Contribution of Tinnitus and Hearing Loss to Depression: NHANES Population Study

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Objectives: Hearing loss affects the emotional well-being of adults and is sometimes associated with clinical depression. Chronic tinnitus is highly comorbid with hearing loss and separately linked with depression. In this article, the authors investigated the combined effects of hearing loss and tinnitus on depression in the presence of other moderating influences such as demographic, lifestyle, and health factors.

Design: The authors used the National Health and Nutrition Examination Survey data (2011–2012 and 2015–2016) to determine the effects of hearing loss and tinnitus on depression in a population of US adults (20 to 69 years). The dataset included the Patient Health Questionnaire-9 for depression screening, hearing testing using pure-tone audiometry, and information related to multiple demographic, lifestyle, and health factors (n = 5845).

Results: The statistical analysis showed moderate to high associations between depression and hearing loss, tinnitus, and demographic, lifestyle, and health factors, separately. Results of logistic regression analysis revealed that depression was significantly influenced by hearing loss (adjusted odds ratios [OR] = 3.0), the functional impact of tinnitus (adjusted OR = 2.4), and their interaction, both in the absence or presence of the moderating influences. The effect of bothersome tinnitus on depression was amplified in the presence of hearing loss (adjusted OR = 2.4 in the absence of hearing loss to adjusted OR = 14.9 in the presence of hearing loss). Conversely, the effect of hearing loss on depression decreased when bothersome tinnitus was present (adjusted OR = 3.0 when no tinnitus problem was present to adjusted OR = 0.7 in the presence of bothersome tinnitus).

Conclusions: Together, hearing loss and bothersome tinnitus had a significant effect on self-reported depression symptoms, but their relative effect when comorbid differed. Tinnitus remained more salient than hearing loss and the latter's contribution to depression was reduced in the presence of tinnitus, but the presence of hearing loss significantly increased the effects of tinnitus on depression, even when the effects of the relevant demographic, lifestyle, or health factors were controlled. Treatment strategies that target depression should screen for hearing loss and bothersome tinnitus and provide management options for the conditions.

Key words: Depression, NHANES, Hearing loss, Tinnitus.

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INTRODUCTION

Hearing loss is one of the three most chronic ailments affecting the global aging population. Estimates suggest that over 40% of individuals 60 years and over have hearing loss and the prevalence increases exponentially with age (World Health Organization 2021). The global impact of untreated hearing loss across the lifespan is upwards of 980 billion US dollars. Not only does hearing loss affect communication, but also impacts cognitive and emotional well-being and quality of life. In their latest report on hearing, World Health Organization (2021) predicts a 1.5-fold increase in hearing loss in the coming decades. Given the compounding effects of hearing loss on cognitive abilities, mood, and social engagement, its impact will be several-fold higher.

Growing evidence suggests that hearing loss impacts social interactions leading to social isolation and loneliness, which could increase the chances of serious health conditions such as depression (Gopinath et al. 2009; Lee et al. 2010; Mener et al. 2013; Golub et al. 2019). Depression is characterized by sadness, feelings of low self-worth or guilt, a loss of interest in daily activities, and disturbed appetite or sleep (World Health Organization 2021). The evidence linking hearing loss and depression is mixed, while some have found a significant association (Lee et al. 2010; Hsu et al. 2016; Brewster et al. 2018), others have failed to see such links on longitudinal follow-ups (Pronk et al. 2011, 2014; Stam et al. 2016). In a meta-analysis of 35 studies, Lawrence et al. (2020) found that hearing loss increases the odds of depression over time.

Hearing loss co-occurs with chronic tinnitus, a common condition (Jarach et al. 2022) with only a few effective treatments. Tinnitus is a perception of a self-generated, often-constant sound and the psychological reaction to it (Tyler 2006). Whereas most individuals experiencing tinnitus are habituated to it, nearly 10% of them complain of difficulties with sleep, concentration challenges, communication issues, anxiety, and depression (Snow 2008). Although some have found evidence that chronic tinnitus is highly comorbid with both anxiety and depressive disorders (Bartels et al. 2008), Shargorodsky et al. (2010) found that tinnitus is only significantly associated with generalized anxiety disorder in the US population. There is a limited number of studies in the literature that have examined the separate or additive contribution of tinnitus and hearing loss to depression and other affective disorders. In this study, our overarching goal was to investigate the multicomorbidity of depression, hearing loss, and tinnitus using a large-scale population-based dataset.

We used the publicly available dataset by National Health and Nutrition Examination Survey (NHANES), which is conducted biennially by the National Center for Health Statistics (NCHS) to assess the health condition and the risk of diseases in the general US population. Previous studies using the NHANES data have examined the prevalence and impact of hearing, tinnitus, and depressive disorders separately with rare exceptions. Li et al. (2014) analyzed the 2005–2010 dataset and found an increased risk of depression in adults with hearing loss, when accounting for factors including sociodemographic and lifestyle

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characteristics, medical history, and health status, trouble seeing. In the most relevant publication, Scinicariello et al. (2019) observed that “moderate or worse” speech and high frequency hearing are associated with depression in women of ages 52 to 69 years, independent of other risk factors. They did not find a similar result in men, nor did they examine tinnitus as one of the risk factors. In the same year, Spankovich et al. (2018) examined self-reported hearing difficulty, tinnitus, and normal audiometric thresholds in the 1999–2002 cohort of the NHANES. They found that tinnitus contributes to the reported hearing difficulty, together with noise exposure, mental or cognitive status, and other sensory deficits. However, none of these studies that have used the NHANES data have investigated the combined effects of tinnitus and hearing loss on depression.

In survey-based studies other than those using NHANES, Kim et al. (2015) found the prevalence rate of tinnitus to be about 20% in a large-scale population study in South Korea. They also found that both prevalence and annoyance increased with age, with the rates of tinnitus associated with “no discomfort” in 69.2%, “moderate annoyance” in 27.9%, and “severe annoyance” in 3.0%. Using the same Korea NHANES as Kim et al., Joo et al. (2015) determined the impact of tinnitus on health-related quality of life. They found that those with both hearing loss and tinnitus reported “some or extreme problems” in all five dimensions (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression) of the health-related quality of life more than the other groups with either hearing loss or tinnitus or neither. In general, while hearing loss and tinnitus were additive in their effects on the quality of life, tinnitus by itself had a stronger impact than hearing loss alone on psychological health. Note that both these studies considered depression as one of the factors that may co-occur with tinnitus, rather than investigate the contributions of tinnitus or hearing loss separately to the occurrence of depression.

In this study, we sought to explicitly examine the combined effects of hearing loss and tinnitus on the prevalence of depression in the general population, while accounting for the relevant risk factors associated with demographics, lifestyle, and health conditions.

MATERIALS AND METHODS

Data and Survey Design

National Center for Health and Human Services conducts biennial NHANES that consists of both interviews and physiological examinations of the subjects. These surveys implement a multistage sampling procedure, stratified by counties, blocks, and households. Trained professionals interview candidates in their homes and perform thorough physiological examinations. Each observation in the survey data was assigned a sampling weight to make it representative of the US civilian noninstitutional population.

We combined datasets from NHANES 2011–2012 and 2015–2016. We included all the individuals who completely answered the depression Patient Health Questionnaire-9 (PHQ-9) (Kroenke et al. 2001) and the hearing-related questionnaire for tinnitus and had complete audiometry test information for the survey periods. Audiometry tests were only conducted on participants aged between 20 and 69 for the survey years. We did not include the years 2013–2014 as the audiometry test information was not available. We considered relevant demographic, lifestyle, and health factors to find their effects on the associations between depression, hearing loss, and tinnitus. We removed observations for those participants who had missing information in any of the measures considered for the analysis. The total number of samples included in the study was n = 5845. We used NHANES’ recommendations for implementing the sampling weights (National Center for Health Statistics, 2011–2014, 2015–2018) for our analysis to get the population estimates of interest.

Throughout this article, the terms “general population” or “population” were used to represent the general US civilian noninstitutionalized population. We have used the term “subpopulation” or “population of individuals” in certain categories to mean the appropriate subset of the general population. The terms “measure” and “variable” have been used interchangeably in this article.

Outcome Measures

The primary measures of interest were the PHQ-9 score for depression, three different measures of tinnitus severity, and the results from pure-tone audiometry (PTA) for hearing loss. Our aim was to determine how hearing loss and tinnitus affected the prevalence of depression in the general population. We also considered how relevant demographic, lifestyle, and health factors affected the relationships between the primary measures of interest.

Depression Measures

The PHQ-9 questions to screen for depression were asked in private interview sessions by trained interviewers in English or Spanish using the Computer-Assisted Personal Interviewing system at the Mobile Examination Center. No proxies or interpreters were permitted for these questions. The responses to the nine questions were recorded in a four-point Likert scale ranging from 0 to 3 where they indicated the presence of the symptoms as “not at all,” “several days,” “more than half the days,” and “nearly all the time,” respectively. A sum of all the responses to the nine questions was used to compute the PHQ-9 score for depression. We also dichotomized the measure into the categories: “not depressed,” or “depressed,” depending on whether the PHQ-9 score was below or above 9. The dichotomized variable was referred to as “depression” for the analysis. This dichotomized version was used to obtain the prevalence of depression in different subpopulations, compute the measures of associations with other categorical variables, and for the logistic regression analysis.

Tinnitus Measures

The tinnitus-related questionnaire was administered by trained interviewers using the Computer-Assisted Personal Interviewing system. They involved questions on perception of different sounds in different settings, symptoms of tinnitus and their intensity, and exposure to situations that may affect tinnitus and hearing. All the questions were ordinal in nature, some of them being binary. The questions of interest were the tinnitus duration, frequency, and functional impact on sleep and lifestyle. Tinnitus duration was categorized as “non-chronic,” “new-onset chronic,” and “chronic” when tinnitus was reported to be present for less than 3 months, 3 months to 1 year, and more than 1 year, respectively. Tinnitus frequency was categorized as "occasional," "intermittent" and "constant" when the number of tinnitus occurrences was less than once a month, once a month to once a day, and more than once a day, respectively, mostly based on the classification of Henry et al. (2016). We also defined another variable tinnitus problem with categories "none," "moderate," and "big" based on the problems faced by the participants due to tinnitus. All the categories of the tinnitus variables were formed based on the categories used in NHANES.

Audiometry Measures

All audiometry components were administered by a trained examiner in a dedicated sound-isolating room at the Mobile Examination Center. Both ears were tested at seven frequencies: 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. The effective ranges for the automatic audiometric testing were from −10 to 100 dB at 500 to 6000 Hz and −10 to 90 dB at 8000 Hz. Thresholds could be tested through 120 dB (110 dB at 8000 Hz) using manual audiometric mode. Observed values, therefore, varied between −10 and 120 dB. We defined speech frequency hearing loss as the mean of thresholds at the frequencies 500, 1000, 2000, and 3000 Hz, averaged over both ears (speech frequency PTA), and high frequency hearing loss as the mean of thresholds at the frequencies 4000, 6000, and 8000 Hz, averaged over both ears (high frequency PTA). We further categorized both speech and high frequency PTA as "no loss" for values up to 25 dB, "mild loss" for values between 26 and 40 dB, and "moderate or worse loss" for values above 41 dB. The categorized versions of these measures were called "speech frequency hearing loss" and "high frequency hearing loss."

Demographic, Lifestyle, and Health Factors

We included several measures related to the demographic, lifestyle, and health factors. The demographic variables age, gender, race, education level, poverty income ratio (PIR), and marital status were included. The lifestyle factors were alcohol consumption and smoking habit. The health variables consisted of obesity, self-reported vision impairment, cardiovascular disease, cancer, diabetes, and hypertension. Obesity was classified into three categories based on body mass index (BMI): "underweight" for BMI ≤18, "normal" for BMI between 18 and 25, and "overweight or obese" for BMI greater than 25. For vision impairment, we combined responses to the question "trouble seeing" from the medical conditions questionnaire from NHANES 2011–2012 with that of "serious difficulty seeing" from the disability questionnaire from NHANES 2015–2016. The variable diabetes was defined as present if a participant was taking insulin or pills to manage diabetes at the time of the survey. The factor hypertension was marked as present if a participant was told by a healthcare provider at least twice that they had hypertension or if they were taking medication for it. Age and PIR were originally recorded as numerical variables. The remaining covariates were categorical and their categories were used as defined in NHANES. These variables were referred to as "covariates" throughout the article.

Statistical Analysis

We performed a two-step statistical analysis, first, a correlation analysis, and as second step, a regression analysis. First, we computed the associations between the primary measures of interest, that is, depression or PHQ-9 score, hearing loss measurements, and the tinnitus variables. We also examined the types and strengths of associations between the primary variables and the covariates to find if these factors significantly impacted the primary variables. Then we fitted three multiple logistic regression models with depression as the response variable and different combinations of the primary measures and the covariates as predictors.

Because categorizing a numerical variable causes information loss, numerical variables were used whenever possible to increase the accuracy of the analysis. However, for logistic regression models, we used the categorical variable speech frequency hearing loss instead of the numerical variable speech frequency PTA as a predictor for easier interpretability.

We used R version 4.2.0. on a personal computer for most of the analysis in this article. We used the latest version of the R package "survey" (Lumley 2004) for implementing NHANES' complex sampling scheme and weights to obtain the population estimates of interest. The R packages "tidyverse" (Wickham et al. 2019) and "dplyr" (Wickham et al. 2022) were used for data cleaning and organizing. We used C++ Desktop App Development Environment of Microsoft Visual Studio 2022 for the computation of "H_{vol}" measure of association, which was written in C language by Chen et al. (2006).

Descriptive Statistics

We used two different types of descriptive statistics depending on the variable type. For numerical variables, we estimated the population means with 95% confidence intervals (CIs) and a five-point summary that consists of the population estimates of their minimum, first quartile, second quartile or median, third quartile, and maximum.

For the categorical variables, we computed the sample sizes of the categories along with the estimated prevalence rates of the categories in the general population, the subpopulation of individuals with depression, the subpopulation with "moderate or worse" speech frequency hearing loss, the subpopulation experiencing one or more occurrences of tinnitus per month, the subpopulation that had been experiencing tinnitus for at least 3 months, and the subpopulation facing "moderate" or "big" problems in life due to tinnitus. The numerical variables "age" and "PIR" were categorized as "age group" and "PIR range" to find how the distributions of age and PIR changed in different subpopulations.

Measures of Association

We used two different measures of association depending on the type of the variable pair. We computed Pearson product moment correlation coefficient (r), and the p values from the corresponding t-tests for pairs of numerical variables.

It is difficult to define associations when one of the variables is categorical. Although there are multiple tests of independence between two categorical variables, they fail to give an easy-to-interpret measure of association between them. Chi-squared test is commonly used to test for independence between two categorical variables. A higher value of Chi-squared test statistic suggests a stronger association, but the test statistic can theoretically be indefinitely large (or p value indefinitely small), making it impossible to judge the strength of the association.

Another drawback of Chi-squared test is that for a large dataset, it has a higher probability of producing significant results even when there is no significant association between the variables (Lin et al. 2013). Instead, we used a volume-based method that measures discrepancy from independence using the sequential Monte Carlo method and is designed to be free from these limitations. We computed homozygosity volume (H_{vol}) for association as defined in Chen et al. (2006). H_{vol} is interpreted similarly as the coefficient of determination R^2, but with a sign for the direction of association. H_{vol} ranges between −1 and 1, where 0 represents perfect independence, and −1 or 1 represents the highest possible discrepancies from independence. It is important to note that the sign of H_{vol} is not the same as the sign of the correlation coefficient. H_{vol} is positive if most of the cell frequencies of the cross-tabulation between the variables of interest are greater than their expected values under independence, and negative otherwise. However, there is no established reference interval for H_{vol} as a measure of the strength of association. For our purposes, we considered any absolute value of H_{vol} greater than 0.2 as a moderate association, and above 0.5 as a strong association. While computing the H_{vol} values for associations between the covariates and the primary variables, we used the categorized "age group" and "PIR range" variables.

Logistic Regression Models

To investigate the joint impact of hearing loss and tinnitus on the prevalence of depression, we utilized logistic regression models to compute both crude and covariate adjusted odds ratios (OR) of depression. We only included the categorical variables of speech frequency hearing loss and tinnitus problems as the primary predictors to avoid any potential issues of multicollinearity. These models aimed to determine the effects of speech frequency hearing loss, tinnitus problem, and how their combined effect influenced depression.

We constructed a series of logistic regression models to analyze the effects of hearing loss, tinnitus and their interactions on different subpopulations, each with two versions: one crude and one adjusted for covariates. The response variable for all models was the dichotomized measure of depression. The baseline category for speech frequency hearing loss was set as "no loss," (implying normal hearing sensitivity), while for tinnitus problem, it was "no problem" (implying mild severity). The race "non-Hispanic White" was used as the baseline category for the covariate race. The baseline category for gender was "female." The category "married or living with partner" was the baseline for the covariate marital status. For all the other covariates, the neutral or the absence or the lowest category was used as the baseline category. The numerical variables age and PIR were categorized for all the covariates adjusted logistic regression models. To account for the increased variation caused by the large volume of data, we used a quasi-binomial model (Shoukri et al. 2022) for logistic regression.

The first set of models (crude and adjusted) was applied to the entire population, based on a sample size of 5845, using speech frequency hearing loss, tinnitus problem, and their interaction as predictors. The second set (crude and adjusted) focused on a subpopulation without speech frequency hearing loss (speech PTA ≤25) and utilized a sample size of 5284, with the tinnitus problem as the predictor. The third set (crude and adjusted) targeted the subpopulation with mild to moderate or worse speech frequency hearing loss (speech PTA ≥26) and consisted of a sample size of 561. These models were like the second set but specific to the designated subpopulation. The fourth set (crude and adjusted) examined the subpopulation without a tinnitus problem, utilizing a sample size of 5157, with speech frequency hearing loss as the predictor. The fifth set (crude and adjusted) followed a similar approach to the fourth set but focused on the subpopulation with moderate to significant tinnitus problem, comprising a sample size of 688. In all adjusted models, we accounted for demographic, lifestyle, and health factors as covariates.

To determine the significance of the results, we estimated crude and covariate adjusted ORs along with their 95% CIs from each set of models. The ORs were considered significant at a 5% level if their CIs did not include 1. These ORs indicate the multiplicative change in the odds of being depressed for a particular category compared with the corresponding baseline category, while controlling for other predictors and covariates, if applicable. The ORs corresponding to interaction terms can be interpreted as the multiplicative change in the OR of depression due to the presence of both the interaction categories compared with the absence of any one of the categories. For example, a value of OR 2 of an interaction term "A × B" indicates that the OR of depression in the presence of both the categories "A" and "B" is twice the OR of depression when exactly one of "A" or "B" is present.

Although the joint effects of hearing loss and tinnitus on depression were of interest, we also computed crude ORs of depression due to each of the primary variables and the covariates to find how the variables in the study individually affected the prevalence of depression.

RESULTS

Demographics

The descriptive statistics are reported in Table 1, in two parts. The top part contains the summary statistics for the numerical variables and the bottom part shows the estimated prevalence rates of the categories in different populations.

On the basis of the sampling weights, this study was estimated to be representative of a population of N = 144.4 million US noninstitutionalized civilians between the ages 20 and 69 years. From Table 1, the proportions of females and males were estimated to be, respectively, 48.5 and 51.5% of the population. The average age of the population was 43.7. The three most frequent races in the population were "Non-Hispanic White," estimated to be at 68.9%, followed by "Non-Hispanic Black" at 10.4%, and "Mexican American" at 7.6%.

Prevalence of Depression

Average PHQ-9 score was estimated to be 3.1, with a median score of 2.0 (Table 1). This indicated that the population had some very high PHQ-9 scores that pushed the average above the median. The prevalence of depression (PHQ-9 >9) was estimated to be 7.9% at the population level. The prevalence rates of depression were estimated to be 18.1% in the subpopulation of individuals experiencing "moderate or worse" speech frequency hearing loss, 17.3% among individuals experiencing one or more occurrences of tinnitus per month, 16.6% among those experiencing tinnitus for at least three months, and 17.0% among individuals

TABLE 1. Descriptive statistics: population summary statistics for the numerical variables and the estimated prevalence rates for the categories of the categorical variables in general population and different subpopulations of interest

	Population Summary Statistics					
Variable	Mean (95% CI)	Minimum	1st Quartile	Median	3rd Quartile	Maximum
PHQ-9 score	3.1 (2.9–3.3)	0.0	0.0	2.0	4.0	27.0
Speech PTA (dB)	11.6 (11.0–12.1)	–5.0	5.0	9.4	15.6	96.2
High PTA (dB)	24.0 (22.7–25.2)	–3.3	10.8	18.3	32.5	113.3
Age (yrs)	43.7 (42.8–44.6)	20.0	31.0	44.0	55.0	69.0
PIR	3.1 (2.9–3.3)	0.0	1.6	3.2	5.0	5.0

	Estimated Prevalence Rates in Different Populations						
	Sample Size (n = 5845)	% in Entire Pop. (95% CI)	% in Pop. With Depression (95% CI)	% in Pop. With Mod./Worse Speech HL (95% CI)	% in Pop. With ≥1 Occurrences of Tinnitus per Month (95% CI)	% in Pop. With Tinnitus for ≥3 mos (95% CI)	% in Pop. With Mod. to Big Tinnitus Problem (95% CI)
Depression							
Absent	5327	92.1 (91.0–93.2)	—	81.9 (68.9–91.1)	82.7 (78.8–86.2)	83.4 (80.0–86.4)	83.0 (79.1–86.5)
Present	518	7.9 (6.8–9.0)	—	18.1 (8.9–31.1)	17.3 (13.8–21.2)	16.6 (13.6–20.0)	17.0 (13.5–20.9)
Speech frequency HL							
No loss	5284	91.0 (89.7–92.2)	87.9 (83.3–91.6)	—	74.7 (69.6–79.4)	75.7 (70.7–80.2)	75.4 (70.1–80.3)
Mild loss	438	7.3 (6.3–8.4)	8.2 (5.2–12.2)	—	19.4 (15.1–24.3)	18.4 (14.4–23.0)	18.1 (13.8–23.2)
Mod./worse loss	123	1.7 (1.2–2.2)	3.9 (1.9–7.1)	—	5.9 (3.9–8.4)	5.9 (3.8–8.7)	6.4 (3.9–9.9)
High frequency HL							
No loss	3879	65.9 (62.9–68.9)	57.5 (52.0–62.8)	0.0	32.8 (28.1–37.7)	35.4 (30.6–40.3)	36.5 (31.0–42.3)
Mild loss	1003	16.9 (15.4–18.5)	19.7 (15.5–24.6)	0.0	23.1 (18.7–28.0)	23.2 (19.1–27.8)	22.3 (18.0–27.1)
Mod./worse loss	963	17.1 (15.2–19.2)	22.8 (17.9–28.2)	100.0	44.1 (39.0–49.3)	41.4 (36.4–46.5)	41.2 (36.1–46.4)
Tinnitus frequency							
Occasional	5158	86.6 (84.7–88.3)	70.5 (65.2–75.4)	53.5 (40.1–66.6)	—	15.8 (12.1–20.1)	13.0 (10.2–16.3)
Intermittent	320	5.5 (4.5–6.5)	14.7 (11.4–18.6)	23.9 (11.1–41.5)	—	32.4 (27.9–37.2)	33.7 (28.5–39.1)
Constant	367	7.9 (6.7–9.3)	14.8 (10.8–19.6)	22.5 (13.5–33.9)	—	51.8 (46.9–56.6)	53.3 (48.0–58.7)
Tinnitus duration							
Non-chronic	5075	85.0 (83.2–86.7)	68.1 (62.3–73.6)	47.5 (33.6–61.8)	5.5 (3.5–8.0)	—	8.3 (6.1–11.1)
New chronic	130	2.1 (1.5–2.8)	6.0 (3.5–9.7)	1.2 (0.3–3.6)	11.1 (7.8–15.1)	—	11.9 (8.6–15.9)
Chronic	640	13.0 (11.5–14.5)	25.8 (20.6–31.5)	51.2 (36.8–65.6)	83.5 (78.5–87.7)	—	79.8 (74.7–84.2)
Tinnitus problem							
No problem	5157	87.7 (86.1–89.1)	73.3 (67.4–78.7)	53.0 (38.8–66.9)	19.9 (15.4–25.0)	24.8 (20.2–29.9)	—
Mod. problem	602	11.0 (9.6–12.5)	21.9 (16.8–27.7)	41.9 (27.8–57.0)	70.8 (64.1–76.9)	66.7 (60.6–72.4)	—
Big problem	86	1.3 (0.9–1.9)	4.7 (2.3–8.5)	5.0 (2.0–10.2)	9.3 (6.5–12.8)	8.5 (5.9–11.8)	—
Age group							
20–29	1248	21.2 (18.8–23.7)	16.8 (13.2–20.9)	3.2 (0.1–15.8)	7.8 (5.9–10.1)	9.0 (6.8–11.5)	8.7 (6.7–11.0)
30–39	1204	19.3 (17.5–21.3)	19.8 (16.5–23.3)	6.4 (2.6–12.8)	12.1 (8.3–16.9)	13.1 (9.4–17.7)	14.0 (9.5–19.5)
40–49	1155	21.4 (19.7–23.3)	20.7 (16.4–25.5)	13.7 (4.5–29.4)	19.0 (15.1–23.5)	19.1 (15.7–22.9)	20.2 (16.2–24.7)
50–59	1159	21.9 (20.2–23.7)	27.8 (22.5–33.7)	19.0 (9.8–31.6)	34.7 (30.4–39.1)	33.3 (29.2–37.6)	31.6 (26.9–36.7)
60–69	1079	16.2 (14.6–17.9)	14.9 (10.4–20.4)	57.8 (44.3–70.5)	26.4 (21.9–31.3)	25.5 (20.6–30.8)	25.4 (20.5–30.9)
Gender							
Female	2747	48.5 (47.3–49.7)	63.1 (56.9–69.1)	32.2 (20.0–46.6)	43.3 (38.2–48.5)	44.5 (39.6–49.5)	46.6 (41.6–51.6)
Male	3098	51.5 (50.3–52.7)	36.9 (30.9–43.1)	67.8 (53.4–80.0)	56.7 (51.5–61.8)	55.5 (50.5–60.4)	53.4 (48.4–58.4)
Race							
NH White	2170	68.9 (63.0–74.4)	67.4 (58.4–75.4)	70.3 (56.9–81.5)	78.5 (72.1–84.1)	78.2 (72.1–83.4)	73.6 (66.6–79.8)
NH Black	1404	10.4 (7.5–13.8)	11.2 (7.2–16.4)	8.0 (4.0–14.0)	6.0 (3.8–9.1)	6.6 (4.0–10.1)	7.8 (4.9–11.5)
Mex. American	785	7.7 (5.2–10.8)	5.7 (3.5–8.7)	8.3 (3.4–16.5)	5.9 (3.4–9.4)	5.5 (3.2–8.7)	7.0 (4.2–10.9)
Other Hispanic	655	5.8 (4.0–8.2)	8.1 (4.8–12.8)	3.2 (0.9–7.7)	3.5 (2.2–5.3)	3.2 (2.0–4.8)	4.0 (2.4–6.1)
NH Asian	610	3.9 (2.7–5.4)	1.9 (1.0–3.4)	2.7 (0.9–6.1)	1.3 (0.7–2.2)	1.4 (0.8–2.3)	1.3 (0.7–2.3)
Other/multiracial	221	3.3 (2.7–4.0)	5.7 (3.2–9.4)	7.6 (1.8–19.6)	4.7 (2.7–7.5)	5.1 (2.9–8.4)	6.4 (3.8–9.9)
Education level							
<High school	1045	11.7 (9.4–14.3)	19.1 (14.3–24.6)	27.5 (16.3–41.3)	12.7 (8.9–17.3)	12.9 (9.3–17.2)	14.8 (10.4–20.3)
High school	1253	19.3 (17.2–21.6)	23.8 (19.8–28.1)	23.3 (11.8–38.8)	23.1 (17.5–29.5)	23.0 (18.1–28.5)	22.6 (17.7–28.3)
>High school	3547	69.0 (64.9–72.9)	57.1 (49.9–64.2)	49.1 (33.3–65.0)	64.2 (55.4–72.4)	64.1 (56.3–71.4)	62.5 (53.9–70.6)
PIR range							
0–1	1249	13.9 (11.8–16.3)	29.8 (24.6–35.4)	18.0 (11.2–26.8)	13.7 (10.5–17.4)	14.0 (10.6–18.0)	16.0 (12.6–19.9)
1–2	1471	19.0 (16.8–21.3)	29.9 (24.9–35.4)	27.6 (16.0–42.0)	22.1 (17.3–27.5)	20.9 (16.2–26.3)	21.6 (16.7–27.2)
2–3	906	15.0 (13.1–17.2)	15.5 (11.7–19.9)	17.2 (7.7–31.0)	12.6 (9.2–16.7)	12.9 (9.5–17.0)	13.2 (9.7–17.5)
3–4	627	12.3 (10.4–14.4)	5.9 (3.1–10.2)	5.3 (1.0–15.0)	10.8 (7.6–14.7)	11.4 (8.1–15.3)	10.8 (7.6–14.7)
4–5	502	11.8 (10.2–13.7)	6.9 (3.5–11.9)	5.3 (1.0–15.5)	12.5 (8.5–17.6)	13.5 (8.9–19.2)	11.5 (7.9–16.1)
>5	1090	28.0 (23.9–32.3)	12.0 (6.6–19.5)	26.6 (15.2–40.7)	28.3 (21.0–36.6)	27.3 (20.2–35.4)	26.8 (19.9–34.7)
Marital status							
Married/partner	3492	64.8 (61.6–68.0)	46.4 (40.8–52.0)	60.6 (45.5–74.4)	62.7 (57.6–67.6)	62.2 (56.9–67.4)	61.5 (56.1–66.7)
Sing./Div./Wid.	2353	35.2 (32.0–38.4)	53.6 (48.0–59.2)	39.4 (25.6–54.5)	37.3 (32.4–42.4)	37.8 (32.6–43.1)	38.5 (33.3–43.9)
Alcohol consumption							
No alcohol	3432	52.4 (48.9–55.8)	61.6 (55.1–67.9)	60.5 (45.0–74.5)	53.4 (45.5–61.1)	54.0 (46.4–61.5)	57.7 (49.0–66.0)
1–5 drinks/wk	2160	42.0 (39.0–45.1)	34.1 (28.4–40.2)	36.2 (22.7–51.6)	38.6 (31.6–46.0)	38.2 (31.1–45.7)	35.4 (27.5–43.9)
>5 drinks/wk	253	5.6 (4.7–6.6)	4.3 (2.2–7.3)	3.3 (0.6–9.8)	8.0 (6.0–10.5)	7.8 (5.9–10.1)	6.9 (4.9–9.4)

(*Continued*)

TABLE 1. Continued

	Sample Size (n = 5845)	% in Entire Pop. (95% CI)	% in Pop. With Depression (95% CI)	% in Pop. With Mod./Worse Speech HL (95% CI)	% in Pop. With ≥1 Occurrences of Tinnitus per Month (95% CI)	% in Pop. With Tinnitus for ≥3 mos (95% CI)	% in Pop. With Mod. to Big Tinnitus Problem (95% CI)
Smoking habit							
Irregular/former	4438	78.2 (76.1–80.3)	56.0 (48.3–63.5)	71.8 (61.2–80.9)	73.9 (68.9–78.5)	74.2 (69.5–78.4)	74.0 (69.0–78.5)
Regular	1407	21.8 (19.7–23.9)	44.0 (36.5–51.7)	28.2 (19.1–38.8)	26.1 (21.5–31.1)	25.8 (21.6–30.5)	26.0 (21.5–31.0)
Obesity							
Normal	1672	29.1 (26.4–31.9)	23.2 (18.9–28.0)	28.4 (16.5–42.8)	22.5 (17.9–27.6)	23.8 (19.2–29.0)	21.7 (17.7–26.1)
Underweight	55	0.9 (0.6–1.2)	1.7 (0.7–3.6)	0.0	0.4 (0.0–1.9)	0.4 (0.0–1.7)	0.4 (0.0–2.1)
Overwgt./Obese	4118	70.1 (67.1–72.9)	75.0 (70.2–79.4)	71.6 (57.2–83.5)	77.1 (71.8–81.8)	75.8 (70.6–80.4)	77.9 (73.4–82.0)
Vision impairment							
Absent	5212	91.5 (90.0–92.9)	75.9 (70.2–81.0)	89.5 (81.7–94.8)	82.5 (77.3–86.8)	83.4 (79.0–87.2)	81.6 (76.5–86.1)
Present	633	8.5 (7.1–10.0)	24.1 (19.0–29.8)	10.5 (5.2–18.3)	17.5 (13.2–22.7)	16.6 (12.8–21.0)	18.4 (13.9–23.5)
Cardiovascular disease							
Absent	5566	96.0 (95.5–96.5)	90.2 (86.4–93.3)	86.1 (73.3–94.2)	91.1 (88.5–93.2)	91.7 (89.5–93.5)	91.6 (89.1–93.7)
Present	279	4.0 (3.5–4.5)	9.8 (6.7–13.6)	13.9 (5.8–26.7)	8.9 (6.8–11.5)	8.3 (6.5–10.5)	8.4 (6.3–10.9)
Cancer							
Absent	5498	92.4 (91.5–93.2)	91.4 (87.5–94.3)	92.2 (84.0–97.0)	87.8 (84.3–90.8)	89.0 (85.9–91.6)	89.1 (85.5–92.1)
Present	347	7.6 (6.8–8.5)	8.6 (5.7–12.5)	7.8 (3.0–16.0)	12.2 (9.2–15.7)	11.0 (8.4–14.1)	10.9 (7.9–14.5)
Diabetes							
Absent	4695	83.1 (81.4–84.7)	71.0 (64.5–76.9)	66.9 (52.9–79.0)	72.1 (67.0–76.9)	73.6 (68.4–78.4)	73.9 (69.3–78.2)
Present	1150	16.9 (15.3–18.6)	29.0 (23.1–35.5)	33.1 (21.0–47.1)	27.9 (23.1–33.0)	26.4 (21.6–31.6)	26.1 (21.8–30.7)
Hypertension							
Absent	4189	74.5 (72.3–76.5)	64.3 (58.7–69.6)	52.8 (39.9–65.5)	59.6 (53.1–65.9)	60.5 (54.3–66.5)	59.2 (53.6–64.7)
Present	1656	25.5 (23.5–27.7)	35.7 (30.4–41.3)	47.2 (34.5–60.1)	40.4 (34.1–46.9)	39.5 (33.5–45.7)	40.8 (35.3–46.4)

Underweight = BMI ≤ 18, normal = 18 < BMI ≤ 25, overweight/obese = BMI >25. Vision impairment is present if a participant is having trouble seeing to serious difficulty seeing. Diabetes is present if a participant was taking insulin or sugar pills for diabetes. Hypertension is present if a participant was told at least twice if they had hypertension or if they were taking medication for it. CI, confidence interval; HL, hearing loss; NH, Non-Hispanic; PHQ-9 score, sum of individual scores of 9 questions from Patient Health Questionnaire for depression; PIR, poverty income ratio.

having "moderate" to "big" tinnitus problems. Higher prevalence rates of depression in individuals with hearing loss or tinnitus suggested a plausible association in the general population.

In the subpopulation of individuals with depression, 63.1% were estimated to be females, whereas the proportion of females was 48.5% in the general population. This suggested a higher incidence rate of depression in females. The age group "50 to 59" was estimated to be 27.8% in the depression subpopulation, but their proportion in the general population was 21.9%. The proportions of the other age groups in the same subpopulation were close to or marginally lower than their proportions in the general population. The races non-Hispanic Black, other Hispanic, and other/multiracial had 1 to 2% higher proportions in the depressed subpopulation than the general population. The categories education "up to high school," PIR lower than 3, "single or divorced or widowed," "non-alcoholic," "regular" smoker, visually impaired, presence of cardiovascular disease, diabetes, and hypertension were estimated to have notably higher proportions in the depressed subpopulation compared with the general population. The prevalence of depression was found to be affected by a majority of the demographic, lifestyle, and health factors considered in the study.

Prevalence of Hearing Loss

The average speech frequency PTA was estimated to be 11.6 dB in the general population and the average high frequency PTA was 24.0 dB (Table 1). The estimated median speech and high frequency PTA were 9.4 and 18.3 dB, respectively. Lower values of medians than the means suggested that there were a few large observations in both speech and high frequency PTA. Almost 1.7% of the population was estimated to experience "moderate or worse" speech frequency hearing loss. The proportion was 17.1% for high frequency hearing loss.

The prevalence of "moderate or worse" speech frequency hearing loss was estimated to be 3.9% in the depression subpopulation and the same for high frequency hearing loss was 22.8%. In the subpopulations experiencing one or more occurrences of tinnitus per month, experiencing tinnitus for 3 months or more, and facing "moderate" to "big" problems due to tinnitus, the prevalence rates of "moderate or worse" speech frequency hearing loss were estimated to be 5.9%, 5.9%, and 6.4%, respectively. These increases in the prevalence rates of "moderate or worse" speech frequency hearing loss in the depressed subpopulation and the different tinnitus subpopulations compared with the general population indicated a plausible dependence between the measures. The increases were more drastic for high frequency hearing loss.

We observed some interesting patterns between hearing loss and the covariates. The proportion of individuals aged 60 to 69 in the subpopulation with "moderate or worse" speech frequency hearing loss was 57.8%, much higher than their proportion of 16.2% in the general population. Estimated proportions of the gender "male," the race "other or multiracial," individuals with education "less than high school," individuals with PIR ranging from 0 to 2, "regular" smoker, individuals with vision impairment, cardiovascular disease, diabetes, and hypertension in the same subpopulation were much higher than their general population estimates. Most of the covariates in this study had some effects on speech frequency hearing loss.

Prevalence of Tinnitus

We used three different measures of tinnitus, based on the frequency, duration, and the severity of problems faced due to tinnitus. Prevalence rates of "constant" tinnitus frequency, "chronic" tinnitus duration, and "big" tinnitus problem were estimated as 7.9%, 13.0%, and 1.3%, respectively, in the general population (Table 1). In the depressed subpopulation, the proportions of "constant" tinnitus frequency, "chronic" tinnitus duration, and "big" tinnitus problem increased to 14.8%, 25.8%, and 4.7%, respectively. In the "moderate or worse" speech frequency hearing loss subpopulation, the prevalence rates were 22.5%, 51.2%, and 5.0% for "constant" tinnitus frequency, "chronic" tinnitus duration, and "big" tinnitus problem, respectively.

In the subpopulations of individuals with one or more occurrences of tinnitus per month, experiencing tinnitus for more than 3 months, and facing "moderate" to "big" tinnitus problems, the proportions of individuals aged 50 or more, the gender "male," the race "non-Hispanic White," individuals with education "up to high school," "regular" smokers, "overweight or obese" individuals, and individuals with cardiovascular disease, cancer, diabetes, and hypertension were much higher than their proportions in the general population.

We were particularly interested in investigating if any race was more susceptible to tinnitus. We reported the estimated prevalence rates of tinnitus measures in different racial subpopulations in Table S1 in Supplemental Digital Content, http://links.lww.com/EANDH/B289. From Table S1 in Supplemental Digital Content, http://links.lww.com/EANDH/B289, the estimated proportions of individuals facing big tinnitus problem was 0.2% for "non-Hispanic Asians," and the same for the other races were between 1 and 3.2%. The highest proportions were for "other or multiracial" subpopulation and "other Hispanic" subpopulation. The same patterns but with higher proportions were observed for the prevalence rates of "chronic" tinnitus frequency and "constant" tinnitus duration across different races.

Associations Among Primary Measures

We reported all the measures of associations in Table 2.

From Table 2, PHQ-9 score was significantly correlated with high frequency PTA, with negligibly small p values. However, the correlation coefficients were very low at 0.07. t-Test for correlation suffers from overreporting significance like Chi-squared test on a large data. We computed H_{vol} between depression and the categorized speech and high frequency hearing loss measures along with H_{vol} of depression and the tinnitus measures.

From the second part of Table 2, depression was strongly associated with both speech and high frequency hearing loss with H_{vol} values 0.73 and 0.82, respectively. Depression was very strongly associated with tinnitus frequency with H_{vol} = 0.95, but weakly associated with tinnitus duration and tinnitus problem. Speech frequency hearing loss was strongly associated with the tinnitus measures with H_{vol} values exceeding 0.50. Overall, both the hearing loss variables and at least one of the tinnitus variables were strongly associated with depression.

We noted that speech and high frequency PTA were very strongly correlated with a correlation coefficient of 0.78. We also noted that all the participants with moderate or worse speech frequency hearing loss suffered from high frequency hearing loss as well (Table 1). Hence, we discarded high frequency hearing loss only from the logistic regression analysis in the upcoming sections to avoid the problem of multicollinearity. Also note that speech frequency PTA is more widely used and clinically accepted and there is no consensus on the metrics that should be used to characterize high frequency hearing as our understanding of it is comparatively limited. For the same reason, we only included tinnitus problem in the logistic regression analysis as we were most interested in the functional impact of tinnitus on depression.

Associations Among Primary Measures and Covariates

From Pearson correlations in Table 2, there was a significantly negative correlation between PHQ-9 score and PIR, but there was no significant correlation with age. Both speech and high frequency PTA were significantly correlated with both age and PIR. (Note that the multicollinearity between speech and high frequency PTA is not a concern for H_{vol} analysis and they are included as separate factors in this analysis.) The correlations were positive between age and speech or high frequency PTA. PIR was negatively correlated with speech frequency PTA, but positively correlated with high frequency PTA.

Overall, all the primary measures were at least moderately associated with most of the covariates based on the H_{vol} measures. The prevalence of depression was most strongly associated with age group and cardiovascular disease (H_{vol} = 0.83), followed by marital status, race, and hypertension. Speech frequency hearing loss was most strongly associated with age group (H_{vol} = 0.99), followed by PIR range, diabetes, and obesity. In contrast, the strongest association for high frequency hearing loss was observed with education level (H_{vol} = 0.99), followed by gender, race, and age group. Both the hearing loss were at least moderately associated with most of the demographic, lifestyle, and health factors. Speech frequency hearing loss displayed overall higher H_{vol} values with the health factors, whereas high frequency hearing loss observed higher H_{vol} values for demographic and lifestyle factors. Tinnitus frequency was most strongly associated with smoking habit (H_{vol} = 0.99), tinnitus duration with alcohol consumption (H_{vol} = 0.95), and tinnitus problem with marital status (H_{vol} = 0.93). All the demographic, lifestyle, and health factors except vision impairment were moderate to strongly associated with at least one of the tinnitus measures.

Logistic Regression Models

The crude and covariate adjusted ORs of depression due to hearing loss, tinnitus, and their interactions along with their 95% CIs were reported in Table 3. We also reported the crude ORs of depression due to the individual effects from the primary variables and the covariates in Table S2 in Supplemental Digital Content, http://links.lww.com/EANDH/B290.

Individual Effects of the Primary Variables and the Covariates on Depression

From Table S2 in Supplemental Digital Content, http://links.lww.com/EANDH/B290, speech frequency hearing loss, high frequency hearing loss, tinnitus frequency, duration, and problem were observed to significantly affect the prevalence of depression in the general population. The category "moderate or worse" speech frequency hearing loss had the highest impact on depression (crude OR = 2.7) among the hearing loss variables. Similarly, the category "big" tinnitus problem had the most impact on depression (crude OR = 5.5) among all the tinnitus variables. All covariates, except the presence of cancer, had at least one category

TABLE 2. Association measures between the variables of primary interest and the covariates

Measure of Association	Variable Pairs					
	Numerical-Numerical Pairs					
Pearson correlation	PHQ-9 score	Speech PTA	HighFreq PTA			
Speech frequency PTA	0.09	—	—			
High frequency PTA	0.07*	0.78*	—			
Age	0.01	0.50*	0.63*			
PIR	−0.25*	−0.03*	0.04*			
	Numerical-Categorical/Categorical-Categorical Pairs					
H_{vol}	Depression	Speech Freq. HL	High Freq. HL	Tinnitus frequency	Tinnitus duration	Tinnitus problem
Depression	—	—	—	0.95†	0.03	0.10
Speech frequency HL	0.73†	—	—	0.50†	0.60†	0.52†
High frequency HL	0.82†	—	—	0.61†	0.16	0.53†
Age group	0.83†	0.99†	0.75†	0.10	0.24‡	0.63†
Gender	0.10	0.10	0.87†	0.80†	0.64†	0.32‡
Race	0.63†	0.53†	0.77†	0.68†	0.19	0.72†
Education level	0.07	0.78†	0.99†	0.98†	0.51†	0.77†
PIR range	0.35‡	0.96†	0.73†	0.32‡	0.24‡	0.33‡
Marital status	0.73†	0.54†	0.34‡	0.77†	0.08	0.93†
Alcohol consumption	0.07	0.70†	0.72†	0.41‡	0.95†	0.53†
Smoking habit	0.15	0.19	0.43‡	0.99†	0.09	0.68†
Obesity	0.60†	0.88†	0.01	0.02	0.57†	0.28‡
Vision impairment	0.50†	0.28‡	0.55†	0.09	0.10	0.15
Cardiovascular disease	0.83†	0.62†	0.36‡	0.66†	0.64†	0.78†
Cancer	0.20‡	0.64†	0.44‡	0.95†	0.17	0.17
Diabetes	0.41‡	0.96†	0.41‡	0.51†	0.56†	0.64†
Hypertension	0.62†	0.87†	0.69†	0.41‡	0.33‡	0.12

**Pearson correlations had p value for corresponding t test less than 0.05.*
†A strong association for H_{vol}.
‡A moderate association for H_{vol}.
PHQ-9 score, sum of individual scores of 9 questions from Patient Health Questionnaire for depression; PIR, poverty income ratio; PTA, pure-tone audiometry.

that had a significant effect on depression. However, these ORs were not indicative of how the primary variables jointly affected the odds of reported depression in the presence or absence of the relevant demographic, lifestyle, and health factors.

Combined Effects of Hearing Loss, Tinnitus, and Their Interactions on Depression

ORs Estimated on the Entire Population • On the basis of the findings presented in Table 3, several predictors were significant indicators of depression based on the crude ORs. Notably, the categories "moderate or worse" speech frequency hearing loss, "moderate" tinnitus problem, "big" tinnitus problem, and the interaction between "moderate or worse" speech frequency hearing loss and "moderate" tinnitus problem were all significant.

Individuals with "moderate or worse" speech frequency hearing loss exhibited 4.2 times higher odds of reporting depression compared with those with "no loss." Similarly, individuals experiencing "moderate" and "big" tinnitus problems had 3.1 and 4.5 times greater likelihood, respectively, of reporting depression compared with individuals without tinnitus issues. The crude ORs for the interaction terms indicated the presence of an interaction effect between hearing loss and tinnitus problem on depression. Notably, the presence of "moderate" tinnitus problem reduced the effects on depression due to "mild" and "moderate or worse" hearing loss by a factor of 0.5 and 0.1, respectively. Furthermore, the presence of "big" tinnitus problem amplified the effect of "mild" hearing loss on depression by 1.5 times, while decreasing the effect of "moderate or worse" hearing loss by a factor of 0.9. Similarly, "mild" hearing loss reduced the effect of "moderate" tinnitus problem on depression by half but increased the effect of "big" tinnitus problem by 1.5 times. Furthermore, the presence of "moderate or worse" hearing loss diminished the effects of "moderate" and "big" tinnitus problems on depression by the factors of 0.1 and 0.9, respectively.

After adjusting for the demographic, lifestyle, and health factors, the ORs displayed a largely consistent pattern with the crude ORs. However, the category of "big" tinnitus problem was no longer a significant predictor. The adjusted OR for depression associated with "moderate or worse" hearing loss was 3.0, while for "moderate" tinnitus problem, it was 2.2. The interaction effects remained present even after accounting for the effects of the covariates. The presence of "moderate" tinnitus problem reduced the effects on depression due to "mild" and "moderate or worse" hearing loss by a factor of 0.7 and 0.2, respectively. Conversely, the presence of "big" tinnitus problem increased the effects of "mild" and "moderate or worse" hearing loss on depression by 3.7 and 1.9 times, respectively. Similarly, "mild" hearing loss diminished the effect of "moderate" tinnitus problem on depression by a factor of 0.7 but increased the effect of "big" tinnitus problem by 3.7 times. Furthermore, the presence of "moderate or worse" hearing loss reduced the effect of "moderate" tinnitus problem on depression by a factor of 0.2 but increased the effect of "big" tinnitus problem by 1.9 times.

In summary, both speech frequency hearing loss and tinnitus problem were significant predictors of depression, even after adjusting for the relevant demographic, lifestyle, and health

TABLE 3. Crude and covariates adjusted OR with 95% CI from logistic regression models of depression on speech frequency hearing loss, tinnitus problem, and their interactions in the entire population and in the subpopulations stratified with respect to speech frequency hearing loss and tinnitus problem

Variable	Crude OR of Depression (95% CI)	Covariates Adjusted OR of Depression (95% CI)
Estimates for the entire population (based on a sample of n = 5845)		
Speech frequency hearing loss		
No loss	Baseline	Baseline
Mild loss	1.1 (0.6–2.0)	0.9 (0.4–1.8)
Moderate/worse loss	4.2 (1.7–10.3)*	3.0 (1.5–6.1)*
Tinnitus problem		
No problem	Baseline	Baseline
Moderate problem	3.1 (2.3–4.1)*	2.2 (1.6–2.9)*
Big problem	4.5 (2.1–9.6)*	2.4 (0.7–8.2)
Speech Frequency Hearing Loss × Tinnitus Problem Interaction		
Mild Loss × Moderate Problem	0.5 (0.2–1.3)	0.7 (0.3–1.7)
Moderate/Worse Loss × Moderate Problem	0.1 (0.1–0.4)*	0.2 (0.1–0.7)*
Mild Loss × Big Problem	1.5 (0.3–6.7)	3.7 (0.7–20.4)
Moderate/Worse Loss × Big Problem	0.9 (0.2–4.2)	1.9 (0.3–12.4)
Estimates for the subpopulation with no speech frequency hearing loss (based on a sample of n = 5284)		
Tinnitus problem		
No problem	Baseline	Baseline
Moderate problem	3.1 (2.3–4.1)*	2.2 (1.6–2.9)*
Big problem	4.5 (2.1–9.6)*	2.4 (0.8–7.8)
Estimates for the subpopulation with mild to moderate or worse speech frequency hearing loss (based on a sample of n = 561)		
Tinnitus problem		
No problem	Baseline	Baseline
Moderate problem	1.1 (0.5–2.3)	1.1 (0.6–2.1)
Big problem	5.7 (1.4–22.7)*	14.9 (3.3–68.4)*
Estimates for the subpopulation with no tinnitus problem (based on a sample of n = 5157)		
Speech frequency hearing loss		
No loss	Baseline	Baseline
Mild loss	1.1 (0.6–2.0)	0.8 (0.4–1.8)
Moderate/worse loss	4.2 (1.7–10.3)*	3.0 (1.6–5.7)*
Estimates for the subpopulation with moderate to big tinnitus problem (based on a sample of n = 688)		
Speech frequency hearing loss		
No loss	Baseline	Baseline
Mild loss	0.7 (0.4–1.3)	0.8 (0.5–1.6)
Moderate/worse loss	0.7 (0.4–1.4)	0.7 (0.3–1.3)

**The significant odds ratios.*
CI, confidence interval; OR, odds ratio.

factors. Adjusting for the covariates, having either speech frequency hearing loss or "big" tinnitus problem amplified the effect of the other predictor on depression. However, the presence of one of speech frequency hearing loss or "moderate" tinnitus diminished the effect of the other. Notably, when some speech frequency hearing loss was present, the chances of reporting depression were less for individuals with "moderate" tinnitus, but more for individuals with "big" tinnitus.

ORs Estimated on the Hearing Loss Subpopulations • Tinnitus problem, alone, was a significant predictor of depression, both in the presence or absence of speech frequency hearing loss based on the crude ORs. Both the categories of "moderate" and "big" tinnitus problem had significant effects on depression when "no" speech frequency hearing loss was present. In the presence of "mild" to "moderate or worse" hearing loss, only "big" tinnitus problem was significant. Having speech frequency hearing loss reduced the OR of depression with "moderate" tinnitus problem from 3.1 to 1.1, while increasing the same with "big" tinnitus problem from 4.5 to 5.7.

After adjusting for covariates, only "moderate" tinnitus problem was significant predictor of depression when no hearing loss was present, and "big" tinnitus problem was significant when hearing loss was present. The OR of depression with "moderate" tinnitus problem reduced from 2.2 to 1.1, but with "big" tinnitus problem increased from 2.4 to 14.9.

ORs Estimated on the Tinnitus Subpopulations • Only the category "moderate or worse" speech frequency hearing loss was a significant predictor of depression when "no" tinnitus problem was present, based on both the crude and covariates adjusted ORs. However, in the presence of "moderate" to "big" tinnitus problem, none of the categories of speech frequency hearing loss were significant from either models. The presence of some tinnitus problem decreased the crude ORs of depression with "moderate or worse" hearing loss from 4.2 to 0.7, and the covariates adjusted ORs from 3.0 to 0.7. Overall, the presence of tinnitus problem minimized the chances of reporting depression due to hearing loss.

DISCUSSION

The goal of this article was to parse out the unique contributions of hearing loss and tinnitus, two commonly co-occurring conditions with depression in a population study. There were strong associations among depression, hearing loss, and tinnitus. Individually, both hearing loss and the severity of the problems due to tinnitus were significant predictors of depression and the presence of these conditions significantly increased the odds of depression. In addition, each of the factors such as age, gender, race, education level, PIR, marital status, alcohol consumption, smoking habit, the presence of vision impairment, cardiovascular diseases, diabetes, or hypertension had significant effects by themselves on the likelihood of an individual reporting depression as observed in Table S2 in Supplemental Digital Content, http://links.lww.com/EANDH/B290. When adjusted for the effects of covariates using logistic regression model, hearing loss, tinnitus, and their interaction still significantly increased the odds of reported depression in the general population. In each of the subpopulations with hearing loss and tinnitus, the presence of one significantly influenced the effect of the other on depression.

Discussion on Tinnitus

Our study provides evidence for the contribution of both hearing loss and tinnitus to depression. But what are the possible links? Hearing loss has been found to increase the risk of having depression, as noted by other studies analyzing various NHANES datasets (Li et al. 2014; Scinicariello et al. 2019), but the evidence for contribution of tinnitus to depression in some cases is new in this dataset. Tinnitus is not only the presence of an intrusive sound, but also the psychological impact of having such sound (Tyler 2006). The psychological impact varies from mild to bothersome, and negatively affects sleep, concentration, and communication. It has been previously noted that the prevalence of anxiety and depression is higher in this group than in the general population (Pinto et al. 2014). Our findings provide support for previously published studies that have noted this high comorbidity between tinnitus and depression. But few have noted, as our study finds, that the likelihood of depression in the general population increases if an individual has tinnitus, increasing with worsening severity of tinnitus symptoms.

But these findings may not be surprising if we consider some of the more efficacious interventions for tinnitus. Cognitive behavior therapy and mindfulness-based cognitive behavior therapy, which were developed to treat depression and other mental-health conditions, have been effective in managing bothersome tinnitus (Tunkel et al. 2014; McKenna et al. 2017). Our findings do suggest that treatment of tinnitus may be beneficial in decreasing overall depressive symptoms in adults with tinnitus. These may take the form of amplification and other sound therapies that have been found effective in treating the communication and attentional challenges associated with tinnitus (Searchfield et al. 2010) and therefore also ameliorate the associated depression, if any.

Race and Ethnicity

Race and ethnicity have not been considered often in prevalence studies of hearing loss or tinnitus within the United States. When a few studies have considered it, there has not been significant difference in prevalence rates of either condition by racial or ethnic categories (Davanipour et al. 2000; Cruickshanks et al. 2015). In our own study, we focused on the proportion of bothersome ("big problem") tinnitus among the different racial/ethnic groups. We found that except for non-Hispanic Asian Americans, the proportion of those reporting bothersome tinnitus varied between 1.2 and 2.3%, with "other Hispanic" and "other/multiracial" categories reporting at the higher end. The most relevant study in this context is the Shargorodsky et al. (2010) study, which also examined NHANES datasets, but from years 1999–2004. They found that non-Hispanic Whites had increased odds of reporting tinnitus relative to non-Hispanic Blacks and Hispanics. The study, unlike ours, did not report on the difference in prevalence rates of bothersome tinnitus.

Race and ethnicity appear to have an impact on cognitive performance in individuals with tinnitus (separate from the impact of hearing loss or depression) and therefore it may be a relevant risk factor to study. In a recent study (Hamza & Zeng 2021), the authors found differences in the impact of tinnitus on cognitive performance based on ethnic categories. Non-Hispanic Whites with tinnitus exhibit improved performance relative to similarly aged older adults without tinnitus, but this advantage is not evident in Hispanic Americans. The authors suggest that the effect of hearing loss without tinnitus on cognition may be higher than that of hearing loss accompanied by tinnitus, although, this appears to vary by ethnicity. Both population studies and careful audiological, psychological, and imaging studies examining potential differences at a mechanistic level are needed to parse out any disparate impact of tinnitus on racial and ethnic groups.

Discussion on Hearing Loss

Our findings that speech frequency hearing loss was a prominent variable in affecting depression is not surprising. Given that being unable to hear speech well may lead to social isolation and reclusiveness (Mick et al. 2014), social disconnect may lead to feelings of loneliness and depression. Because NHANES uses PTA to establish hearing ability rather than only self-reported hearing handicap, we were able to establish that speech frequency PTA is linked to depression even when other important covariates are controlled. Future studies that investigate multicomorbid associations more systematically with better characterization of hearing, tinnitus, and depression either by using brain imaging or including genetic data, are needed to clarify these associations. Amelioration strategies aimed at improving speech communication via amplification and aural rehabilitation may be useful in not just addressing hearing challenges but may also be useful to reduce the incidence of depression in those with hearing loss.

The Additive Effect of Tinnitus and Hearing Loss on Depression

Studies (Ratnayake et al. 2009; Mazurek et al. 2010) have previously noted that the degree of hearing loss contributes to the severity of tinnitus. Our study extends this finding by making the connection not only with tinnitus severity but also with depression. In addition, we have described the impact of tinnitus on the contribution of hearing loss as a risk factor for depression.

In general, the combined presence of tinnitus and hearing loss significantly increased the odds of an individual reporting depression. When speech hearing loss was considered as the primary condition, adding tinnitus reduced contribution of the hearing loss to the odds of reporting depression (the OR decreasing from 3.0 to 0.7). It appears that any risk of depression was explained almost entirely by the comorbid tinnitus, rather than the primary condition of hearing loss. Thus, any handicap perceived due to moderate speech frequency hearing loss is overshadowed by the presence of chronic tinnitus. A person may be aware of their hearing loss only when communicating or listening to relevant stimuli, whereas chronic tinnitus may play a constant salient role in their lives and thus, contribute more to depression. It is interesting that when tinnitus was considered to be the primary condition, the presence of secondary speech frequency hearing loss magnified the effect of tinnitus on depression several times over (the OR increasing from 2.4 to 14.9).

LIMITATIONS

There are several limitations of the study, primarily the narrow focus of the study precludes investigation of other factors that may impact depression. For instance, vision impairment by itself may be a contributory factor. Here, our focus was on the comorbidity of tinnitus, hearing loss, and depression. Further, because these conditions co-occur does not necessarily imply a common causal link in their occurrence, but it does suggest that their amelioration may be linked. The entire analysis was done through post hoc data collection, which, from a statistical point of view, may impact the causality among the variables of interest. A properly designed experiment must be conducted before collecting the data to investigate the associations and directions of causality among the measures of interest. Results from this analysis provide a basis to design a sampling scheme and an analysis plan before collecting the data for future experiments investigating conclusive links between hearing disorders and depression adjusting for the relevant comorbidities and demographic, health, and lifestyle factors.

CONCLUSION

Our findings underscored the additive effect of tinnitus and hearing loss on depression, while also finding that individually each of these conditions contributed significantly to having depression. Both hearing loss and tinnitus significantly increased the risk of experiencing depression, even after controlling for the important demographic, lifestyle, and health factors. The results highlight the importance of managing hearing loss and bothersome tinnitus, which may in turn decrease the odds of reporting depression.

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REFERENCES

Bartels, H., Middel, B. L., van der Laan, B. F. A. M., Staal, M. J., Albers, F. W. J. (2008). The additive effect of co-occurring anxiety and depression on health status, quality of life and coping strategies in help-seeking tinnitus sufferers. *Ear Hear*, *29*, 947–956.

Brewster, K. K., Ciarleglio, A., Brown, P. J., Chen, C., Kim, H.-O., Roose, S. P., Golub, J. S., Rutherford, B. R. (2018). Age-related hearing loss and its association with depression in later life. *Am J Geriatr Psychiatry*, *26*, 788–796.

Chen, Y., Lin, C.-H., Sabatti, C. (2006). Volume measures for linkage disequilibrium. *BMC Genet*, *7*, 54.

Cruickshanks, K. J., Dhar, S., Dinces, E., Fifer, R. C., Gonzalez, F., Heiss, G., Hoffman, H. J., Lee, D. J., Newhoff, M., Tocci, L., Torre, P., Tweed, T. S. (2015). Hearing impairment prevalence and associated risk factors in the Hispanic Community Health Study/Study of Latinos. *JAMA Otolaryngol Head Neck Surg*, *141*, 641–648.

Davanipour, Z., Lu, N., Lichtenstein, M., Markides, K. (2000). Hearing problems in Mexican American elderly. *Am J Otolaryngol*, *21*, 168–172.

Golub, J. S., Brewster, K. K., Brickman, A. M., Ciarleglio, A. J., Kim, A. H., Luchsinger, J. A., Rutherford, B. R. (2019). Association of audiometric age-related hearing loss with depressive symptoms among Hispanic individuals. *JAMA Otolaryngol Head Neck Surg*, *145*, 132–139.

Gopinath, B., Wang, J. J., Schneider, J., Burlutsky, G., Snowdon, J., McMahon, C. M., Leeder, S. R., Mitchell, P. (2009). Depressive symptoms in older adults with hearing impairments: The Blue Mountains Study. *J Am Geriatr Soc*, *57*, 1306–1308.

Hamza, Y., & Zeng, F.-G. (2021). Tinnitus is associated with improved cognitive performance in non-Hispanic elderly with hearing loss. *Front Neurosci*, *15*, 735950.

Henry, J. A., Griest, S., Austin, D., Helt, W., Gordon, J., Thielman, E., Theodoroff, S. M., Lewis, M. S., Blankenship, C., Zaugg, T. L., Carlson, K. (2016). Tinnitus screener: Results from the first 100 participants in an Epidemiology Study. *Am J Audiol*, *25*, 153–160.

Hsu, W.-T., Hsu, C.-C., Wen, M.-H., Lin, H.-C., Tsai, H.-T., Su, P., Sun, C.-T., Lin, C.-L., Hsu, C.-Y., Chang, K.-H., Hsu, Y.-C. (2016). Increased risk of depression in patients with acquired sensory hearing loss. *Medicine (Baltimore)*, *95*, e5312.

Jarach, C. M., Lugo, A., Scala, M., van den Brandt, P. A., Cederroth, C. R., Odone, A., Garavello, W., Schlee, W., Langguth, B., Gallus, S. (2022). Global prevalence and incidence of tinnitus: A systematic review and meta-analysis. *JAMA Neurol*, *79*, 888–900.

Joo, Y.-H., Han, K., Park, K. H. (2015). Association of hearing loss and tinnitus with health-related quality of life: The Korea National Health and Nutrition Examination Survey. *PLoS One*, *10*, e0131247.

Kim, H.-J., Lee, H.-J., An, S.-Y., Sim, S., Park, B., Kim, S. W., Lee, J. S., Hong, S. K., Choi, H. G. (2015). Analysis of the prevalence and associated risk factors of tinnitus in adults. *PLoS One*, *10*, e0127578.

Kroenke, K., Spitzer, R. L., Williams, J. B. W. (2001). The PHQ-9: Validity of a brief depression severity measure. *J Gen Intern Med*, *16*, 606–613.

Lawrence, B. J., Jayakody, D. M. P., Bennett, R. J., Eikelboom, R. H., Gasson, N., Friedland, P. L. (2020). Hearing loss and depression in older adults: A systematic review and meta-analysis. *Gerontologist*, *60*, e137–e154.

Lee, A. T. H., Tong, M. C. F., Yuen, K. C. P., Tang, P. S. O., Vanhasselt, C. A. (2010). Hearing impairment and depressive symptoms in an older Chinese population. *J Otolaryngol Head Neck Surg*, *39*, 498–503.

Li, C.-M., Zhang, X., Hoffman, H. J., Cotch, M. F., Themann, C. L., Wilson, M. R. (2014). Hearing impairment associated with depression in US Adults, National Health and Nutrition Examination Survey 2005-2010. *JAMA Otolaryngol Head Neck Surg*, *140*, 293–302.

Lin, M., Lucas, H. C., Shmueli, G. (2013). Research commentary—Ttoo big to fail: Large samples and the p-value problem. *Inf Syst Res*, *24*, 906–917.

Lumley, T. (2004). Analysis of complex survey samples. *J Stat Softw*, *9*, 1–19.

Mazurek, B., Olze, H., Haupt, H., Szczepek, A. J. (2010). The more the worse: The grade of noise-induced hearing loss associates with the severity of tinnitus. *Int J Environ Res Public Health*, *7*, 3071–3079.

McKenna, L., Marks, E. M., Hallsworth, C. A., Schaette, R. (2017). Mindfulness-based cognitive therapy as a treatment for chronic tinnitus: A randomized controlled trial. *Psychother Psychosom*, *86*, 351–361.

Mener, D. J., Betz, J., Genther, D. J., Chen, D., Lin, F. R. (2013). Hearing loss and depression in older adults. *J Am Geriatr Soc*, *61*, 1627–1629.

Mick, P., Kawachi, I., Lin, F. R. (2014). The association between hearing loss and social isolation in older adults. *Otolaryngol Head Neck Surg*, *150*, 378–384.

NCHS. *NHANES Survey Design and Analytic Guideline*. https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx

Pinto, P. C. L., Marcelos, C. M., Mezzasalma, M. A., Osterne, F. J., de Melo Tavares de Lima, M. A., Nardi, A. E. (2014). Tinnitus and its association with psychiatric disorders: Systematic review. *J Laryngol Otol*, *128*, 660–664.

Pronk, M., Deeg, D. J. H., Smits, C., Twisk, J. W., van Tilburg, T. G., Festen, J. M., Kramer, S. E. (2014). Hearing loss in older persons. *J Aging Health*, *26*, 703–723.

Pronk, M., Deeg, D. J. H., Smits, C., van Tilburg, T. G., Kuik, D. J., Festen, J. M., Kramer, S. E. (2011). Prospective effects of hearing status on loneliness and depression in older persons: Identification of subgroups. *Int J Audiol*, *50*, 887–896.

Ratnayake, S. A. B., Jayarajan, V., Bartlett, J. (2009). Could an underlying hearing loss be a significant factor in the handicap caused by tinnitus? *Noise Health*, *11*, 156–160.

Scinicariello, F., Przybyla, J., Carroll, Y., Eichwald, J., Decker, J., Breysse, P. N. (2019). Age and sex differences in hearing loss association with depressive symptoms: Analyses of NHANES 2011–2012. *Psychol Med*, *49*, 962–968.

Searchfield, G. D., Kaur, M., Martin, W. H. (2010). Hearing aids as an adjunct to counseling: Tinnitus patients who choose amplification do better than those that don't. *Int J Audiol*, *49*, 574–579.

Shargorodsky, J., Curhan, G. C., Farwell, W. R. (2010). Prevalence and characteristics of tinnitus among US adults. *Am J Med*, *123*, 711–718.

Shoukri, M. M., Aleid, M. M., Shoukri, M. M., Aleid, M. M. (2022). Quasi-binomial regression model for the analysis of data with extra-binomial variation. *Open J Stat*, *12*, 1–14.

Snow, J. B. (2008). 3.18—Tinnitus. In R. H. Masland, T. D. Albright, T. D. Albright, R. H. Masland, P. Dallos, D. Oertel, S. Firestein, G. K. Beauchamp, M. Catherine Bushnell, A. I. Basbaum, J. H. Kaas, & E. P. Gardner (Eds.), *The Senses: A Comprehensive Reference* (pp. 301–308). Academic Press. https://doi.org/10.1016/B978-012370880-9.00027-X

Spankovich, C., Gonzalez, V. B., Su, D., Bishop, C. E. (2018). Self reported hearing difficulty, tinnitus, and normal audiometric thresholds, the National Health and Nutrition Examination Survey 1999–2002. *Hear Res*, *358*, 30–36.

Stam, M., Smit, J. H., Twisk, J. W. R., Lemke, U., Smits, C., Festen, J. M., Kramer, S. E. (2016). Change in psychosocial health status over 5 years in relation to adults' hearing ability in noise. *Ear Hear*, *37*, 680–689.

Tunkel, D. E., Bauer, C. A., Sun, G. H., et al. (2014). Clinical practice guideline: Tinnitus. *Otolaryngol Head Neck Surg*, *151*(2_Suppl), S1–S40.

Tyler, R. S. (Ed.) (2006). Neurophysiological models, psychological models, and treatments for tinnitus. In *Tinnitus Treatment: Clinical Protocols* (pp. 1–22). Georg Thieme Verlag. https://doi.org/10.1055/b-0034-62459

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., Yutani, H. (2019). Welcome to the tidyverse. *J Open Source Softw*, *4*, 1686.

Wickham, H., François, R., Henry, L., Müller, K. (2022). *dplyr: A Grammar of Data Manipulation*

World Health Organization. (2021). *World report on hearing*. https://www.who.int/publications/i/item/world-report-on-hearing.