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Association between HEI-2015 and Hearing Loss Among American Adults: National Health and Nutrition Examination Survey

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Summary Statement

What is already known

- Hearing loss (HL) is a major global health burden linked to cognitive decline, depression, and reduced quality of life, with modifiable risk factors understudied.

- Prior studies suggest associations between single nutrients (e.g., vitamins, fatty acids) and HL, but evidence on overall dietary patterns remains limited.

- The Healthy Eating Index (HEI) is a validated tool for assessing diet quality, yet its relationship with HL in adults is poorly characterized.

What this paper adds

- First large-scale study demonstrating a significant inverse association between HEI-2015 scores and HL across low-, speech-, and high-frequency thresholds in U.S. adults.

- Higher HEI-2015 scores (indicating better diet quality) correlate with reduced odds of HL, particularly in quintile-based analyses (e.g., OR = 0.52 for high-frequency HL in the 80 – 89 score group).

- Provides actionable evidence for integrating dietary guidelines into HL prevention strategies, highlighting diet quality as a modifiable lifestyle factor.

- Strengthens the rationale for future longitudinal studies to explore causal links between diet and auditory health.

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Abstract

Purpose. To investigate the association between the Healthy Eating Index 2015 (HEI-2015) scores and hearing loss.

Methods. This study utilized cross-sectional data from individuals aged over 20 years (n=5171) who participated in the National Health and Nutrition Examination Survey from 1999 - 2012 and 2015 - 2018. We collected information on their hearing, HEI-2015, and several other important covariates using multivariate regression analyses.

Results. After adjusting for potential confounders, when hearing loss was defined as ≥20 dB, the odds ratio for low-frequency hearing loss and high-frequency hearing loss was 0.99 (95% CI: 0.98–0.99, *p* < 0.001) and 0.99 (95% CI: 0.98–1, *p* = 0.006), respectively. When hearing loss was defined as ＞25 dB, the odds ratio for low-frequency hearing loss and speech-frequency band hearing loss was 0.98 (95% CI: 0.98–0.99, *p* < 0.001) and 0.99 (95% CI: 0.98–1, *p* = 0.008), respectively.

Conclusion. In American adults, HEI is associated with hearing loss.

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Keywords. Hearing Loss; NHANES; Healthy Eating Index; Noise Exposure

1. Introduction

The World Health Organization estimated that 466 million people, or 6.1% of the global population, were living with disabling hearing loss (HL) in 2018, and this number is expected to increase as the population ages rapidly[1]. In 2019, World Health Organization estimated the annual global cost of HL to be $750 billion. This not only causes considerable economic losses but also seriously reduces the quality of human life. Hearing loss has recently been ranked as the fifth leading cause of years lived with a disability [2]. Many large epidemiological studies have found that HL is independently associated with falls, isolation, cognitive decline, dementia, anxiety, depression, social isolation, increased rates of hospitalization, and healthcare use [3 4 5 6]. This emphasizes the importance of early detection to potentially delay or prevent its onset. The pathogenesis of hearing loss involves various factors, including microcirculation disorders, viral infections such as rubella, measles, head trauma, genetic factors, noise exposure, autoimmune diseases, etc. These factors can lead to damage or degeneration of the hair cells in the cochlea, disruption of the auditory nerve pathways, or impairment of the auditory processing in the brain, ultimately resulting in a decrease in hearing function[7]. Multiple studies have shown that the dietary intake of carbohydrates, cholesterol, fiber, protein, sugar, fruits, vegetables, saturated fats, and trans-fats is associated with self-reported HL and requires public health interventions to prevent HL [8 9 10 11]; however, comprehensive guidelines on healthy eating are lacking. As the concept of dietary patterns continues to develop and evolve, the Healthy Eating Index (HEI) is

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widely used in different types of research, including surveillance, epidemiological, and intervention studies, involving different populations in the United States. It can be indexed to guide the diet of Americans for early prevention of HL [12]. The HEI is a measure that assesses whether a group of foods meets the Dietary Guidelines for Americans, which measures diet quality rather than quantity; that is, it assesses density rather than absolute quantity, providing a guide to the overall diet [13]. There were no changes in the components or standards between HEI-2015 and HEI-2020 [14]. The relation between the HEI and HL is an important topic in healthcare and public health. In this context, by conducting a retrospective cross-sectional study involving 5,171 U.S. adults from the National Health and Nutrition Examination Survey (NHANES), we sought to clarify the relation between the HEI and HL in adults.

2. Materials and Methods

This cross-sectional study utilized NHANES data from 1999 to 2012 and 2015 to 2018, conducted by the Centers for Disease Control and Prevention [15]. The purpose of the NHANES was to assess the health and nutritional status of non-hospitalized Americans. NHANES collects demographic and in-depth health information through home visits, screenings, and laboratory tests at mobile screening centers. The NHANES was authorized by the National Center for Health Statistics Ethics Review Committee, and all participants provided written informed consent prior to participation. The secondary analysis did not require additional approval from the Institutional Review Board [16].

Data from NHANES may be obtained through the NHANES website (visited on March 1, 2022; http://www.cdc.gov/nchs/nhanes.htm). Individuals aged over 20 years who completed the interviews participated in our study. We excluded individuals who lacked data on HL, HEI, or covariates. The total sample size of adults evaluated was N = 49,312, the details of which are described in Figure 1. Only publicly available data were used in the analysis, and ethical approval was not required for this study.

The HEI assesses diet quality and refers to how well a group of foods meets the Dietary Guidelines for Americans [17]. HEI-2020 contains 13 components and scoring criteria, and this is the first time that there has been no change in the index; the score of HEI-2020 is the same as that of HEI-2015. Krebs-Smith et al. described the details of each component in the HEI-2015 update [13]. The HEI-2015 score ranges from 0 to 100 and is graded as follows: Grade A (highest score): Total score between 90 and 100 points, indicating that an individual's dietary nutrient intake is very consistent with dietary guidelines. Grade B: Total score between 80 and 89 points, indicating that an individual's dietary nutrient intake is somewhat consistent with dietary guidelines. Grade C: Total score between 60 and 79 points, indicating that an individual's dietary nutrient intake has room for improvement, but can still adopt a healthy eating pattern. Grade D: Total score below 60 points, indicating that an individual's dietary nutrient intake needs significant adjustment to improve dietary quality. Grade F: Total score between 0 and 59 points, indicating that an individual's dietary nutrient intake is severely inadequate and requires special attention and

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improvement. A higher score reflects better diet quality. We used Day 1 Total Nutrient Intake to calculate the 13 components of HEI-2015.

All hearing tests were performed by a trained examiner on candidates aged 20–69 years in a dedicated soundproof room at a mobile test center. Hearing thresholds were tested in both ears at seven frequencies (500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz), with observed values ranging between -10 and 120 dB. The pure tone average (PTA) of speech-frequency in both ears was calculated as the average of the hearing thresholds at 0.5, 1, 2, and 4 kHz. Good ear PTA is a continuous variable; the higher the value, the worse the hearing. Low-frequency PTA calculations used hearing thresholds at 0.5, 1, and 2 kHz in the better ears, while high-frequency PTA calculations used hearing thresholds at 4, 6, and 8 kHz in the better ears. All hearing thresholds were reported as dB HL. Sensitivity analysis was performed using PTA with the bad ear rather than the good ear. In addition, good ear PTAs were classified according to clinical cut-off points defined by the 1997 World Health Organization, where a hearing level ≤25 dB HL indicates normal hearing and >25 dB HL indicates HL [18]. As defined by the World Health Organization in 2021, HL is defined as the speech-frequency of good ear PTA ≥20 dB, and <20 dB is normal hearing [19].

Multiple potential covariates were evaluated based on literature [20] [21] [22], including age, sex, marital status, race/ethnicity, education level, household income, smoking status, physical activity, high blood pressure, diabetes mellitus, history of cardiovascular disease, body mass index (BMI), and noise exposure. Race/ethnicity was classified as Mexican American, other Hispanic, Non-Hispanic White, Non-Hispanic Black, or other races, including multiple races. Marital status was divided into married, never married, living with a partner, widowed, divorced, or separated. The level of education was classified as less than 9th grade, 9–11th grade (including 12th grade with no diploma), high school graduate/General Educational Development or equivalent, college or AA degree, and college graduate or above. Smoking status, as defined in previous literature, was classified as never smoked (smoking less than 100 cigarettes), current smoker, or former smoker (quitting after smoking more than 100 cigarettes). Physical activity was classified as sedentary, moderate (at least 10 min of exercise in the past 30 days that resulted in only slight sweating or a mild-to-moderate increase in breathing or heart rate), and vigorous (at least 10 min of exercise in the past 30 days that resulted in heavy sweating or an increase in breathing or heart rate). Previous medical conditions (including hypertension, diabetes, stroke, and coronary heart disease) were determined based on questions in the questionnaire regarding whether the doctor had been informed of the condition in the past. BMI was calculated using a standardized technique based on weight and height. Noise exposure included exposure to gun noise outside the workplace, noise outside the workplace, working in a noisy environment, and exposure to loud noise at work.

For statistical analysis, categorical variables were expressed as proportions (%), and continuous variables were expressed as mean (standard deviation) or median (interquartile distance). To compare the differences between groups, one-way ANOVA (normal distribution), Kruskal–Wallis test (skewed distribution), and chi-square test (categorical variables) were performed. After adjusting for all covariates, linear regression was used to describe the relation between the healthy diet index and hearing. Logistic regression models were used to determine the odds ratios (ORs) and 95% confidence intervals (CIs) between HEI and HL. Model 1 was adjusted for sociodemographic characteristics, including age, sex, race, marital status, household income, and educational level. Model 2 was adjusted for sociodemographic characteristics, smoking status, alcohol consumption, physical activity, and BMI. Model 3 was comprehensively adjusted for sociodemographic characteristics, smoking status, alcohol consumption, physical activity, BMI, CVD, hypertension, DM, and noise exposure.

Furthermore, potential changes in the relation between healthy dietary index and HL were assessed, including the following variables: age (20–65 years vs >65 years), sex, marital status (married vs. never married, living with a partner, other: widowed, divorced, or separated individuals), and BMI (<25 vs. 25–30, ≥30 Kg/m2). Multivariate logistic regression was used to assess the heterogeneity among the subgroups, and the interaction between the subgroups and the healthy diet index was examined using the likelihood ratio test.

All analyses were performed using the statistical package R 4.3.1 (http://www.R-project.org; R Foundation, Shanghai, China) (accessed on March 10, 2024) and Free Statistics software version 1.9. Descriptive statistics were calculated for all participants. In the bilateral test, statistical

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significance was set at $p < 0.05$.

3. Results

3.1. Study Population

A total of 49,312 participants, all aged 20 years and older, completed interviews. We excluded those with missing data on the HEI-2015 (n=8,162), those with missing data on HL (n =32,422), or those with covariates (n = 3,557). Ultimately, this cross-sectional study includes 5,171 participants from the NHANES between 1999 and 2012, and 2015 and 2018. The detailed inclusion and exclusion processes are presented in Figure 1.

3.2. Baseline Characteristics

Table 1 illustrates the baseline characteristics of all participants according to the HEI-2015. We included a total 5,171 patients with a mean age of 50.9 ± 18.5 years, among whom 60.9% were Non-Hispanic Whites and 52.9% were men. HL was defined according to speech-frequency pure-tone average in the better-hearing ear, with ＞25 dB HL and ≥20 dB HL as having HL. The overall prevalence rates of HL in the study population were 25.0% and 37.6%, respectively.

The group with a higher HEI was observed to have a higher proportion of men, Non-Hispanic Whites, married individuals, those with a higher family poverty income ratio, those with a higher educational level, never smokers, mild alcohol users, those with a lower BMI, those with greater

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physical activity, those having a lower incidence of stroke and history of cardiovascular disease, those with no hypertension, no diabetes, no noise, and normal hearing.

3.3. Relation between the HEI-2015 and HL

Univariate analysis demonstrated that age, sex, race, marital status, family income, educational level, smoking status, alcohol consumption, physical activity, BMI, coronary heart disease, hypertension, DM, and noise exposure were associated with low-frequency HL, speech-frequency HL and high-frequency HL (see Tables 4, 5 and 6 in attachment respectively). In linear multifactor analysis (Table 2), after adjusting for potentially confounding factors, there was a significant negative association between the HEI-2015 and low-frequency hearing, with a coefficient of -0.03 (95% CI: -0.05 to -0.01, p = 0.001), speech-frequency hearing, with a coefficient of -0.04 (95% CI: -0.06 to -0.01, p = 0.003), and high-frequency hearing, with a coefficient of -0.05 (95% CI: -0.08 to -0.02, p = 0.003). When the HEI-2015 was a continuous variable, after adjusting for potential confounders, there was a significant negative association between the HEI-2015 and low-frequency HL (Table 3), with OR values of 0.99 (95% CI: 0.98–0.99, $p < 0.001$) and 0.98 (95% CI: 0.98–0.99, $p < 0.001$). The OR was 0.99 in speech-frequency HL, defined as HL greater than 25 dB (95% CI: 0.98–1, p = 0.008), and the OR was 0.99 (95% CI: 0.98–1, p = 0.006) in high-frequency HL, defined as HL greater than or equal to 20 dB. When the HEI-2015 was analyzed using quintiles (see Table 7 in the attachment), a significant negative association was found between the HEI-

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2015 and HL after adjusting for potential confounders. The adjusted OR values of HEI-2015 and F-scores (0–59), D(60–69), C(70–79), B(80–89), and A(90–100) for HL are shown in Table 7 of the annex. With hearing less than 20 dB as the normal value, the OR value of low-frequency hearing in B(80–89) was 0.54 (95% CI: 0.34–0.88, *p* = 0.013). The OR values of speech-frequency band listening were 0.7 (95% CI: 0.53–0.93, *p* = 0.013) in C(70–79) and 0.14 (95% CI: 0.03–0.56, p = 0.005) in A(90–100). The OR values for high-frequency hearing were 0.76 (95% CI: 0.61–0.96, p = 0.02) in D(60–69) and 0.66 (95% CI：0.47–0.91，*p* = 0.012) in C(70–79), and the OR value in B(80–89) was 0.52 (95% CI: 0.3–0.91, *p* = 0.021). However, when hearing was less than or equal to 25 decibels, the OR value of low-frequency hearing was 0.7 (95% CI: 0.51–0.96, *p* = 0.029) in C(70–79) and 0.54 (95% CI: 0.3–0.96, *p* = 0.035) in B(80–89).

3.4 Stratified Analyses Based on Additional Variables

Stratified analysis was performed on several subgroups to assess the potential impact of the relation between the HEI-2015 and HL. When stratified by sex, age, BMI, and marital status, no significant interactions were observed between the subgroups. Given the sample size, a P-value of less than 0.05 for marriage and BMI may not be statistically significant (see Figures 2, 3, and 4 in the attached appendix).

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4. Discussion

We found that the HEI scores were associated with HL, and subgroup analyses showed stable results.

Spankovich's findings support the link between healthier diets and lower high-frequency thresholds in adults [23]. Adherence to healthy eating patterns has been linked to a reduced risk of HL in women [24]. An Australian cross-sectional study found that the overall diet quality was associated with concurrent vision and HL [25]. Previous studies have linked a healthy diet to HL, which is similar to our findings.

Some studies have suggested that dietary supplement use is positively associated with hearing improvement at all frequencies [26]. Studies by Rosenhall et al. have shown that fish are beneficial for hearing, while eating 'junk food' rich in low-molecular-weight carbohydrates is detrimental [27]. A diet high in saturated fat, cholesterol, and carbohydrates is a risk factor for HL, and conversely, increasing antioxidants in the form of protein, zinc, magnesium, selenium, iron, iodine, fruits, vegetables, polyunsaturated fatty acids (omega-3), and vitamins A, C, and E can prevent HL from developing [8 28 29 30]. Ji Eun Choi et al. believe that a high intake of seeds, nuts, fruits, seaweed, and vitamin A has protective effects on hearing, and dietary antioxidants or anti-inflammatory foods may help reduce the occurrence of HL [31]. Xinmin Wei believes that the dietary intake of Mg and Ca is associated with a lower risk of HL [32]. Many scholars have studied the relation between diet and HL; some diets are protective factors, whereas others are risk factors.

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Most previous studies on diet and hearing have focused on the analysis of single nutrients, with the limitation that nutrient intake is correlated, making it difficult to isolate the effects of one nutrient from those of others. Single-nutrient analyses, which do not consider biochemical interactions between nutrients, also increase the possibility of false-positive associations [33]. As a supplement to single-nutrient analysis, dietary pattern analysis can better capture the synergistic and cumulative effects of total dietary intake on health outcomes [34].

The HEI assesses whether a group of foods meets the American Dietary Guidelines for Americans. The HEI can be applied to any group of foods by assigning a score to each component and comparing its density to the relevant criteria. HEIs have been widely used in numerous studies on diet quality in populations, the relation between diet quality and health outcomes, the impact of interventions on diet quality, and economic and food-context-based studies [13]. The HEI includes eating more fruits, vegetables, legumes, whole grains, nuts, dairy products, seafood, plant proteins, and fatty acids, and less saturated fat, sugar, and sodium. There are many mechanisms by which this healthy eating pattern prevents HL, including the prevention of microvascular and macrovascular damage to cochlear blood flow, inhibition of oxidative damage, and reduction of inflammation [24]. A lower high-fat diet in a high-quality diet may reduce induced oxidative stress, mitochondrial damage, and apoptosis in the inner ear, which has a protective effect on inner ear cells [35] [36]. Inadequate blood supply to the cochlea can lead to hypoxia and ischemic injury, oxidative stress, mitochondrial dysfunction, cellular damage, and peripheral and central auditory neurodegeneration [37]. Dietary nutrients of polyunsaturated fatty acids and multivitamins, such as vitamin B12, vitamin C, calcium, and selenium, may have antioxidant and neuroprotective effects [38]. They may also protect against neurodegeneration of auditory nerve fibers and central auditory pathways [24]. Dietary guidance for patients with potential HL is provided by examining the effects of a healthy diet index on HL.

This study has several limitations. First, the cross-sectional design was a major limitation, and no causal relation could be inferred from this study. Second, the use of self-reported 24-hour food recall data is limited because they are prone to overestimation or underestimation. Finally, more participants were excluded because of the lack of data on any covariates that could have affected the results. Despite these limitations, our study has several strengths. The use of a large, nationally representative database to assess diet quality is a major strength of the present study.

We found an association between the HEI-2015 score and HL. Therefore, attention should be paid to the relation between dietary quality and HL. Future cohort studies or randomized controlled trials are needed to confirm this relation.

5. Conclusions

We found that higher HEI scores were associated with better hearing, and that a healthy diet may also help reduce the risk of HL.

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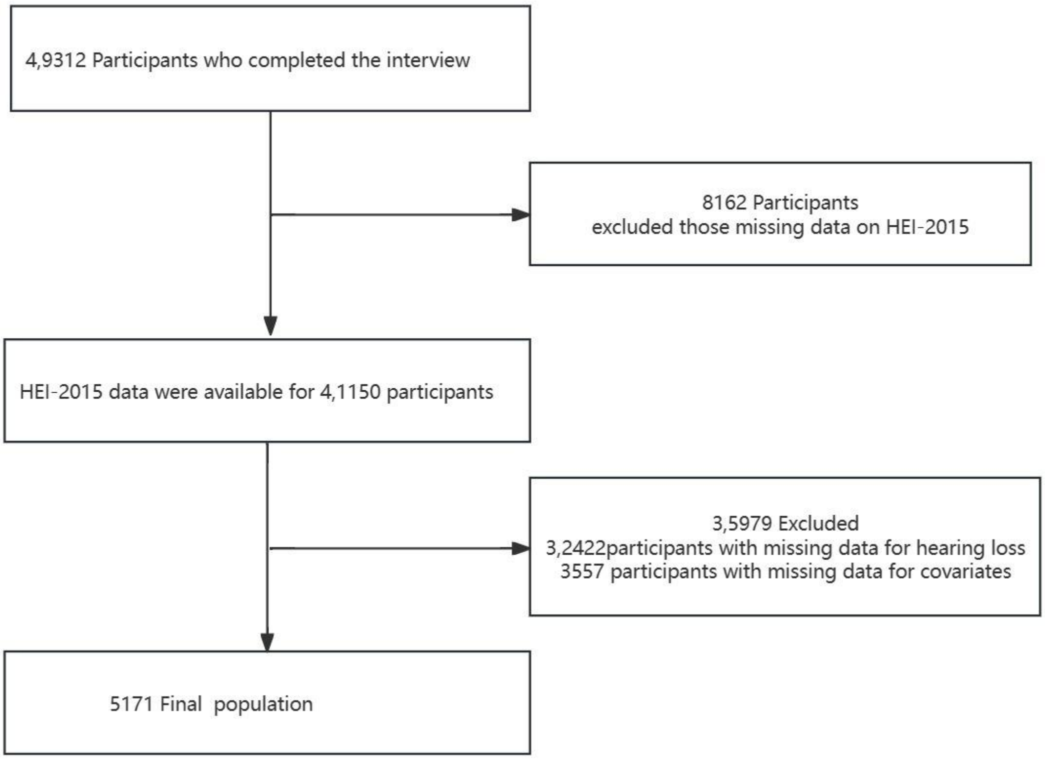

Figure1. the study's flow diagram

Table 1. Population characteristics by categories of the Healthy Eating Index （HEI-2015）.

Characteristic	HEI-2015	
	No.	*P*-Value
Age, Mean ± SD	50.9 ± 18.5	< 0.001
Sex, n (%)		< 0.001
Male	2736 (52.9)	
Female	2435 (47.1)	

Race, n (%)		< 0.001
Mexican American	833 (16.1)	
Other Hispanic	174 (3.4)	
Non-Hispanic White	3151 (60.9)	
Non-Hispanic Black	851 (16.5)	
Other Race-Including Multi-Racial	162 (3.1)	
Marry, n (%)		< 0.001
Married	3048 (58.9)	
Never married	761 (14.7)	
Living with partner	317 (6.1)	
Other: widowed, divorced, or separated individuals	1045 (20.2)	
PIR, Mean ± SD	2.9 ± 1.6	< 0.001
Education, n (%)		< 0.001
Less Than 9th Grade	455 (8.8)	
9-11th Grade (Includes 12th grade with no diploma)	637 (12.3)	
High School Grad/GED or Equivalent	1287 (24.9)	
Some College or AA degree	1563 (30.2)	
College Graduate or above	1229 (23.8)	
smoke, n (%)		< 0.001
never	2540 (49.1)	
former	1537 (29.7)	

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now	1094 (21.2)	
alcohol, n (%)		< 0.001
never	625 (12.1)	
former	965 (18.7)	
mild	1887 (36.5)	
moderate	792 (15.3)	
heavy	902 (17.4)	
BMI_kg.m2, Mean ± SD	28.2 ± 6.1	< 0.001
CVD, n (%)	574 (11.1)	< 0.001
Hypertension, n (%)	2177 (42.1)	< 0.001
DM, n (%)	682 (13.2)	< 0.001
NOISE, n (%)	1708 (33.0)	0.04
Low-frequency hearing loss(≥20dB), n (%)	1112 (21.5)	< 0.001
Low-frequency hearing loss (>25 dB), n (%)	606 (11.7)	< 0.001
Speech-frequency hearing loss (≥20dB), n (%)	1946 (37.6)	< 0.001
Speech-frequency hearing loss (>25 dB) n (%)	1295 (25.0)	< 0.001
High-frequency hearing loss (≥20dB).trans, n (%)	2674 (51.7)	< 0.001
High-frequency hearing loss (>25 dB), n (%)	2149 (41.6)	< 0.001

Physical activity, Median (IQR)	480.0 (157.5, 1145.3)	< 0.001
Low-frequency hearing, Median (IQR)	10.0 (5.0, 16.7)	< 0.001
Speech-frequency hearing, Median (IQR)	13.8 (7.5, 26.2)	< 0.001
High-frequency hearing, Median (IQR)	20.0 (10.0, 45.0)	< 0.001

the HEI-2015: the Healthy Eating Index; IQR: interquartile range; GED: General Educational Development

Table 2. Association between the Healthy Eating Index-15(HEI-2015) and hearing

Variable	Coefficient (95% CI)			
	Crude	*P*- value	Adjust	*P*-value
low-frequency hearing	0.12 (0.1~0.14)	<0.001	-0.03 (-0.05~-0.01)	0.001
speech-frequency hearing	0.17 (0.14~0.2)	<0.001	-0.04 (-0.06~-0.01)	0.003
high-frequency hearing	0.35 (0.3~0.39)	<0.001	-0.05 (-0.08~-0.02)	0.003

CI, confidence interval;

Table 3. Association between the Healthy Eating Index-15(HEI-2015) and hearing loss.

Variable	OR (95% CI)								
	No.	Crude	*P*-value	Model 1	*P*-value	Model 2	*P*-value	Model 3	*P*-value
Low-frequency hearing loss(≥20dB)	1112	1.02 (1.02~1.03)	<0.001	0.98 (0.98~0.99)	<0.001	0.99 (0.98~0.99)	<0.001	0.99 (0.98~0.99)	<0.001
low-frequency hearing loss (>25 dB)	606	1.02 (1.01~1.03)	<0.001	0.98 (0.98~0.99)	<0.001	0.98 (0.98~0.99)	<0.001	0.98 (0.98~0.99)	<0.001
speech-frequency hearing loss (≥20 dB)	1946	1.03 (1.02~1.03)	<0.001	0.99 (0.99~1)	0.008	0.99 (0.99~1)	0.079	0.99 (0.99~1)	0.077
speech-frequency hearing loss (>25 dB)	1295	1.02 (1.02~1.03)	<0.001	0.99 (0.98~1)	0.001	0.99 (0.98~1)	0.008	0.99 (0.98~1)	0.008
high-frequency hearing (≥20 dB)	2674	1.03 (1.02~1.03)	<0.001	0.99 (0.98~0.99)	0.001	0.99 (0.98~1)	0.008	0.99 (0.98~1)	0.006
high-frequency	214	1.03	<0.00	0.99	0.097	1	0.343	1	0.307

hearing (>25 dB)	9	(1.03~1.04)	1	(0.99~1)	(0.99~1)	(0.99~1)

OR: odds ratio; CI, confidence interval; Ref: reference. Model 1 was adjusted for sociodemographic variables (Age, Sex, Race, Marry, PIR, Education). Model 2 was adjusted for sociodemographic variables (Age, Sex, Race, Marry, PIR, Education), smoke, alcohol, physical activity, BMI. Model 3 was adjusted for sociodemographic variables (Age, Sex, Race, Marry, PIR, Education), smoke, alcohol, physical activity, BMI, CVD, hypertension, DM, noise.

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