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Original Article

Association Between Obstructive Sleep Apnea and Hearing Loss Using 2019–2021 Korea National Health and Nutrition Examination Survey Data

Jungmin Ahn, Seung-Eun Hong, Brian Kim, Byeong-Cheol Lee, Myung-Chul Lee, Ik Joon Choi

Department of Otorhinolaryngology-Head and Neck Surgery, Korea Cancer Center Hospital, Korea Institute of Radiological and Medical Science, Seoul, Korea

ORCID iDs of the authors: J.A. 0000-0003-2029-6243, S-E.H. 0000-0003-4282-6268, B.K. 0000-0002-0933-079X, B-C.L. 0000-0002-4149-273X, M-C.L. 0000-0002-2574-4976, I.J.C. 0000-0002-9680-3873.

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BACKGROUND: The association of hearing loss with obstructive sleep apnea (OSA) has been investigated in several studies, but analyses using large national population-based datasets are lacking. Therefore, we aimed to determine the effect of the severity of OSA on hearing loss using data from the Korea National Health and Nutrition Examination Survey (KNHANES).

METHODS: We reviewed the KNHANES data from 2019 to 2021, analyzing 7730 subjects aged 40 and older who completed the sleep health survey (STOP-BANG questionnaire, SBQ) and hearing assessment. According to their SBQ scores, subjects were classified into low-, intermediate-, and high-risk OSA groups. Hearing loss was defined as a pure-tone average (PTA) greater than 25 dB at frequencies of 0.5, 1, 2, and 4 kHz in the better ear. In addition, low- and high-frequency hearing loss was defined as PTA >25 dB at 0.5, 1, and 2 kHz and PTA >40 dB at 2, 4, and 8 kHz, respectively.

RESULTS: Of a total of 7730 subjects, 4781 (62.4%), 2534 (31.7%), and 415 (5.9%) belonged to the low-, intermediate-, and high-risk groups, respectively. Mean hearing thresholds were significantly higher in the intermediate-, high-, and intermediate/high-risk groups compared to the low-risk group (all $P < .001$). After adjusting for related variables, logistic regression analyses revealed that hearing loss was not significantly correlated with OSA severity in the male subgroup. However, female subjects with more than an intermediate risk of OSA had a 1.372 times higher risk of hearing loss than those with a low risk of OSA (odds ratio: 1.372, 95% CI: 1.039-1.814).

CONCLUSION: The study found that the risk of hearing loss was significantly related to the severity of OSA in the female subgroup.

KEYWORDS: Sleep apnea, obstructive, hearing loss, national health and nutritional examination survey

INTRODUCTION

Obstructive sleep apnea (OSA) is characterized by repeated interruptions in breathing during sleep caused by an obstructed or collapsed upper respiratory tract, resulting in decreased blood oxygen saturation. Intermittent hypoxia wakes patients up to resume normal breathing. This sleep fragmentation can lead to serious chronic health problems. With a global prevalence of 4%-6%, OSA is a relatively common sleep-related health problem.[1] In South Korea, it has been reported to be 4.5% for adult men and 3.4% for women, which are similar to those in other countries.[2]

Polysomnography (PSG), the standard for OSA diagnosis, is a test that comprehensively measures brain waves, eye movements, chest and abdominal movements, respiratory flow, electrocardiogram, and blood oxygen saturation levels during sleep and has a high sensitivity in the range of 75%-88%.[3,4] However, not only is the test time-consuming, but patients complain of discomfort because they have to sleep while being monitored by experts in a laboratory environment. Therefore, there is increasing interest in tools that can screen for OSA prior to PSG, and the STOP means frequent snoring (S), tiredness (T), observed apnea (O), HTN (P). This

Corresponding author: Jungmin Ahn, e-mail: jungmin.ahn.0316@gmail.com
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was indicated in Method section. STOP-Bang questionnaires (SBQ), and Berlin questionnaires are being used. The SBQ, which consists of 8 binary questions related to OSA, has been reported to have sensitivities of 83.9%, 92.9%, and 100% for screening for all OSA, moderate-to-severe OSA, and severe OSA, respectively.[5] In addition, based on the usefulness and reliability of the SBQ, it has been included in the sleep health survey of the Korea National Health and Nutrition Examination Survey (KNHANES) since 2019.

Obstructive sleep apnea affects several body systems, including the cardiovascular, endocrine, neuropsychiatric, cognitive, and vestibular systems.[6,7] The exact mechanisms remain unclear; however, systemic inflammation, hypercoagulation, sympathetic activation, oxidative stress, and metabolic dysregulation, among others, have been suggested.[8]

Obstructive sleep apnea is also associated with hearing impairment. The inner ear, especially the cochlea, has a high demand for an oxygen supply. Therefore, the chronic repetitive hypoxemia and changes in blood oxygen concentrations observed in patients with OSA may damage the inner ear, causing hearing loss that may be temporary or permanent. A previous study by Martines et al[9] reported significant high-frequency hearing loss above 6 kHz in moderate-to-severe OSA patients, but no hearing loss in simple snoring patients. Chopra et al[10] also found a significant association between hearing loss and OSA in Hispanics. Individuals with severe OSA had a greater likelihood of developing high-frequency hearing loss than those with mild OSA or no OSA, after adjustment for cardiovascular risk factors and age. However, Hwang et al[11] reported no association between OSA and either low-frequency or high-frequency hearing thresholds in 224 hospital volunteers aged >50 years. In addition, some studies have shown that treatment with continuous positive airway pressure, the standard OSA therapy, does not significantly improve average hearing thresholds.[12,13] Due to these inconsistent results, no definitive conclusions have been drawn about the relationship between OSA and hearing loss.

It has been considered that limited sample sizes and different definitions of OSA and hearing loss may account for the conflicting results of these previous studies. In addition, given the association between OSA and multiple comorbidities, studies with large national population-based datasets are required. Population-based studies linking OSA and hearing loss have been reported in other countries,[10,14] but not in South Korea. Since OSA risk assessment items were first introduced in the eighth KNHANES, we attempted to demonstrate the relationship between OSA and hearing loss in the Korean population using the KNHANES dataset.

MAIN POINTS

- A possible association between OSA severity and hearing loss has been demonstrated in a large population-based dataset.
- The risk of hearing loss was related to the severity of OSA in the female.
- Early detection of OSA may be necessary to prevent the worsening of hearing in women.

METHODS

Study Participants

The KNHANES is a nationwide survey system conducted by the Korea Disease Control and Prevention Agency (KDCA) since 1998 for the assessment of health conditions, health behaviors, and nutritional status of Koreans. Data from the eighth KNHANES from 2019 to 2021 were used for the study. For each year, this cross-sectional survey included 10 000-12 000 individuals from approximately 4600 households using multi-stage clustering and stratified random sampling methods. In all of the analyses, sample weights were used to generate estimates that were representative of the non-institutionalized population in Korea. The Institutional Review Board (IRB) of the KDCA approved the KNHANES survey protocols (approval numbers: 2018-01-03-C-A, 2018-01-03-2C-A, and 2018-01-03-3C-A), and written informed consent was obtained from all participants. In addition, this study was approved by the Ethics Committee of Korea Institute of Radiological and Medical Science (approval no: 2023-05-001, date: May 10th, 2023).

In total, 22 559 individuals were registered in the 2019-2021 KNHANES. The subjects excluded from this study are as follows: subjects aged <40 years (n = 8725); subjects who did not participate in the sleep health survey (n = 1588); subjects without results of pure tone audiometry (n = 3222); subjects with abnormal tympanometry results (n = 805); and subjects without records on household income, neck circumference, body mass index (BMI, kg/m^2), noise exposure history, smoking status, alcohol consumption, and hypertension/hyperlipidemia/diabetes (n = 489). Finally, 7730 subjects were included in the study (Figure 1).

Demographic Variables

The demographic and socioeconomic information of the subjects was collected. Self-reported questionnaires were used to obtain their age, sex, alcohol consumption, smoking status, noise exposure history, sleep health, and socioeconomic status. Household income was quartile-ranked (lowest, low-middle, high-middle, and highest) based on total monthly household income divided by the square root of the number of people in the household. Obesity was assessed using BMI, which was classified as follows: underweight (<18.5), normal (≥18.5 and <23), overweight (≥23 and <25), obese I (≥25 and <30), and obese II (≥30).[15] Hypertension (HTN) was defined as systolic and diastolic blood pressure ≥140 mm Hg and ≥90 mm Hg, respectively, or current use of antihypertensive medication. Diabetes was

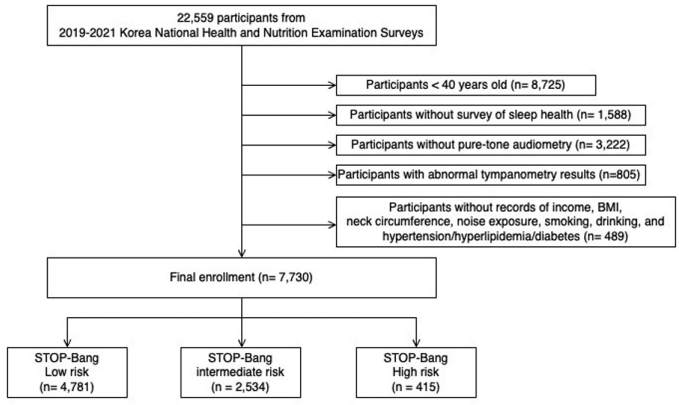

Figure 1. Flow diagram for participant selection.

defined as having a fasting glucose ≥126 mg/dL, HbA1c concentration ≥6.5%, current use of antidiabetic agents, or use of insulin injections. Hyperlipidemia was defined as a total cholesterol level ≥240 mg/dL or taking lipid-lowering medications. Those who had smoked 100 or more cigarettes in their lifetime and who were still smoking were defined as current smokers. Based on daily alcohol consumption in the month prior to the survey, a heavy drinker was defined as a person who consumed more than 7 drinks (for men) or 5 drinks (for women) on a single occasion or who drank alcohol more than 2 times per week.

Risk Assessment for OSA

The risk of OSA was evaluated using the SBQ, which consisted of 8 questions, including frequent snoring (S), tiredness (T), observed apnea (O), HTN (P), BMI >35 kg/m^2 (B), age >50 years (A), neck circumference >40 cm (N), and male sex (G). For each question, a "yes" answer was assigned a score of 1. A score of 2 or less indicates a low risk for OSA, a score of 3-4 indicates an intermediate risk, and a score of 5 or more indicates a high risk for having either moderate or severe OSA.

Hearing Evaluation

Pure-tone audiometry was performed using an automatic AD629 audiometer (Interacoustics, Assens, Denmark) and supra-auricular headphones. Hearing thresholds were obtained for each ear at 0.5, 1, 2, 4, and 8 kHz. Hearing loss was defined as a pure-tone average (PTA) of >25 dB at 4 frequencies (4 frequency average (4FA): 0.5, 1, 2, and 4 kHz) in the better ear. Additionally, PTA >25 dB at 0.5, 1, and 2 kHz and PTA >40 dB at 2, 4, and 8 kHz were defined as low- and high-frequency hearing losses, respectively.

Statistical Analysis

All analyses were conducted with SPSS version 26 (IBM SPSS Corp.; Armonk, NY, USA). The weighted values recommended by the KNHANES were used, and all results were presented as weighted values. Analysis of variance (ANOVA) or the Rao–Scott χ^2 test was performed to compare the low-, intermediate-, and high-risk OSA groups. Student *t*-test or Rao–Scott χ^2 test was performed to compare the low- and intermediate/high-risk OSA groups. Using logistic regression analysis, the risk of hearing loss is presented as an odds ratio (OR) and a 95% CI. Different adjustment models were used to assess the risk of hearing impairments. First, we adjusted for sex, age, and BMI (Model 1). In addition to those adjusted for in Model 1, Model 2 was adjusted for heavy drinking, current smoking, and noise exposure history. Finally, we adjusted a third model for HTN, diabetes, and hyperlipidemia in addition to the adjustments made in Model 2. Statistical significance was indicated by *P* values less than .05.

RESULTS

A total of 7730 subjects were included, of whom 3321 (48.2%) were male and 4409 (51.8%) were female. Based on the SBQ results, subjects were classified as low (62.4%), intermediate (31.7%), or high risk (5.9%) of OSA. Intermediate- and high-risk OSA groups accounted for 37.6% of the study participants. The basic characteristics of participants are shown in Tables 1 and2. Compared to the low-risk OSA group, older subjects with a higher proportion of males and higher BMIs were found in the intermediate-, high-, and intermediate/high-risk OSA groups (all $P < .001$). The intermediate-, high-, and intermediate/high-risk OSA groups also had higher rates of current smoking, heavy alcohol use, and prevalence of HTN, diabetes, and hyperlipidemia. The history of noise exposure, which can affect hearing, significantly differed between the groups (all $P < .001$).

The average hearing thresholds and percentage of hearing loss for each group are shown in Table 3. The mean PTA at the low-, high-, and 4 frequencies was higher for the intermediate-, high-, and intermediate/high-risk OSA groups than for the low-risk OSA group (all $P < .001$). Furthermore, the proportion of hearing loss at the low, high, and 4 frequencies was higher in the intermediate-, high-, and intermediate/high-risk OSA groups compared to the low-risk OSA group (all $P < .001$).

Table 4 summarizes the incidence of hearing impairment associated with different severities of OSA. Because the sample size of the high-risk OSA group was relatively small, subjects were divided into a low-risk and an intermediate/high-risk OSA group for analysis. The OR for hearing impairment related to the severity of OSA was >2-fold in the unadjusted analysis. However, after adjusting for the relevant variables, the risk of hearing loss was not significantly correlated with the severity of OSA. Table 5 shows the association of hearing loss with other variables in gender subgroups. Factors associated with hearing loss in the male subgroup were age (OR: 1.151; 95% CI: 1.137-1.164), obese II (OR: 2.024; 95% CI: 1.131-3.620), current smoking (OR: 1.371; 95% CI: 1.070-1.757), noise exposure (OR: 2.228; 95% CI: 1.735-2.860), and diabetes (OR: 1.342; 95% CI: 1.047-1.721). In the male subgroup, the severity of OSA was not related to hearing loss after adjusting for other relevant factors. In the female subgroup, the risk of hearing loss was significantly related to age (OR: 1.180; 95% CI: 1.162-1.197), obese II (OR: 1.904; 95% CI: 1.214-2.987), noise exposure (OR: 1.602; 95% CI: 1.150-2.231), and the severity of OSA (OR: 1.372; 95% CI: 1.039-1.814). That is, females with more than an intermediate risk of OSA were 1.372 times more likely to experience hearing loss compared to females with a low risk of OSA. The ORs for low- and high-frequency hearing loss by the OSA severity were more than 2-fold in the unadjusted analysis. However, after adjusting for relevant variables, there was no association between the severity of OSA and low-/high-frequency hearing loss.

DISCUSSION

Using data from the 2019-2021 KNHANES, this study examined the associations between hearing impairment and OSA severity after controlling for demographic characteristics and comorbid conditions in the Korean population. We found that the intermediate/high-risk OSA group had more hearing loss compared to the low-risk OSA group, but this was only statistically significant in the female subgroup.

Although several mechanisms may underlie the association of OSA with hearing loss, previous studies have proposed that chronic repetitive hypoxemia may be involved.[9,16] Because the cochlea depends on a single distal artery and does not have an adequate collateral blood supply, it is sensitive to changes in the circulatory system.[17] Hemodynamic changes in OSA, such as intermittent hypoxia and reoxygenation, can lead to cerebrovascular dysfunction, resulting in reduced cerebral blood flow.[18] In addition, the blood pressure fluctuations that occur during apnea and the increased sympathetic

Table 1. General Characteristics of the Subjects

	Total	Low	Intermediate	High	Intermediate/High	$P^{\dagger}$	$P^{\ddagger}$
	n = 7730	n = 4781	n = 2534	n = 415	n = 2949		
Age (mean [yrs], SD)	56.41 ± 0.211	54.48 ± 0.228	59.95 ± 0.284	57.74 ± 0.493	59.60 ± 0.264	<.001*	<.001***
Sex (n, %)						<.001**	<.001**
Male	3321 (48.2)	1182 (30.5)	1746 (74.2)	393 (95.1)	2139 (77.5)		
Female	4409 (51.8)	3599 (69.5)	788 (25.8)	22 (4.9)	810 (22.5)		
Household income level (n, %)						.283	.120
Lowest	1836 (22.7)	1084 (21.8)	641 (24.1)	111 (25.8)	752 (24.4)		
Low-middle	1913 (24.7)	1190 (25.0)	625 (24.1)	98 (25.3)	723 (24.3)		
High-middle	1998 (26.0)	1249 (26.3)	651 (26.1)	98 (22.5)	749 (25.6)		
Highest	1983 (26.5)	1258 (26.9)	617 (25.7)	108 (26.4)	725 (25.8)		
Obesity (BMI, n, %)						<.001**	<.001**
<18.5 kg/m^2 (underweight)	198 (2.5)	157 (3.2)	38 (1.4)	3 (0.9)	41 (1.3)		
≥18.5- <23 kg/m^2 (normal)	2684 (34.2)	2023 (41.9)	626 (23.9)	35 (8.8)	661 (21.5)		
≥23-<25 kg/m^2 (overweight)	1882 (24.3)	1163 (24.8)	651 (25.1)	68 (15.0)	719 (23.5)		
≥25-<30 kg/m^2 (obese I)	2519 (33.0)	1259 (26.3)	1031 (41.5)	229 (57.6)	1260 (44.1)		
≥30 kg/m^2 (obese II)	447 (6.0)	179 (3.8)	188 (8.0)	80 (17.7)	268 (9.6)		
Hypertension (n, %)	3099 (36.7)	1034 (18.8)	1730 (64.0)	335 (79.3)	2065 (66.4)	<.001**	<.001**
Diabetes (n, %)	1485 (17.7)	668 (12.7)	664 (24.0)	153 (36.4)	817 (25.9)	<.001**	<.001**
Hyperlipidemia (n, %)	2595 (32.2)	1441 (28.1)	968 (37.6)	186 (46.1)	1154 (38.9)		
Current smoker (n, %)	1146 (16.9)	528 (13.1)	501 (22.2)	117 (28.5)	618 (23.2)	<.001**	<.001**
Heavy drinker (n, %)	814 (12.4)	328 (8.5)	374 (17.3)	112 (28.2)	486 (19.0)	<.001**	<.001**
Noise exposure (n, %)	1247 (16.1)	639 (13.4)	514 (20.2)	94 (22.2)	608 (20.5)	<.001**	<.001**

BMI, body mass index; SD, standard deviation.
*Analyzed by ANOVA.
**Analyzed by Rao-Scott $\chi 2$ test.
***Analyzed by student *t*-test.
†Compared among 3 groups (low-, intermediate-, and high-risk group).
‡Compared between 2 groups (low- and intermediate-/high-risk group).

activity resulting from the reflex effect of hypoxic and hypercapnic conditions can cause ischemic damage to the cochlea through adverse cerebrovascular reactions.[19] We found in this study that the risk of hearing loss increased with the severity of OSA. This finding supports a possible mechanism: more apneic and hypopneic episodes lead to more frequent cochlear oxygen depletion and exacerbation of hearing loss.

The association between OSA and hearing thresholds at different frequencies has been investigated in several studies. In a meta-analysis of 20 observational studies examining the association of OSA with hearing loss, the mean hearing thresholds in the mid-frequency (0.5, 1 kHz, and 2 kHz) and high-frequency (4 kHz and 8 kHz) ranges were higher in the OSA group compared with the control group.[20] In addition, the mean differences in hearing thresholds between the OSA and control groups were slightly greater at high frequencies than at mid frequencies. These findings may be explained by acoustic trauma or noise-induced hearing loss due to chronic noise exposure with loud snoring, which is another possible mechanism for hearing loss in OSA patients. A significant difference in hearing of extended high frequencies in subjects with simple snoring and OSA compared to controls suggests that snoring noise may cause hearing loss.[21] Alternatively, the hypothesis that spiral ganglion neurons in the cochlear basal turn may be more sensitive to ototoxicity than the middle and apical spiral regions could explain the greater hearing loss at higher frequencies.[22] The present study also confirmed that the severity of OSA is associated with higher hearing thresholds, which is consistent with previous studies. However, after adjusting for relevant variables, including age and noise exposure history, there was no significant difference in high-frequency hearing loss by OSA severity. This may indicate that aging or occupational noise exposure is more likely to account for the high-frequency hearing loss in our study subjects.

In both the male and female subgroups, age, severe obesity with a BMI of 30 or more (obese II), and noise exposure history were factors significantly associated with hearing loss. The link between obesity and hearing loss has also been established in another large-scale study of the Korean population. Kim et al[23] found that the OR for hearing loss in severely obese individuals (BMI ≥ 30) was approximately 1.3 times that of normal-weight individuals. Obesity can affect hearing in many ways. Reduced cochlear blood flow due to obesity-related atherosclerosis is one of the factors reported to influence this relationship.[24] In addition, the excessive accumulation of reactive oxygen species in the auditory epithelium is also known to cause hearing loss.[25]

Table 2. General Characteristics for Each Gender

	Men						Women				
	Low	Intermediate	High	Intermediate/High	$P^{\dagger}$	$P^{\ddagger}$	Intermediate	High	Intermediate/High	$P^{\dagger}$	$P^{\ddagger}$
	n = 1182	n = 1746	n = 393	n = 2139			n = 788	n = 22	n = 810		
Age	52.04 ± 0.328	58.82 ± 0.312	57.51 ± 0.497	58.57 ± 0.280	<.001*	<.001***	63.20 ± 0.442	62.12 ± 2.120	63.17 ± 0.435	<.001*	<.001***
Obesity					<.001**	<.001**				<.001**	<.001**
Underweight	36 (2.2)	33 (1.7)	3 (1.0)	36 (1.6)			5 (0.6)	0 (0)	5 (0.6)		
Normal	413 (32.5)	438 (23.3)	31 (8.4)	469 (20.4)			188 (25.7)	4 (16.1)	192 (25.3)		
Overweight	361 (31.3)	461 (25.5)	65 (15.6)	526 (23.6)			190 (24.0)	3 (4.9)	193 (23.3)		
Obese I	352 (31.7)	721 (43.1)	220 (57.7)	941 (45.9)			310 (37.1)	9 (54.2)	319 (37.7)		
Obese II	20 (2.1)	93 (6.4)	74 (17.4)	167 (8.5)			95 (12.6)	6 (24.8)	101 (13.1)		
Hypertension	79 (7.9)	1092 (58.5)	313 (78.3)	1405 (62.4)	<.001**	<.001**	638 (79.5)	22 (100)	660 (80.2)	<.001**	<.001**
Diabetes	173 (13.8)	457 (24.0)	142 (36.3)	599 (26.4)	<.001**	<.001**	207 (24.0)	11 (37.9)	218 (24.5)	<.001**	<.001**
Dyslipidemia	246 (21.1)	565 (33.3)	172 (45.6)	737 (35.6)	<.001**	<.001**	403 (50.0)	14 (56.7)	417 (50.2)	<.001**	<.001**
Current smoker	391 (34.4)	468 (28.4)	116 (29.9)	584 (28.7)	<.01**	<.01**	33 (4.6)	2 (2.1)	34 (4.5)	.582	.529
Heavy drinker	182 (18.2)	346 (22.0)	112 (29.7)	458 (23.5)	<.001**	<.01**	28 (3.8)	0 (0)	28 (3.7)	.495	.586
Noise exposure	231 (18.9)	393 (22.0)	92 (22.9)	485 (22.2)	.139	.059	121 (15.0)	2 (7.8)	123 (14.7)	.018**	<.01**

*Analyzed by ANOVA.
**Analyzed by Rao-Scott χ^2 test.
***Analyzed by student *t*-test.
†Compared among 3 groups (low-, intermediate-, and high-risk group).
‡Compared between 2 groups (low-, and intermediate-/high-risk group).

Table 3. Hearing Impairment According to the Severity of Obstructive Sleep Apnea (OSA)

	Severity of OSA						
	Total	Low	Intermediate	High	Intermediate/High	$P^{\dagger}$	$P^{\ddagger}$
	n = 7730	n = 4781	n = 2534	n = 415	n = 2949		
Pure Tone Average in the Better Ear (dB)							
4FA (0.5, 1, 2, 4 kHz)	16.41 ± 0.20	14.27 ± 0.20	20.13 ± 0.33	19.13 ± 0.61	19.97 ± 0.30	<.001*	<.001**
Low frequency (0.5, 1, 2 kHz)	13.58 ± 0.18	12.28 ± 0.19	15.95 ± 0.29	14.51 ± 0.55	15.73 ± 0.27	<.001*	<.001**
High frequency (2, 4, 8 kHz)	24.31 ± 0.29	20.48 ± 0.29	30.82 ± 0.48	29.93 ± 0.87	30.68 ± 0.44	<.001*	<.001**
Hearing Impairment (n, %)							
4FA >25 dB in the better ear	1780 (18.6)	792 (13.2)	866 (28.3)	122 (24.5)	988 (27.7)	<.001***	<.001***
Low-frequency hearing loss	1163 (11.7)	546 (8.9)	548 (17.1)	69 (13.7)	617 (16.5)	<.001***	<.001***
High-frequency hearing loss	1748 (18.7)	741 (12.4)	883 (29.7)	124 (25.5)	1007 (29.1)	<.001***	<.001***

4FA, 4 frequency average.
*Analyzed by ANOVA.
**Analyzed by Rao-Scott $\chi 2$ test.
***Analyzed by student *t*-test.
†Compared among 3 groups (low-, intermediate-, and high-risk group).
‡Compared between 2 groups (low-, and intermediate-/high-risk group).

In addition, diabetes and current smoking were significantly positively associated with hearing loss only in the male subgroup. Diabetes has been reported to increase the prevalence of hearing loss in previous studies. According to a large cross-sectional study,[26] the prevalence of hearing loss in diabetic patients and controls was significantly different at 17.3% and 6.5%, respectively. Diabetes is also known to worsen hearing loss. Mitchell et al[27] demonstrated that patients with diabetes had a significantly higher rate of hearing

Table 4. Odds Ratios for Hearing Impairment by OSA Severity in Total Subjects

	Total Participants			
	Crude	Model 1	Model 2	Model 3
	ß (95% CI)	ß (95% CI)	ß (95% CI)	ß (95% CI)
Age		1.157 (1.148-1.167)	1.164 (1.154-1.174)	1.162 (1.152-1.172)
Sex				
Male			1 (reference)	
Female		0.442 (0.368-0.531)	0.510 (0.422-0.618)	0.510 (0.419-0.620)
Obesity (BMI)				
≥18.5-<23 kg/m^2 (ormal)			1 (reference)	
<18.5 kg/m^2 (underweight)		0.885 (0.486-1.610)	0.874 (0.481-1.588)	0.893 (0.493-1.619)
≥23-<25 kg/m^2 (overweight)		1.239 (1.013-1.516)	1.221 (0.996-1.498)	1.207 (0.982-1.483)
≥25-<30 kg/m^2 (obese I)		1.314 (1.095-1.578)	1.296 (1.079-1.558)	1.265 (1.049-1.525)
≥30 kg/m^2 (obese II)		2.049 (1.467-2.863)	2.103 (1.498-1.953)	1.984 (1.399-2.814)
Current smoker			1.430 (1.125-1.817)	1.414 (1.114-1.794)
Heavy drinker			1.208 (0.891-1.637)	1.201 (0.884-1.631)
Noise exposure			2.001 (1.630-2.457)	1.996 (1.623-2.455)
Hypertension				1.052 (0.876-1.262)
Diabetes				1.221 (1.023-1.457)
Hyperlipidemia				0.976 (0.833-1.143)
Severity of OSA				
Low			1 (reference)	
Intermediate/high	2.531 (2.224-2.880)	1.145 (0.954-1.374)	1.110 (0.923-1.336)	1.076 (0.884-1.311)

Model 1. Adjusted for age, sex, and BMI.
Model 2. Adjusted for age, sex, BMI, current smoking, heavy drinker, and noise exposure.
Model 3. Adjusted for age, sex, BMI, current smoking, heavy drinker, noise exposure, HTN, DM, and hyperlipidemia.
BMI, body mass index; ORs, odd ratios; OSA, obstructive sleep apnea.

Table 5. Odds Ratios for Hearing Impairment by OSA Severity in Male and Female Subgroups

	Men				Women			
	Crude	Model 1	Model 2	Model 3	Crude	Model 1	Model 2	Model 3
	ß (95% CI)	ß (95% CI)	ß (95% CI)	ß (95% CI)	ß (95% CI)	ß (95% CI)	ß (95% CI)	ß (95% CI)
Age		1.144 (1.132-1.157)	1.154 (1.141-1.167)	1.151 (1.137-1.164)		1.177 (1.161-1.193)	1.179 (1.162-1.195)	1.180 (1.162-1.197)
Obesity (BMI)								
Normal			1 (reference)				1 (reference)	
Underweight		0.677 (0.331-1.387)	0.636 (0.307-1.319)	0.669 (0.324-1.383)		1.260 (0.486-3.267)	1.299 (0.512-3.298)	1.294 (0.507-3.300)
Overweight		1.129 (0.858-1.486)	1.125 (0.853-1.484)	1.096 (0.828-1.451)		1.345 (1.004-1.801)	1.323 (0.984-1.779)	1.326 (0.985-1.785)
Obese I		1.330 (1.010-1.750)	1.334 (1.008-1.764)	1.280 (0.967-1.695)		1.209 (0.910-1.606)	1.188 (0.898-1.572)	1.195 (0.898-1.591)
Obese II		2.068 (1.184-3.612)	2.239 (1.266-3.960)	2.024 (1.131-3.620)		1.909 (1.233-2.954)	1.895 (1.224-2.933)	1.904 (1.214-2.987)
Current smoker			1.398 (1.090-1.794)	1.371 (1.070-1.757)			1.283 (0.664-2.477)	1.279 (0.657-2.489)
Heavy drinker			1.192 (0.876-1.621)	1.177 (0.863-1.604)			1.122 (0.474-2.657)	1.129 (0.477-2.672)
Noise exposure			2.235 (1.744-2.863)	2.228 (1.735-2.860)			1.606 (1.153-2.238)	1.602 (1.150-2.231)
Hypertension				1.147 (0.868-1.516)				0.941 (0.739-1.198)
Diabetes				1.342 (1.047-1.721)				1.048 (0.810-1.355)
Hyperlipidemia				0.953 (0.747-1.216)				0.976 (0.798-1.195)
Severity of OSA								
Low			1 (reference)				1 (reference)	
Intermediate/ high	2.170 (1.763-2.670)	1.029 (0.795-1.333)	0.987 (0.761-1.280)	0.902 (0.658-1.237)	2.756 (2.208-3.439)	1.364 (1.034-1.800)	1.339 (1.013-1.770)	1.372 (1.039-1.814)

Model 1. Adjusted for age and BMI.
Model 2. Adjusted for age, BMI, current smoking, heavy drinker, and noise exposure.
Model 3. Adjusted for age, BMI, current smoking, heavy drinker, noise exposure, HTN, DM, and hyperlipidemia.
BMI, body mass index; ORs, odd ratios; OSA, obstructive sleep apnea.

loss worsening than normal subjects when hearing loss worsening was defined as a threshold increase of more than 5 dB over 5 years (OR = 2.71). Several biological mechanisms explain how diabetes and hearing loss relate. It is possible that the high level of blood glucose can cause damage to the small blood vessels of the inner ear and neuropathic complications. Indeed, several histopathologic findings, such as microangiopathologic changes in the stria vascularis, thickening of the vascular wall of the basilar membrane, loss of cochlear outer hair cells, and demyelination of the auditory nerve, have been observed in the inner ear of experimental diabetic models or diabetic patients.[28,29] Smoking is also known to cause many health problems, including cardiovascular disease and lung cancer.[30] A growing body of research suggests that smoking may cause hearing loss, although the link between hearing loss and smoking is not consistent.[31-33] The mechanisms by which smoking is ototoxic are not clear, but a biologically plausible argument has been made that nicotine causes hearing loss via cochlear anemia due to vasoconstriction.[34]

A gender difference in the association between hearing loss and OSA severity was observed in this study. Only in the female subgroup did the intermediate/high-risk OSA group have more hearing loss than the low-risk OSA group. It is unclear why the link between hearing loss and OSA severity only reached statistical significance in women, although men were more prevalent in the intermediate/high-risk OSA group. However, gender differences in how other comorbidities affect hearing loss should be considered. There are several known potential risk factors for hearing loss, including increasing age, HTN, diabetes, cardiovascular disease, cerebrovascular disease, smoking, and noise exposure.[35,36] In South Korea, as in other countries, the prevalence of these comorbidities of hearing loss is higher in males than in females.[37] The association between OSA severity and hearing loss in men disappeared after adjustment for several related factors, suggesting that auditory dysfunction due to other comorbidities had a greater effect than hypoxic damage from OSA. Another possible explanation is hormonal factors, which were not controlled in this study. Men are more commonly diagnosed with OSA compared to

women. This higher prevalence could potentially increase their risk of related conditions, including hearing loss. However, some studies indicate that postmenopausal women experience a stronger association with hearing loss compared to premenopausal women.[38,39] This is explained by hormonal changes such as the decline in estrogen, which has protective effects on vascular and auditory systems. After menopause, when estrogen levels drop, women's risk of both OSA and hearing loss increases,[40] suggesting a potential shift in the gender difference in association as age progresses. Considering age, it would be expected that the proportion of postmenopausal women in the intermediate/high-risk OSA group would be higher than in the low-risk OSA group. Therefore, these hormonal effects may have influenced the significant correlation between OSA severity and hearing loss in women. Finally, vascular differences could also be considered a factor contributing to the significant association in women. Cardiovascular disease, a known complication of OSA and a contributing factor to hearing loss can manifest differently in men and women. Men generally experience these cardiovascular risks earlier,[41] which could make them more susceptible to hearing loss earlier in life when associated with OSA. Postmenopausal women, however, may catch up in terms of cardiovascular risk and related conditions like hearing loss, as hormone changes affect vascular health. This means that the risk of hearing loss in women with OSA could increase later in life.

The strength of this study is that it used a national, population-based dataset that provided a sample of sufficient size to examine the relationship between OSA severity and hearing loss. To our knowledge, this study is the first to analyze the association of OSA severity with hearing loss using KNHANES data. This is because the sleep health survey was introduced for the first time in the eighth KNHANES. However, there were some limitations to this study. First, diagnosing OSA based on responses to the OSA risk assessment questionnaire, SBQ, may be less accurate than diagnosing OSA based on PSG. Nevertheless, SBQ has been used in several studies worldwide because it has high diagnostic accuracy, is easy to use, and clearly stratifies risk.[42] In addition, SBQ has been reported to be highly sensitive in screening patients with moderate-to-severe OSA and is therefore considered reliable in preventing misdiagnosis.[43] Second, we attempted to exclude cases with other otological diseases by including only subjects with normal tympanometry; however, some subjects without normal sound conduction mechanisms may have been included. Finally, we could not directly determine the mechanisms underlying the association between OSA severity and hearing loss because of the cross-sectional survey design of this study.

In conclusion, our study demonstrated a possible association of OSA severity with hearing loss using a large population-based dataset. We found that women with intermediate-to-high risks of OSA had a higher risk of hearing loss than those with low risks, but this was not observed in men. This finding suggests that early detection of OSA may be necessary to prevent the worsening of hearing loss in women.

Availability of Data and Materials: The data that support the findings of this study are available on request from the corresponding author, J.A.

Ethics Committee Approval: This study was approved by the Ethics Committee of Korea Institute of Radiological and Medical Science (approval no: 2023-05-001, date: May 10th, 2023).

Informed Consent: Written informed consent was obtained from the participants who agreed to take part in the study.

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