF hearing (OR 1.43; 95% CI 1.10 to 1.86) and HF hearing (OR 1.43; 95% CI 1. 15 to 1.78), and Americans exposed to noise off-work were only associated with poorer HF hearing (OR 1.66; 95% CI 1.25 to 2.21) (table 2).

Subgroup analysis by sex and age

Sex-specific BLR revealed that associations between SPD ≥8 hours/night and HFHL were identified only in Chinese male participants (OR 0.59, p<0.05) and US female participants (OR 1.42, p<0.05) (table 3). Notably, we only found significant associations between noise at work and SFHL and HFHL in men among American participants (OR >1, p<0.05), and the relationship between noise at work and HFHL was found in Chinese women (OR 1.57; 95% CI 1.26 to 1.95) but not men (p>0.05). Associations between noise off-work and SFHL and HFHL still varied in Chinese men and women (table 3).

Subgroup analyses based on age suggested that the negative association between SPD ≥8 hours/night and HFHL were observed in Chinese participants aged 19–59 years (OR <1, p<0.05). Moreover, we found null evidence of associations between noise at work and HL among both Chinese and Americans in the age ≥60 years group. In addition, the association between noise off-work and HFHL were identified in age ≥45 years groups among

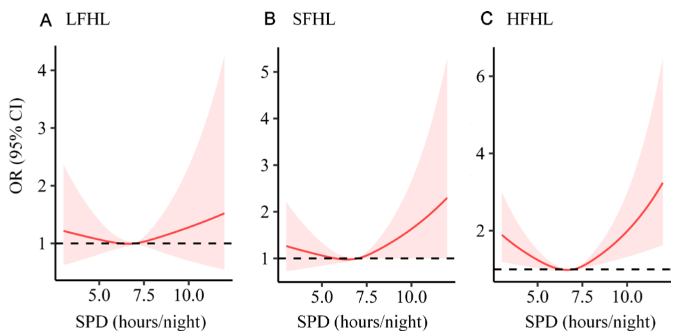

Figure 1 Multivariable adjusted dose-response associations between sleep duration and specific HL among American participants. (a) LFHL, p for non-linearity=0.41; (b) SFHL, p for non-linearity=0.089; (c) HFHL, p for non-linearity <0.001. All the dose-response associations were examined in the fully adjusted logistic regression models based on restricted cubic splines with three knots, the pink shaded area represents the 95% CI for the dose-response curve. HFHL, high-frequency hearing loss; LFHL, low-frequency hearing loss; SFHL, speech-frequency hearing loss; SPD, sleep duration.

Americans. Regarding Chinese participants, no association between noise off-work and HL were observed in age 45–59 years group (figure 2).

Associations of sleep duration and specific types of HL by noise exposure

Stratification analyses by noise exposure revealed that the negative relationship between SPD ≥8 hours/night and HL (including LFHL, SFHL and HFHL) were mainly observed in the Chinese participants with noise exposure (both noise at work and noise off-work) (OR <1, p<0.05). Notably, in the group of Chinese participants without noise off-work, the negative association between SPD ≥8 hours/night and HFHL were also observed (OR 0.80; 95% CI 0.66 to 0.98). Regarding Americans, the relationship of SPD ≥8 hours/night with poorer HF hearing were only identified in participants without noise at work (OR 1.33; 95% CI 1.03 to 1.71) and without noise off-work (OR 1.33; 95% CI 1.06 to 1.67) (figure 3).

Sensitivity analyses

Sensitivity analysis provides evidence for the robustness of the results. First, we defined noise at work, noise off-work, SPD <8 hours/night in the Chinese participants or SPD ≥8 or <6 hours/night in the Americans participants as unfavourable factors. As shown in online supplemental etable 1, the higher the number of unfavourable factors, the higher the tendency for worse hearing. Second, the results of subgroup analysis by disease history support that noise exposure were associated with poorer hearing. It also provided evidence that SPD ≥8 hours/night was negatively associated with HFHL in the Chinese participants and positively related to HFHL in the American participants. Additionally, participants with DM or hyperlipidemia are more likely to have higher odds of HL (online supplemental etables 2–4). Third, by reusing 7–9 or 7–8 hours/night as the cut-off point for the US participants, we found that >9 hours/night were associated with poorer LF and SF hearing, and >8 hours/night were associated with worse HF hearing among the American participants (online supplemental etable 5).

DISCUSSION

To the best of our knowledge, this is the first study to compare the effects of noise at work, noise off-work and SPD on HL in the Chinese and American participants. Our study found that both noise at work and off-work have a severe impact on HL in the Chinese and American participants. Associations between noise at work and poorer hearing are more likely to be observed in American adult men aged <60 years. Furthermore, SPD ≥8 hours/night was negatively associated with HFHL among the Chinese participants. Presumably due to sex and ethnic differences, a U-shaped non-linear dose-response association between SPD and HFHL was observed among the American participants, and SPD ≥8 hours/night was associated with worse HF hearing. Information regarding the impact of sex and racial differences on HL is limited, despite several studies identifying racial differences in

Table 2 OR (95% CI) of specific HL according to sleep duration or noise exposure

End points	Sleep duration (hours/night)				Noise at work			Noise off-work		
	<6	6 to 8	≥8	P trend	No	Yes	P value	No	Yes	P value
Chinese										
LFHL	1.03 (0.79 to 1.35)	1.00	0.93 (0.79 to 1.09)	0.587	1.00	1.58 (1.37 to 1.83)*	<0.001	1.00	1.43 (1.22 to 1.69)*	<0.001
SFHL	1.38 (1.04 to 1.83)*	1.00	0.94 (0.80 to 1.11)	0.046	1.00	1.63 (1.41 to 1.90)*	<0.001	1.00	1.29 (1.09 to 1.52)*	0.003
HFHL	1.46 (1.05 to 2.03)*	1.00	0.71 (0.59 to 0.84)*	<0.001	1.00	1.37 (1.17 to 1.60)*	<0.001	1.00	1.23 (1.03 to 1.46)*	0.023
American										
LFHL	0.98 (0.67 to 1.42)	1.00	0.98 (0.71 to 1.35)	0.987	1.00	1.23 (0.89 to 1.69)	0.212	1.00	0.94 (0.59 to 1.49)	0.791
SFHL	1.00 (0.74 to 1.38)	1.00	1.02 (0.78 to 1.33)	0.990	1.00	1.43 (1.10 to 1.86)*	0.008	1.00	1.34 (0.95 to 1.90)	0.097
HFHL	1.22 (0.95 to 1.58)	1.00	1.28 (1.03 to 1.58)*	0.055	1.00	1.43 (1.15 to 1.78)*	0.002	1.00	1.66 (1.25 to 2.21)*	0.001

*P values <0.05 were considered statistically significant, and maintains significance after the Benjamini-Hochberg procedure with a false discovery rate at 0.12 concerning all the 12 tests. The binary logistic regression analysis adjusted for age, sex, marriage status and education level.
LFHL, low-frequency hearing loss; SFHL, speech-frequency hearing loss; HFHL, high-frequency hearing loss.

Table 3 OR (95% CI) of specific HL according to sleep duration or noise exposure stratified by sex

	Sleep duration (≥8 vs 6–8 hours/night)			Noise at work (yes vs no)			Noise off-work (yes vs no)		
End points	**Male**	**Female**	**P interaction**	**Male**	**Female**	**P interaction**	**Male**	**Female**	**P interaction**
Chinese									
LFHL	0.83 (0.66 to 1.04)	1.02 (0.81 to 1.28)	0.445	1.77 (1.45 to 2.17)*	1.41 (1.14 to 1.75)*	<0.001	1.59 (1.28 to 1.98)*	1.31 (1.03 to 1.66)*	0.011
SFHL	0.89 (0.70 to 1.13)	0.97 (0.77 to 1.22)	<0.001	1.69 (1.37 to 2.08)*	1.60 (1.29 to 1.99)*	0.248	1.33 (1.06 to 1.68)*	1.27 (1.00 to 1.62)	0.150
HFHL	0.59 (0.45 to 0.76)*	0.81 (0.64 to 1.02)	<0.001	1.20 (0.96 to 1.50)	1.57 (1.26 to 1.95)*	0.003	1.15 (0.90 to 1.48)	1.32 (1.03 to 1.69)*	<0.001
American									
LFHL	1.15 (0.73 to 1.82)	0.85 (0.54 to 1.32)	0.958	1.35 (0.90 to 2.01)	1.02 (0.59 to 1.78)	0.368	0.68 (0.38 to 1.23)	1.77 (0.85 to 3.67)	0.290
SFHL	1.04 (0.72 to 1.49)	0.99 (0.66 to 1.48)	<0.001	1.63 (1.19 to 2.24)*	1.01 (0.61 to 1.69)	0.238	1.20 (0.80 to 1.80)	1.89 (0.98 to 3.68)	<0.001
HFHL	1.13 (0.83 to 1.54)	1.42 (1.05 to 1.92)*	<0.001	1.44 (1.09 to 1.90)*	1.40 (0.95 to 2.05)	<0.001	1.47 (1.04 to 2.07)*	2.35 (1.37 to 4.02)*	<0.001

The binary logistic regression model adjusted for age, sex, marriage status and education level. Male or female participants without the corresponding noise or 6 ≤sleep duration <8 hours/night were considered the reference group.
The $p_{interaction}$ were estimated by including an interaction term beta of the sleep duration/noise-sex in full binary logistic regression model.
*P values <0.05 were considered statistically significant and maintains significance after the Benjamini-Hochberg procedure with a false discovery rate at 0.12 concerning all the 36 tests.
LFHL, low-frequency hearing loss; SFHL, speech-frequency hearing loss; HFHL, high-frequency hearing loss.

conditions.[36,37] Our findings potentially result from noise differences in the living environments of the two participant groups (USA and China). They may be due to direct differences or indirect effects of other diseases caused by racial differences.

We investigated the effects of different noises and sleep conditions on HL. Further stratification by noise exposure demonstrated that the negative associations between SPD ≥8 hours/night and LFHL, SFHL and HFHL in the Chinese population were mainly identified in noise at

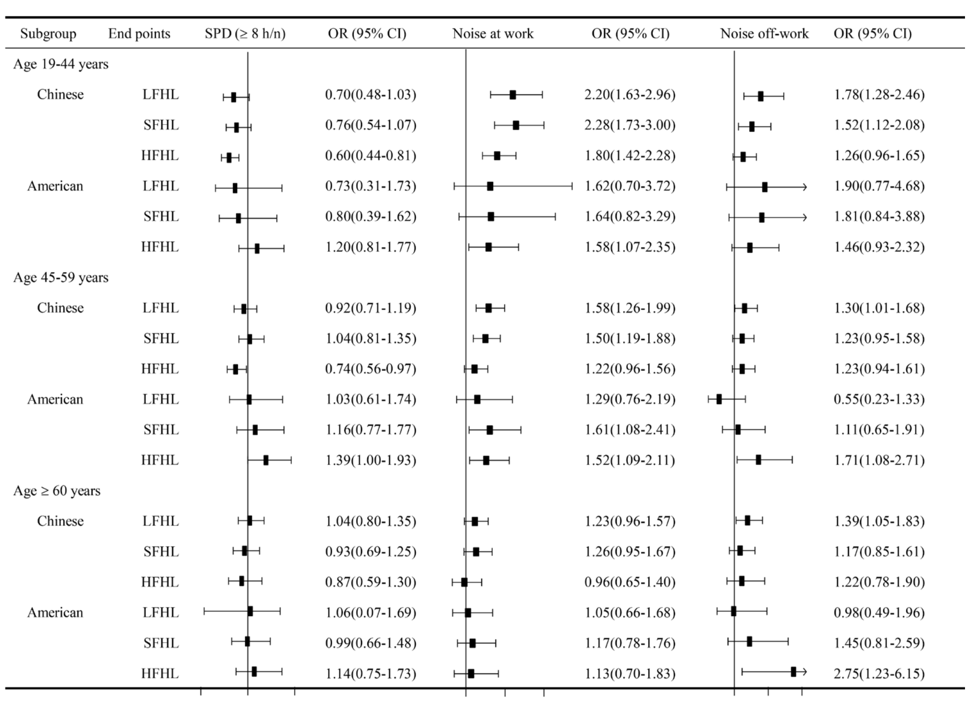

Figure 2 OR (95% CI) of specific HL according to SPD or noise exposure stratified by age. The binary logistic regression analysis adjusted for age, sex, marriage status and education level. HFHL, high-frequency hearing loss; h/n: hours/night; LFHL, low-frequency hearing loss; SFHL, speech-frequency hearing loss; SPD, sleep duration. Participants without the corresponding noise or 6 ≤sleep duration <8 hours/night were considered the reference group.

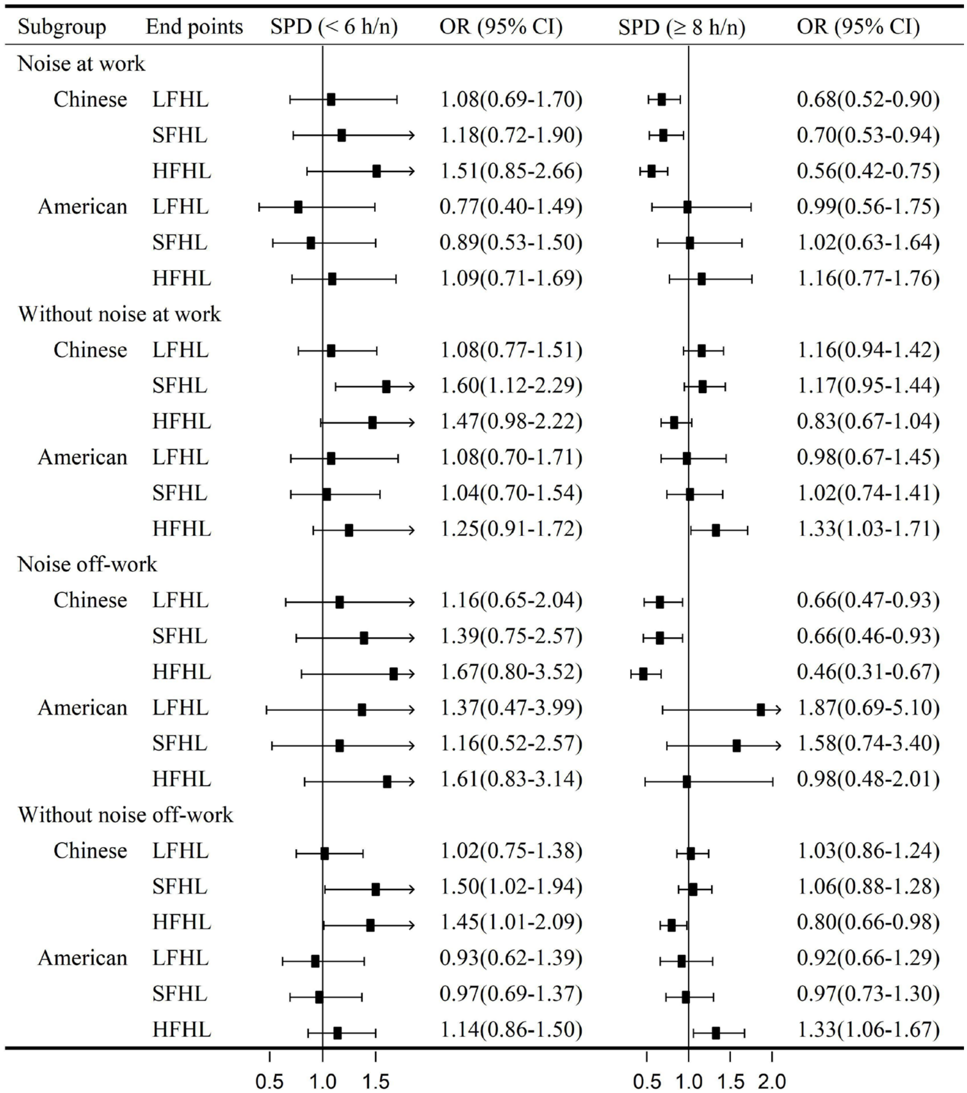

Figure 3 OR (95% CI) of specific HL according sleep duration by noise exposure. The binary logistic regression adjusted for age, sex, marriage status and education level. HFHL, high-frequency hearing loss; LFHL, low-frequency hearing loss; SFHL, speech-frequency hearing loss. 6 ≤sleep duration <8 hours/night was considered the reference group.

work and off-work groups. Notably, we found null associations of SPD ≥8 hours/night with any specific HL among the American participants when exposed to noise. The associations between SPD ≥8 hours/night and poorer HF hearing were exclusively observed in the US participants without noise exposure group, suggesting that adequate sleep may be beneficial in reducing noise-induced hearing impairment. Our results are consistent with a previous study of 13 967 Hispanic/Latino participants aged 18–74 years.[24] Because the cochlea is one of the most metabolically active organs in the human body, sleep deprivation may impair hearing by disrupting energy metabolism and cochlear blood flow.[38 39] Long-term exposure to high-intensity noise can directly affect hearing, resulting in noise-induced HL; however, adequate sleep can effectively relieve cochlear-cell fatigue. Most previous studies have suggested that sleep disturbance is a potential risk factor for sudden HL.[40 41] Sleep disturbance can cause negative emotions, such as anxiety and depression, which may affect the hearing of patients.[42] Animal and human studies have demonstrated that repeated sleep deprivation potentially aggravates noise-induced damage to the outer and inner hair cells of the cochlear basal gyrus synaptic band, thus reducing the ability of the cochlea to transcode sound. Damage to the tactile cord decreases the cochlea's ability to encode sounds.

In addition, our study found that both Chinese and American participants with DM and hyperlipidemia were more likely to have higher odds of HL. This indicates that HL due to a noisy environment at work or in life may be prevented by controlling blood glucose and cholesterol, and prolonging sleep time to ≥8 hours/night, particularly in men. Notably, our research has shown that work noise, off-work noise and unfavourable SPD were further classified as unfavourable factors, and there was a cumulative effect of risk in both groups than those without any unfavourable factors. This is consistent with other studies that used occupational cohorts.[43 44]

While interpreting these results, certain limitations of this study should be acknowledged. First, although the sample size of this study was large, it used two cross-sectional studies, so temporality cannot be inferred. These results should be validated in independent populations from other cohort studies. Second, due to the limited information in the questionnaire that the SPD of the Chinese participants was collected only as a categorical variable, it is unable to analyse the dose-response relationship between sleep and HL in the Chinese participants, and the effect of prolonged sleep on HL could also not be explored. Finally, all judgements of noise in our study were subjective, and there was a lack of measures of objectively observed noise exposure to compare the validation of subjective noise judgements.

Conclusions

Our study demonstrated that both noise at work and noise off-work are associated with poorer hearing. The negative relationship between SPD ≥8 hours/night and HL was mainly identified in Chinese participants with noise exposure. Association of SPD ≥8 hours/night with worse HF hearing was exclusively observed in the American participants without noise exposure. The null association of SPD ≥8 hours/night with HL among the Americans participants with noise exposure implies that the association might be modified by adequate sleep. Thus, prolonged SPD in individuals exposed to noise may have the potential to reduce noise-induced hearing impairment, especially among Chinese adults with DM and hyperlipidemia.

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Competing interests None declared.

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Patient consent for publication Not applicable.

Ethics approval The NHANES protocol was obtained from the NCHS Ethics Review Board. The use of data on the Zhejiang, Chinese participants was approved by the Research Ethics Committees of Affiliated Hangzhou Chest Hospital, Zhejiang University School of Medicine (Zhejiang, China; Approval Number: 2020-32). The privacy rights of the human subjects were consistently observed. All study participants signed a written informed consent form.

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