Lai et al. BMC Public Health (2025) 25:1891
https://doi.org/10.1186/s12889-025-23052-0

BMC Public Health

RESEARCH

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Association between the number of pregnancies and hearing loss: NHANES 1999–2018

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Abstract

Background Hearing loss represents an escalating global health concern with profound implications for individuals and society. While prior studies suggest that reproductive factors may influence women's auditory health, the specific association between the number of pregnancies and auditory function remains inadequately understood. This research aimed to investigate the association between the number of pregnancies and hearing loss in U.S. women.

Methods We conducted a cross-sectional analysis of 5,269 U.S. women aged 20 years and older from the National Health and Nutrition Examination Survey (NHANES) 1999–2018. Reproductive health data, including the number of pregnancies, were obtained via self-reported questionnaires. Hearing loss was defined as a pure-tone average ≥ 25 dB HL at speech frequencies (0.5, 1, 2, and 4 kHz) in the better-hearing ear. All analyses incorporated NHANES sample weights. Weighted multivariable logistic regression and restricted cubic spline regression were employed to evaluate the relationship between the number of pregnancies and hearing loss. Subgroup and sensitivity analyses were used to test the consistency and robustness of the association. And mediation analyses explored the roles of white blood cells and high-density lipoprotein in this association.

Results A total of 5,269 adult women were included in the analysis, of whom 624 (9.81%) exhibited hearing loss. After adjusting for confounders, the number of pregnancies was significantly associated with hearing loss (OR: 1.12; 95% CI: 1.05–1.20; $P < 0.001$). Conversely, the use of birth control pills was associated with lower odds of hearing loss (OR: 0.67; 95% CI: 0.47–0.94; $P < 0.05$). Restricted cubic spline regression demonstrated a linear increase in the odds of hearing loss with a greater number of pregnancies. This positive association was consistent across most subgroups. Mediation analyses revealed that white blood cells and high-density lipoprotein partially mediated this association. Sensitivity analyses, including alternative definitions of hearing loss and multiple imputation for missing covariates, confirmed the robustness of the results.

Conclusion Our findings demonstrated that a higher number of pregnancies was significantly associated with hearing loss, while birth control pill use appeared protective. These findings highlight the importance of recognizing

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potential auditory health implications associated with multiple pregnancies and may inform future public health strategies aimed at supporting women's hearing health across the reproductive lifespan.

Keywords Hearing loss, Reproductive, Number of pregnancies, Birth control pills, NHANES

Background

Hearing loss is a pervasive and increasingly pressing public health concern [1, 2]. The World Health Organization's (WHO) *World Report on Hearing 2021* states that approximately 1.5 billion individuals worldwide are currently living with hearing loss, a number projected to reach 2.5 billion by 2050 [3]. Hearing loss not only severely impairs interpersonal communication but also significantly diminishes an individual's quality of life and psychological well-being. It is associated with profound consequences, including cognitive decline, depression, anxiety, social isolation, and other challenges, which collectively impose substantial health and economic burdens [4–7]. Notably, according to the Global Burden of Disease studies, hearing loss ranks as the third leading cause of years lived with disability [8]. These alarming statistics underscore the urgency of identifying modifiable risk factors to mitigate its impact and guide timely interventions aimed at reducing the associated health and economic toll.

In recent years, the inclusion of sex as a biological variable (SABV) in scientific research has been emphasized by the U.S. National Institutes of Health (NIH) [9–11]. This shift, coupled with growing evidence of sexual dimorphism in hearing loss [12, 13], has fueled interest in exploring how sex-specific factors, particularly reproductive history, influence auditory health. Women exhibit greater hearing sensitivity than men, with fluctuations observed throughout the menstrual cycle [14]. However, after menopause, hearing sensitivity declines sharply, likely due to reduced endogenous estrogen levels, which are thought to contribute to auditory deterioration [15]. Studies suggest that estrogen therapy may mitigate hearing loss in aging postmenopausal women, although prolonged use of hormone therapy has been linked to an elevated risk of hearing impairment [16–19]. Furthermore, pregnancy-related auditory changes have also garnered attention. The highest prevalence of inner ear deficits, including hearing loss, has been demonstrated during the third trimester of pregnancy, compared to the first and second trimesters [20]. Transient hearing loss during pregnancy has been documented [21], along with reports of sudden sensorineural hearing loss during this period [22, 23]. Additionally, preeclampsia has been identified as a possible contributor to sensorineural hearing loss [24]. These findings suggest that reproductive factors may influence auditory health through hormonal alterations, metabolic and vascular dysfunction, heightened systemic inflammation, and lipid profile disturbances, such as reduced high-density lipoprotein (HDL) levels [20–22]. However, despite growing recognition of the importance of reproductive factors in women's hearing health, this area remains relatively underexplored in the fields of audiology and reproductive medicine.

The number of pregnancies, a pivotal indicator of a woman's reproductive history, reflects her reproductive health status and fertility potential, providing insight into her overall reproductive trajectory over the life course [25]. The physical and psychological changes associated with multiple pregnancies, such as hormonal fluctuations, hematologic changes, and metabolic alterations, not only affect maternal health during gestation but also have long-term consequences for overall well-being [26–28]. Accumulating evidence links the number of pregnancies to various health outcomes, including cardiovascular disease [29, 30], cognitive decline [27], depression [31], urinary incontinence [28], and frailty [32]. Despite these established associations, the potential relationship between the number of pregnancies and hearing loss remains unexplored, leaving a significant gap in our understanding of how reproductive factors might influence women's auditory health.

To address this gap, this study represents the first investigation into the association between the number of pregnancies and hearing loss, using data from the National Health and Nutrition Examination Survey (NHANES). It aims to provide novel insights into the potential association between the number of pregnancies and hearing health and to offer recommendations for the management of auditory health in women.

Methods

Study population

NHANES is a nationwide survey that collects nationally representative health data from the U.S. population [33]. It follows a rigorous four-stage sampling design and gathers comprehensive data through detailed interviews, physical examinations, and laboratory tests. The NHANES protocols were approved by the National Center for Health Statistics Ethics Review Board, and all participants provided written informed consent. Further information on the study design, methodology, and data collection procedures is available on the NHANES official website.

In this study, we incorporated data from ten NHANES cycles conducted between 1999 and 2018, encompassing 101,316 participants. The following exclusion criteria were applied: (1) females under 20 years of age and all male participants; (2) participants without valid pure-tone average (PTA) data at speech frequencies (0.5, 1, 2, and 4 kHz) in both ears, including those with missing thresholds or unreliable 1 kHz retest results (> 10 dB HL difference between repeated measurements); (3) participants missing data on the number of pregnancies; (4) participants who were currently pregnant; and (5) participants with incomplete covariate data. After applying these criteria, 5,269 eligible participants were included in the study, with 624 classified as having hearing loss. A detailed participant screening flowchart is provided in Fig. 1.

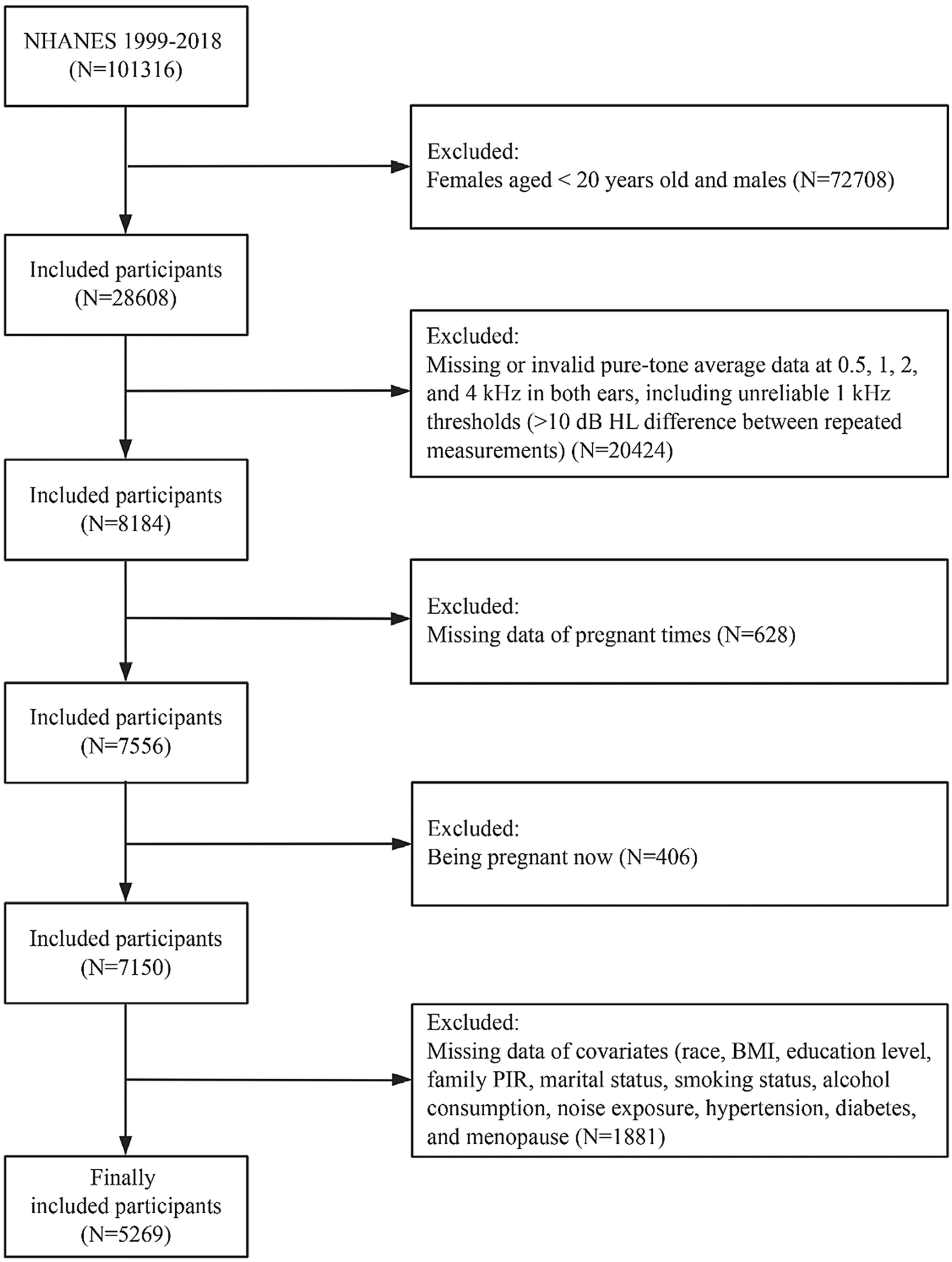

Fig. 1 Flowchart of eligible participants selection. Abbreviations: BMI, body mass index; NHANES, National Health and Nutrition Examination Survey; PIR, income-to-poverty ratio

Number of pregnancies

Participants were invited to the Mobile Examination Center to complete interviews and undergo health assessments to examine their health and nutritional status. Reproductive health data, including the number of pregnancies, were obtained from a self-reported reproductive health questionnaire. The number of pregnancies was determined based on participants' responses to the question, "How many times have you been pregnant?" Participants were instructed to include all pregnancies, including current pregnancies, live births, miscarriages, stillbirths, tubal pregnancies, or abortions.

Hearing assessment

Hearing assessments were conducted using pure-tone air conduction audiometry, performed by trained examiners in sound-attenuated booths. Hearing thresholds were measured bilaterally across seven frequencies (0.5, 1, 2, 3, 4, 6, and 8 kHz) using calibrated Interacoustics Model AD226 audiometers with TDH-39 standard headphones or Etymotic EarTone 3 A insert earphones, depending on the testing environment and ear canal status, within an intensity range from −10 to 120 decibels (dB). To ensure reliability, hearing threshold at 1 kHz was tested twice in both ears, and results were not accepted when the measurements differed by more than 10 dB HL. Further details about the audiometric procedures are available in the NHANES Audiometry Procedures Manual. In this study, PTAs at speech frequencies (0.5, 1, 2, and 4 kHz) were calculated separately for the left and right ears. Hearing loss was defined as a PTA ≥ 25 dB HL in the better-hearing ear [34].

Covariates

The analysis included the following potential confounders: age, race, body mass index (BMI), education level, family income-to-poverty ratio (PIR), marital status, smoking status, alcohol consumption, noise exposure, hypertension, diabetes mellitus, and menopause. Participants identifying as Mexican American, other Hispanic, or other races were classified under a single category labeled "Others," which was analyzed alongside "Non-Hispanic White" and "Non-Hispanic Black." [35]. BMI was calculated by dividing weight (kg) by height squared (m^2). Education level was classified into two categories: college or above and high school graduate or lower. Family PIR was grouped into three levels: low income (≤ 130% of the federal poverty level), medium income (130–350%), and high income (> 350%). Marital status was divided into married/living with a partner, never married, and divorced/separated/widowed. Smoking status was classified based on two questions: (1) "Have you smoked at least 100 cigarettes in your entire life?" and (2) "Do you now smoke cigarettes?" Participants who answered "no" to the first question were defined as non-smokers. Those who answered "yes" to the first question and "no" to the second question were classified as former smokers, and those who answered "yes" to both questions were considered current smokers. Alcohol consumption was determined based on the answer: "In any one year, have you had at least 12 drinks of any type of alcoholic beverage?" Participants who answered "yes" were classified as consumers; those who answered "no" were classified as non-consumers. Noise exposure status was determined based on responses to five survey questions regarding exposure to loud noises. Four types of chronic noise exposure were considered: (1) work-related noise (ever exposed to loud noise at work for at least 3 months), (2) military service/veteran status, (3) recreational firearm use (firearm noise exposure at least once a month for a year), and (4) non-occupational recreational noise exposure (loud noise other than firearm use outside of work at least once a month for a year). Participants who answered "Yes" to any of these questions were categorized as exposed, while those who answered "No" to all were categorized as not exposed. Additionally, participants reporting loud noise or music exposure within the past 24 hours were excluded to avoid potential bias from temporary noise-induced hearing threshold shifts [36]. Hypertension was defined as meeting any of the following criteria: a previous diagnosis of hypertension, current use of antihypertensive medications, or an average systolic blood pressure ≥ 140 mmHg or diastolic blood pressure ≥ 90 mmHg. Diabetes was defined as fulfilling any of the following criteria: a documented history of diabetes, current use of oral hypoglycemic agents or insulin therapy, a glycohemoglobin level of ≥ 6.5%, or a fasting blood glucose level of ≥ 7.0 mmol/L. Menopausal status was determined via a self-reported reproductive health questionnaire. Women were defined as menopausal if they answered 'no' to having had at least one menstrual period in the past 12 months and then reported 'hysterectomy/menopause' as the reason.

Statistical analysis

All analyses accounted for the complex, multistage, and probability sampling design of NHANES by incorporating appropriate sample weights, strata, and primary sampling units, as recommended by the National Center for Health Statistics. Sample weights were applied to ensure that the results are nationally representative of the U.S. civilian non-institutionalized population. Specifically, MEC examination sample weights were used following NHANES analytic guidelines [37]. Baseline characteristics were presented as sample sizes with weighted percentages and as weighted means with standard errors for categorical and continuous variables, respectively. Differences between groups were assessed using weighted chi-square tests for categorical variables and weighted t-tests for continuous variables. Weighted multivariable logistic regression models were applied to investigate the association between the number of pregnancies and hearing loss in adult women (aged ≥ 20 years). To specifically examine the association between the number of pregnancies and age-related hearing loss (ARHL), a separate analysis was conducted for older women (aged ≥ 60 years). Three weighted multivariable logistic regression models were implemented: Model 1 was unadjusted; Model 2 adjusted for age, race, BMI, education level, family PIR, marital status, smoking status, and alcohol consumption; and Model 3 further adjusted for noise exposure, hypertension, diabetes, and menopause. Restricted cubic spline (RCS) models with three knots were employed to visualize the association between the number of pregnancies and hearing loss. Subgroup analyses assessed the consistency of findings across different populations, and interaction analyses explored potential interactions between the number of pregnancies and covariates. Results from subgroup analyses and interaction analyses were presented using a forest plot. Mediation analyses were conducted to investigate the roles of white blood cells (WBC) and high-density lipoprotein (HDL) as mediators in the relationship between the number of pregnancies and hearing loss. In addition, two sensitivity analyses were performed to further assess the robustness of the results: (1) redefining hearing loss as a PTA ≥ 20 dB HL to align with the classification recommended by the Global Burden of Disease (GBD) Expert Group on Hearing Loss [38–40]; and (2) conducting multiple imputation for missing covariate data to address potential selection bias arising from the exclusion of participants with incomplete information. R software (version 4.3.1) was used for all statistical analyses, with statistical significance set at a two-sided P value < 0.05.

Results

Baseline characteristics

The baseline characteristics are presented in Table 1. A total of 5,269 participants were included in this study, of whom 624 (9.81%) had hearing loss. The average age of the participants was 46.57 ± 0.37 years. Except for BMI, which showed no significant differences, all other covariates displayed significant differences between participants with and without hearing loss. Participants with hearing loss were generally older, non-Hispanic White, divorced, separated, or widowed, former smokers, non-alcohol consumers, and had lower levels of education and family income, as well as noise exposure, hypertension, diabetes, and menopause. Regarding reproductive characteristics, participants with hearing loss exhibited notable differences compared to those with normal hearing. They were more likely to have had later menarche, a later last menstruation, and a longer reproductive period. Furthermore, they tended to have their first delivery at an earlier age and their last delivery at an older age. Importantly, those with hearing loss were more likely to have a higher number of pregnancies while being less likely to have used birth control pills. However, no significant differences were observed in the number of pregnancy losses.

Association between the number of pregnancies and hearing loss

Weighted multivariable logistic regression analyses were performed to investigate the association between the number of pregnancies and hearing loss, with results presented in Table 2. The analyses revealed that a higher number of pregnancies was significantly associated with an increased risk of hearing loss. After adjusting for covariates (Model 3, Table 2), for adult women, the number of pregnancies was significantly associated with hearing loss, with an odds ratio (OR) of 1.12 (95% CI: 1.05–1.20; $P < 0.001$). Similarly, in elderly women (aged ≥ 60 years), as shown in Supplementary Table 1, the OR for the number of pregnancies was 1.12 (95% CI: 1.03–1.21; $P < 0.01$). Conversely, the use of birth control pills was associated with a significantly lower risk of hearing loss. In Model 3, the birth control pill use was linked to a reduction in the risk of hearing loss in both adult women (OR: 0.67; 95% CI: 0.47–0.94; $P < 0.05$) and elderly women (OR: 0.45; 95% CI: 0.31–0.66; $P < 0.001$). In addition, no statistically significant associations were observed for age at menarche, age at last menstruation, length of reproductive period, age at first delivery, age at last delivery, or number of pregnancy losses.

Figure 2 illustrates the association between the number of pregnancies and hearing loss in adult women, while Supplementary Fig. 1 depicts the same relationship in elderly women, as assessed through RCS regression analyses. The RCS curves for both adult and elderly women demonstrated a clear, linear increase in the odds of hearing loss as the number of pregnancies increased.

Subgroup and mediation analysis

We conducted stratified analyses on all covariates to explore the associations between the number of pregnancies and hearing loss across various population subgroups, with results shown in Fig. 3 and Supplementary Table 2. A significant positive association was observed in all subgroups, except for those based on race, family income, marital status, and diabetes status. This suggests the robustness of the association across different population subgroups. Notably, the association was more pronounced among non-Hispanic White, high-income, married or cohabiting, and non-diabetic women, but not significant in their respective counterparts. In the

Table 1 Baseline characteristics of study population grouped by hearing from NHANES 1999–2018

	Total (*n* = 5269)	Normal hearing (*n* = 4645)	Hearing loss (*n* = 624)	*P* value
Age, **year**	46.57 (0.37)	44.15 (0.35)	68.90 (0.72)	< 0.001
Race, **No. (%)**				< 0.001
Non-Hispanic White	2309 (71.22)	1926 (70.07)	383 (81.86)	
Non-Hispanic Black	1143 (10.72)	1066 (11.29)	77 (5.46)	
Other Race	1817 (18.06)	1653 (18.64)	164 (12.67)	
BMI, **kg/m^2**	28.75 (0.15)	28.70 (0.15)	29.19 (0.36)	0.193
Education level, **No. (%)**				< 0.001
High school graduate or lower	2202 (33.32)	1832 (31.36)	370 (51.30)	
College or above	3067 (66.68)	2813 (68.64)	254 (48.70)	
Family PIR, **No. (%)**				< 0.001
< 1.3	1601 (21.17)	1405 (21.22)	196 (20.71)	
1.3–3.5	1965 (35.18)	1690 (34.18)	275 (44.34)	
≥ 3.5	1703 (43.65)	1550 (44.60)	153 (34.95)	
Marital status, **No. (%)**				< 0.001
Married or living with a partner	2914 (61.86)	2635 (63.27)	279 (48.90)	
Divorced/separated/widowed	1353 (21.57)	1046 (18.89)	307 (46.20)	
Never married	1002 (16.57)	964 (17.84)	38 (4.90)	
Smoking status, **No. (%)**				0.003
Never smoker	3442 (61.32)	3020 (61.01)	422 (64.16)	
Former smoker	911 (19.74)	772 (19.33)	139 (23.55)	
Current smoker	916 (19.84)	853 (19.66)	63 (12.29)	
Alcohol consumption, **No. (%)**				< 0.001
No	1871 (27.82)	1587 (26.17)	284 (46.08)	
Yes	3182 (72.18)	2945 (73.83)	237 (53.92)	
Noise exposure, **No. (%)**				< 0.05
No	3506 (66.54)	3057 (67.51)	449 (61.00)	
Yes	1763 (33.56)	1588 (32.49)	175 (39.00)	
Hypertension, **No. (%)**				< 0.001
No	3237 (66.71)	3038 (69.88)	199 (37.48)	
Yes	2032 (33.29)	1607 (30.12)	425 (62.52)	
Diabetes, **No. (%)**				< 0.001
No	4479 (89.08)	4055 (90.71)	424 (74.17)	
Yes	790 (10.92)	590 (9.29)	200 (25.83)	
Menopause, **No. (%)**				< 0.001
No	2778 (55.23)	2733 (60.18)	45 (9.67)	
Yes	2491 (44.77)	1912 (39.82)	579 (90.33)	
Birth control pills, **No. (%)**				< 0.001
No	1668 (24.18)	1315 (21.61)	353 (47.87)	
Yes	3592 (75.82)	3323 (78.39)	269 (52.13)	
Menarche, **year**	12.67 (0.03)	12.65 (0.03)	12.89 (0.09)	0.008
Last menstruation, **year**	44.16 (0.26)	43.83 (0.30)	45.62 (0.41)	< 0.001
Reproductive period, **year**	31.45 (0.27)	31.14 (0.31)	32.78 (0.40)	< 0.001
First delivery, **year**	23.03 (0.19)	23.12 (0.20)	22.41 (0.29)	< 0.05
Last delivery, **year**	28.71 (0.17)	28.53 (0.19)	30.06 (0.32)	< 0.001
Number of pregnancies	2.47 (0.04)	2.36 (0.05)	3.52 (0.12)	< 0.001
Number of pregnancy loss	0.75 (0.03)	0.76 (0.03)	0.69 (0.07)	> 0.05

Values were presented as the sample numbers (weighted percentages) or weighted mean (standard errors). The differences between groups were assessed using the weighted chi-square test or the weighted t-test (*P*-value < 0.05 indicates statistical significance). Abbreviations: BMI, body mass index; NHANES, National Health and Nutrition Examination Survey; PIR, income-to-poverty ratio

Table 2 Association between reproductive characteristics and hearing loss in adult women

	Model 1		Model 2		Model 3	
Variable	**OR (95%CI)**	***P* value**	**OR (95%CI)**	***P* value**	**OR (95%CI)**	***P* value**
Menarche, **year**	1.09 (1.03, 1.16)	< 0.05	1.06 (0.96, 1.16)	> 0.05	1.06 (0.96, 1.16)	> 0.05
Last menstruation, **year**	1.02 (1.01, 1.04)	< 0.001	0.99 (0.97, 1.01)	> 0.05	0.99 (0.97, 1.01)	> 0.05
Reproductive period, **year**	1.02 (1.01, 1.03)	< 0.05	0.99 (0.97, 1.01)	> 0.05	0.99 (0.97, 1.01)	> 0.05
First delivery, **year**	0.97 (0.95, 0.99)	< 0.05	0.96 (0.93, 1.00)	< 0.05	0.96 (0.93, 1.00)	> 0.05
Last delivery, **year**	1.05 (1.02, 1.07)	< 0.001	1.01 (0.98, 1.04)	> 0.05	1.01 (0.98, 1.04)	> 0.05
Number of pregnancies	1.29 (1.23, 1.36)	< 0.001	1.12 (1.05, 1.19)	< 0.001	1.12 (1.05, 1.20)	< 0.001
Number of pregnancy loss	0.95 (0.84, 1.07)	> 0.05	1.01 (0.91, 1.12)	> 0.05	1.01 (0.91, 1.13)	> 0.05
Birth control pills	0.30 (0.24, 0.37)	< 0.001	0.66 (0.47, 0.93)	< 0.05	0.67 (0.47, 0.94)	< 0.05

Model 1: Crude model

Model 2: Adjusted for age, race, BMI, education level, family PIR, marital status, smoking status, and alcohol consumption

Model 3: Combination of model 2 and noise exposure, hypertension, diabetes, and menopause

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratios; PIR, income-to-poverty ratio

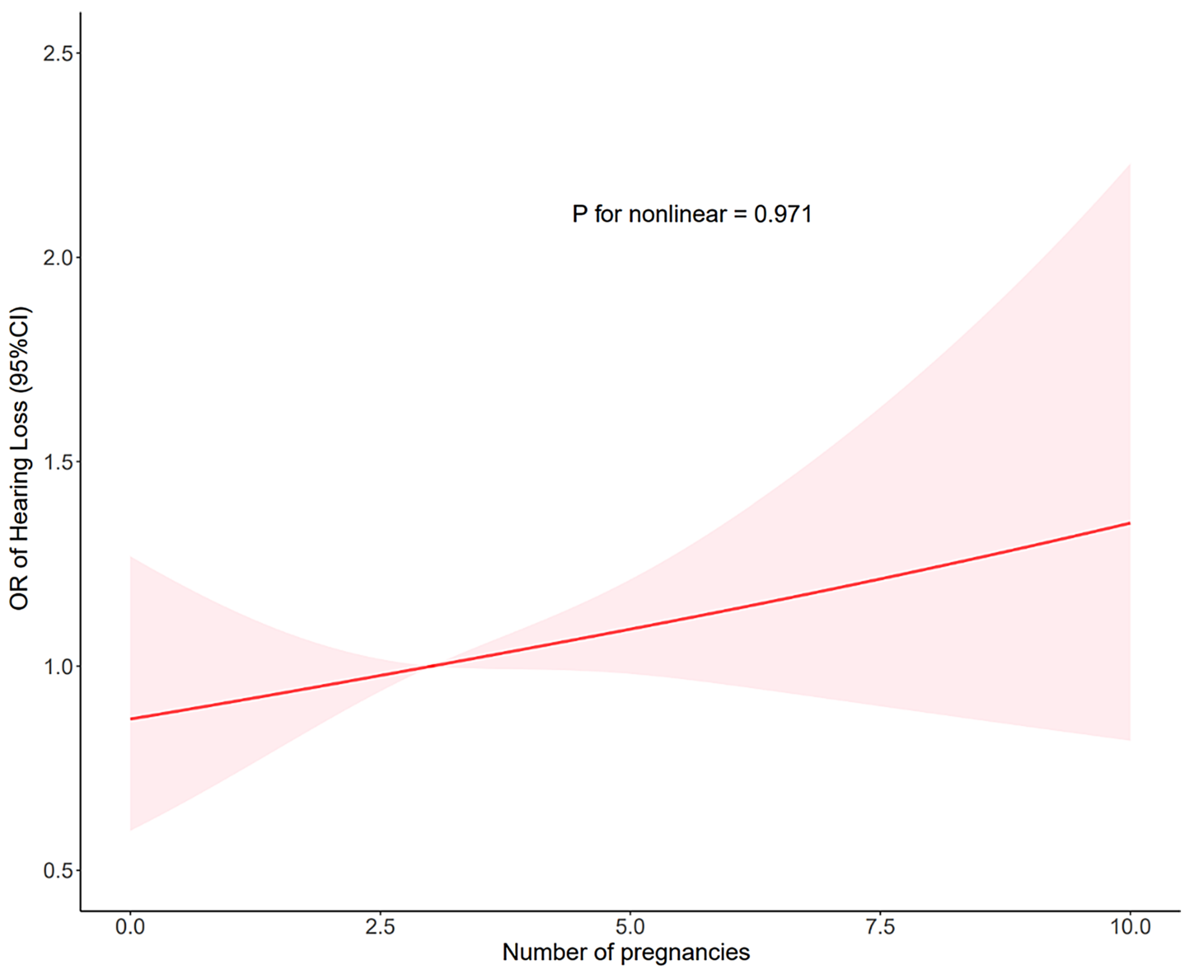

Fig. 2 Restricted cubic spline plot of the association between the number of pregnancies and hearing loss in adult women. The solid lines and shaded areas represent the central risk estimates and 95% CIs. Odds ratios (95% confidence intervals) were obtained from the weighted multivariable logistic regression models, adjusted for age, race, BMI, education level, family PIR, marital status, smoking status, alcohol consumption, noise exposure, hypertension, diabetes, and menopause. Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratios; PIR, income-to-poverty ratio

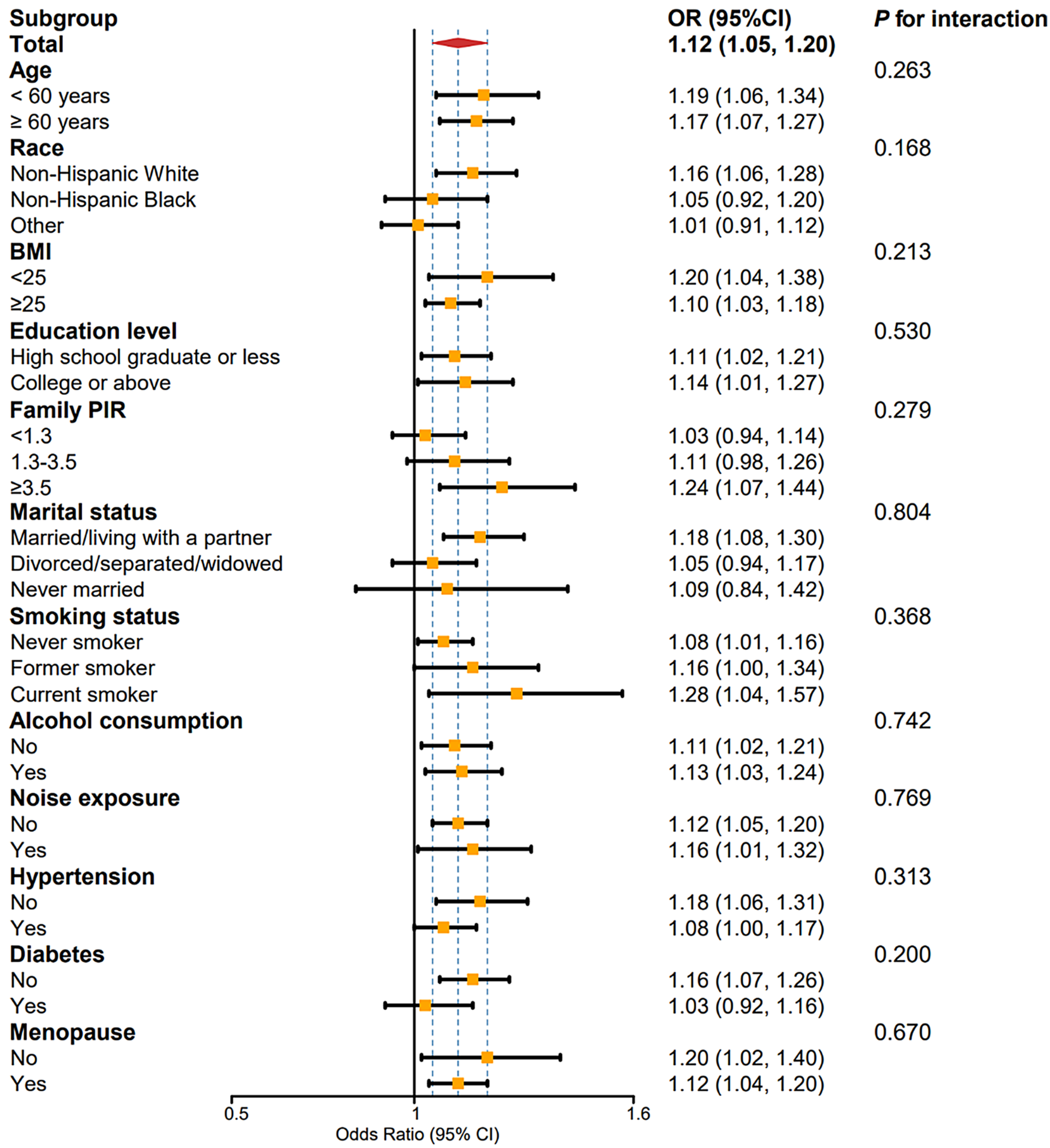

Fig. 3 Forest plot of subgroup analysis of the association between the number of pregnancies and hearing loss in adult women. Odds ratios (95% confidence intervals) were obtained after individually removing the examined variable from the weighted multivariable logistic regression models, adjusted for age, race, BMI, education level, family PIR, marital status, smoking status, alcohol consumption, noise exposure, hypertension, diabetes, and menopause. Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratios; PIR, income-to-poverty ratio

interaction analyses, none of the interactions reached statistical significance, indicating that no heterogeneity was observed in the association across different subgroups.

Figure 4 presents the results of mediation analysis, which investigated potential mediators in the association between the number of pregnancies and hearing loss. Significant indirect effects of WBC and HDL were identified. The Sobel test confirmed that WBC and HDL mediated the association between the number of pregnancies and hearing loss, accounting for 3.44% and 7.72% of the effect, respectively (both $P < 0.001$).

Sensitivity analysis

To evaluate the robustness of our findings, two sensitivity analyses were conducted. First, hearing loss was redefined as a PTA ≥ 20 dB HL in the better-hearing ear, according to the classification recommended by the GBD Expert Group (Supplementary Table 3). Under this definition, a higher number of pregnancies remained

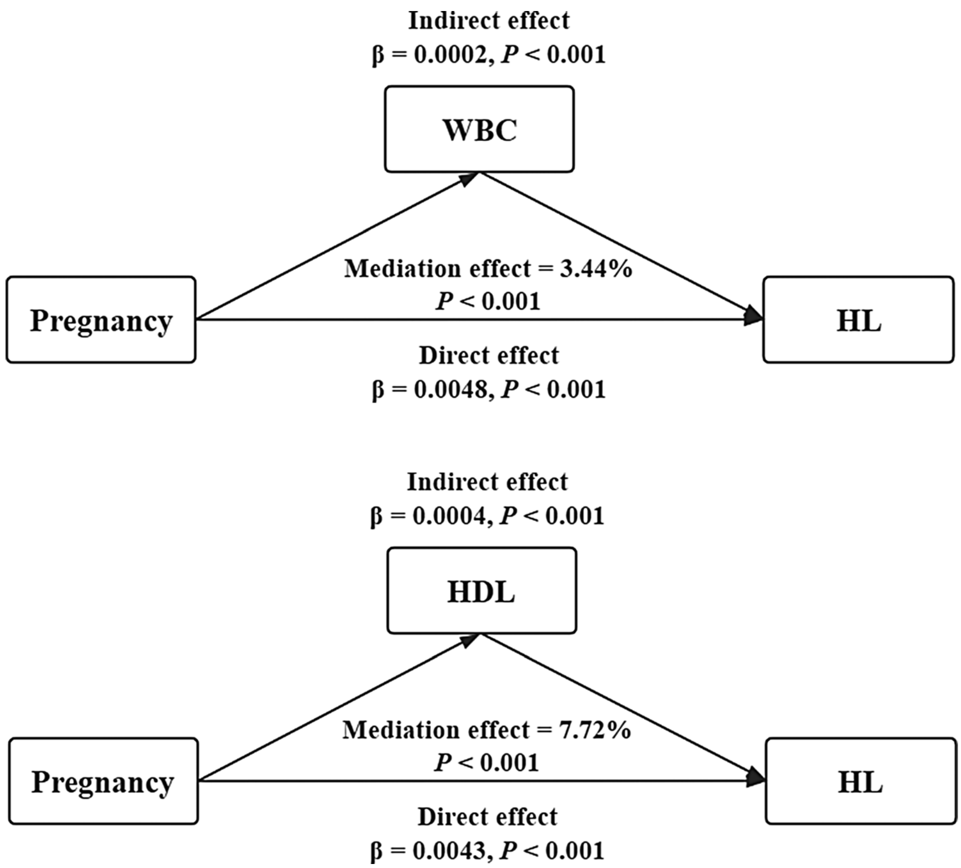

Fig. 4 Mediation models of WBC and HDL in the association between the number of pregnancies and hearing loss in adult women. Adjusted for age, race, BMI, education level, family PIR, marital status, smoking status, alcohol consumption, noise exposure, hypertension, diabetes, and menopause. Abbreviations: BMI, body mass index; β, regression coefficient; HL, hearing loss; HDL, high-density lipoprotein; PIR, income-to-poverty ratio; WBC, white blood cell

significantly associated with hearing loss. After adjusting for covariates in Model 3, the OR for adult women was 1.09 (95% CI: 1.02–1.15; $P<0.01$). Conversely, birth control pill use continued to be associated with lower odds of hearing loss, with an OR of 0.66 (95% CI: 0.49–0.89; $P<0.01$). Second, to address potential selection bias arising from the exclusion of participants with missing covariate data, we performed multiple imputation followed by reanalysis (Supplementary Table 4). In the imputed dataset, a higher number of pregnancies was still significantly associated with hearing loss (OR: 1.11; 95% CI: 1.06–1.17; $P<0.001$), and birth control pill use remained associated with reduced odds of hearing loss (OR: 0.75; 95% CI: 0.59–0.94; $P<0.05$) after full adjustment in Model 3. In both sensitivity analyses, no statistically significant associations were observed for age at menarche, age at last menstruation, length of reproductive period, age at first delivery, age at last delivery, or number of pregnancy losses. Overall, the sensitivity analyses yielded results consistent with the main findings, supporting the robustness of our conclusions.

Discussion

In our study, we analyzed data from 5,269 adult women in NHANES, a nationally representative survey of the U.S. population. We observed that women with a higher number of pregnancies were more likely to have hearing loss compared to those with fewer pregnancies. Based on this finding, we provide the first evidence that, among U.S. women, a higher number of pregnancies is independently associated with hearing loss. Meanwhile, we identified a protective effect of birth control pill use, as women who used birth control pills were significantly less likely to experience hearing impairment. Similar associations were observed in elderly women, where a higher number of pregnancies was linked to ARHL. Subgroup and sensitivity analyses further corroborated the consistency and robustness of the association between the number of pregnancies and hearing loss. Additionally, mediation analyses revealed that WBC and HDL partially mediated this association.

The WHO's World Report on Hearing 2021 indicates that 211 million women worldwide suffer from moderate or more severe degrees of hearing loss [3]. Compared with men, women with hearing loss experience disproportionately higher levels of social isolation and loneliness, and are more susceptible to cognitive decline and brain atrophy [3, 41, 42]. Furthermore, hearing loss is more strongly associated with depression and anxiety in women than in men [43]. Additionally, hormonal changes associated with pregnancy, which may contribute to hearing loss, are often accompanied by symptoms such as tinnitus and vertigo, which can worsen mental health issues in women [44, 45]. Consequently, women's hearing health has become an increasingly urgent focus within public health, and the demand for research into female-specific hearing health issues is growing. However, significant sex bias remains in hearing loss research. Basic and preclinical studies often rely on male animals, with female subjects being notably underrepresented [46, 47]. Similarly, clinical trials often feature a higher number of male participants [48]. This disparity hinders the development of a comprehensive understanding of the unique risk factors for hearing loss in women and the creation of tailored treatment strategies that address the specific needs and physiological differences of female patients.

Pregnancy, as one of the most significant physiological differences between males and females, triggers a range of physical and psychological changes, which are associated with various health conditions, including hearing loss [22, 49, 50]. These changes not only affect maternal health during gestation but also have lasting consequences for overall well-being, with potential implications for hearing as well [26–28]. Fluctuations in estrogen levels during pregnancy can impact auditory function by interacting with the spiral ganglion's estrogen receptor α and the stria vascularis's estrogen receptor β, both of which are critical for auditory transmission and inner ear homeostasis [51, 52]. Additionally, estrogen may modulate auditory function at multiple levels of the central nervous system by influencing the glutamatergic and GABAergic systems [53, 54]. Under normal physiological conditions, such as during the menstrual cycle and menopause, estrogen is generally considered to exert protective effects on hearing [55]. However, recent studies have shown that high doses of estrogen or combined estrogen-progesterone therapy may accelerate auditory deterioration by disrupting cochlear ion homeostasis, impairing outer hair cell function, diminishing auditory neural excitability, and increasing oxidative stress [56–58].

During pregnancy, the interaction and positive feedback between the placenta and the maternal hypothalamic-pituitary-gonadal axis lead to a marked elevation in circulating hormone levels [59]. By the third trimester, circulating progesterone levels increase by approximately 20-fold, and serum estradiol levels rise by 30- to 40-fold compared to those during a normal menstrual cycle [20]. However, this surge in estrogen and progesterone has not been shown to confer protective effects on hearing. Instead, the elevated estrogen and progesterone during pregnancy modulate neurological function and are associated with a high prevalence of inner ear disorders, particularly during the third trimester [20]. Moreover, increased levels of estrogen and progesterone have been linked to sudden sensorineural hearing loss during pregnancy [60, 61]. Prolonged hyperprolactinemia induced by pregnancy-related estrogen elevation has also been implicated in damage to the saccule and hair cells, and proposed as a potential mechanism contributing to the development of otosclerosis in women with multiple pregnancies [62–64]. Additionally, estrogen activity during pregnancy may contribute to Eustachian tube dysfunction, promoting tube obstruction and predisposing individuals to glue ear or otitis media with effusion [65]. Collectively, these findings suggest that high levels of estrogen and progesterone during pregnancy may contribute to the development of hearing loss rather than confer protection. Although a single pregnancy is associated with statistically significant, yet subclinical, changes in hearing thresholds [21], an increasing number of pregnancies leads to substantial cumulative exposure to elevated hormone levels, which may, in turn, strengthen the association with hearing impairment. However, direct mechanistic evidence linking cumulative hormonal exposure during multiple pregnancies to progressive auditory degeneration remains limited, warranting further investigation.

In our study, subgroup analyses revealed that the association between the number of pregnancies and hearing loss was more pronounced among non-Hispanic White, high-income, married or cohabiting, and non-diabetic women. These findings suggest that the relationship between the number of pregnancies and hearing loss may be more evident in population subgroups characterized by relatively stable endocrine environments and more regular cumulative exposure to elevated estrogen and progesterone levels. In particular, among women who are more likely to experience planned pregnancies and receive consistent prenatal care—such as those with higher socioeconomic status and better overall health [66, 67]—the cumulative hormonal fluctuations associated with repeated pregnancies may more markedly contribute to progressive microstructural alterations in the auditory system. Moreover, in these populations, the effects of hormonal changes may be more readily detectable, as they are less likely to be masked by competing risk factors such as poor nutritional status, chronic disease burden, or limited access to healthcare. Importantly, we observed no statistically significant interactions across subgroups, indicating that these differences do not modify the overall association and further reinforcing the robustness of the link between the number of pregnancies and hearing loss.

Multiple pregnancies also contribute to long-term metabolic dysregulation, promoting atherosclerosis [68, 69], where cumulative vascular stress may progressively impair cochlear microcirculation and ultimately lead to hearing loss [70]. Additionally, a higher number of pregnancies is associated with increased coagulation activity and decreased fibrinolysis, resulting in a hypercoagulable state [71]. This increased coagulability exerts pressure on the inner ear's microcirculation and raises the risk of thrombosis in the cochlear artery, potentially disrupting inner ear circulation and contributing to hearing loss [22, 72]. Moreover, other mechanisms may be implicated in pregnancy-related hearing loss, such as lipid metabolism and chronic inflammation. Women who have given birth often exhibit lower levels of HDL compared to those who have never been pregnant [73], and low HDL levels have been linked to hearing loss [74, 75]. Inflammation has been established as one of the key mechanisms underlying hearing loss [76], and inflammatory responses during pregnancy have also been implicated in auditory dysfunction [77]. Multiple pregnancies exacerbate chronic systemic inflammation [71, 78], which may further impair auditory function. Our study identifies HDL and WBC as mediators in the relationship between the number of pregnancies and hearing loss, consistent with findings from previous research.

Birth control pills, which achieve contraception by regulating circulating estrogen and progesterone levels, are among the primary methods used to control the number of pregnancies and have become a focus of research due to their impact on various health conditions [79–81]. While studies have reported relationships between the use of birth control pills and various audiological outcomes—such as otoacoustic emissions (OAE) [82], auditory brainstem response (ABR) [83], and auditory sensitivity [84]—some evidence suggests that birth control pills have no significant effect on hearing function or otological diseases [85–87]. In our study, we found that women with a higher number of pregnancies had higher odds of hearing loss, whereas women who used birth control pills exhibited a protective effect against hearing impairment. This discrepancy may stem from variations in study populations and methodologies. Previous research predominantly involved younger women who had recently used birth control pills, focusing on short-term, direct effects on hearing function. In contrast, our study investigated the potential long-term, indirect association of birth control pill use with hearing loss, indicating that the observed association may be mediated by a lower cumulative number of pregnancies over a woman's lifetime. This hypothesis is further supported by our supplementary analysis restricted to women with zero pregnancies, where birth control pill use was not significantly associated with hearing loss (Supplementary Table 5). Additionally, the small sample sizes in previous studies, along with variations in the type of birth control pills used and the duration of use, may also contribute to these differing findings. Further research is required to elucidate the association between birth control pill use and hearing health, particularly in differentiating short-term direct effects from long-term indirect impacts.

Recent studies on women's health across the life course have increasingly shifted their focus from short-term health and socioeconomic outcomes to the long-term physical and psychological consequences of childbearing, particularly high parity [26, 88, 89]. High parity has been associated not only with chronic conditions such as cardiovascular disease, diabetes, hypertension, and chronic kidney disease, but also with mental diseases, such as depression, bipolar disorder, and schizophrenia [31, 90–94]. These conditions have far-reaching consequences, including reduced quality of life, functional impairment, and greater reliance on medical care. Moreover, they place a substantial burden on families, healthcare systems, and society as a whole, contributing to reduced productivity, a greater demand for caregiving, and increased healthcare costs. As a result, controlling the number of pregnancies has been widely promoted by organizations including the WHO, the U.S. Office of Population Affairs, the Centers for Disease Control and Prevention, and the Society of Family Planning [95–98]. These organizations emphasize the importance of family planning and reproductive health education as integral components of public health strategies aimed at improving women's health outcomes. Our findings demonstrated that a higher number of pregnancies is associated with hearing loss in women while also showing that the use of birth control pills provides a protective effect against hearing loss. Consistent with the perspectives advocated by these organizations, our findings emphasize the importance of recognizing the potential auditory health implications of multiple pregnancies and highlight the possible role of appropriate birth control methods in addressing the observed associations related to high parity.

To our knowledge, our study is the first to investigate the association between the number of pregnancies and hearing loss in women. By utilizing a large, nationally representative sample and implementing extensive covariate adjustments, our findings provide valuable insights into the U.S. female population. However, several shortcomings should be admitted. First, the cross-sectional design restricts the ability to infer causality between the number of pregnancies and hearing loss. Longitudinal research is necessary to examine the temporal patterns. Second, hearing loss is a multifactorial condition driven by a combination of genetic and environmental factors. Although we have accounted for a range of confounders, residual confounding from unmeasured variables, such as genetic predisposition or lifestyle factors not captured in NHANES, may still influence our findings. Third, the reliance on self-reported questionnaires for reproductive history introduces the possibility of recall bias, which may impact the accuracy of the data collected. Additionally, this study did not classify hearing loss according to its etiology, limiting the understanding of how different types of hearing loss may be linked to the number of pregnancies. Given the heterogeneity of hearing loss causes, future research should explore whether distinct etiologies contribute to variations in this association. Furthermore, due to the absence of complete otoscopic and tympanometric data across all NHANES cycles, we were unable to exclude participants with potential conductive hearing loss. This may have led to a small degree of outcome misclassification and should be considered when interpreting the results. Addressing these limitations will be essential for further elucidating the complex relationship between the number of pregnancies and hearing health in women.

Conclusion

In conclusion, our study found that a higher number of pregnancies was significantly associated with hearing loss among U.S. women, whereas the use of birth control pills was inversely associated with hearing loss. These findings highlight the importance of considering reproductive history in the evaluation of women's auditory health and may provide valuable insights for future public health strategies.

Abbreviations

ABR	Auditory brainstem response
ARHL	Age-related hearing loss
BMI	Body mass index
β	regression coefficient
CI	Confidence interval
dB	Decibel
HDL	High-density lipoprotein
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Survey
NIH	National Institutes of Health
OAE	Otoacoustic emissions
OR	Odds ratios
PIR	Income-to-poverty ratio
PTA	Pure-tone average
RCS	Restricted cubic spline
SABV	Sex as a biological variable
WBC	White blood cell
WHO	World Health Organization

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-23052-0.

Supplementary Material 1: Supplementary Table 1. Association between reproductive characteristics and age-related hearing loss in elderly women

Supplementary Material 2: Supplementary Fig. 1. Restricted cubic spline plot of the association between the number of pregnancies and age-related hearing loss in elderly women

Supplementary Material 3: Supplementary Table 2. Subgroup analysis of the association between the number of pregnancies and hearing loss in adult women

Supplementary Material 4: Supplementary Table 3. Sensitivity analysis of the association between reproductive characteristics and hearing loss defined as ≥20 dB HL in adult women

Supplementary Material 5: Supplementary Table 4. Sensitivity analysis of the association between reproductive characteristics and hearing loss in adult women based on imputed data

Supplementary Material 6: Supplementary Table 5. Association between birth control pill use and hearing loss in adult women with zero pregnancies (n=933)

Acknowledgements

All authors sincerely thank the NCHS for their efforts in creating the data for the NHANES.

Author contributions

HY played key roles in the conceptualization and design of this study, as well as in the critical revision of the manuscript, ensuring its clarity and scientific rigor. HL and JW contributed to the data curation and statistical analysis process, while also taking the lead in drafting the manuscript and integrating feedback for refinement. ZC and MG provided essential support in the data collection phase, ensuring the accuracy and completeness of the dataset.

Funding

This work was supported by Featured Clinical Technique of Guangzhou (2023P-TS37, Haidi Yang).

Data availability

The datasets generated and/or analyzed during the current study are available in the [National Health and Nutrition Examination Survey], [https://wwwn.cdc.gov/nchs/nhanes/].

Declarations

Ethics approval and consent to participate

The study protocol was approved by the National Center for Health Statistics Research Ethics Review Committee, and was performed in accordance with the Declaration of Helsinki, with all NHANES participants providing signed informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Received: 22 January 2025 / Accepted: 6 May 2025
Published online: 22 May 2025

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