Annals of Internal Medicine | ARTICLE

Diabetes and Hearing Impairment in the United States: Audiometric Evidence from the National Health and Nutrition Examination Survey, 1999 to 2004

Kathleen E. Bainbridge, PhD, MPH; Howard J. Hoffman, MA; and Catherine C. Cowie, PhD, MPH

Background: Diabetes might affect the vasculature and neural system of the inner ear, leading to hearing impairment.

Objective: To determine whether hearing impairment is more prevalent among U.S. adults with diabetes.

Design: Cross-sectional analysis of nationally representative data.

Setting: National Health and Nutrition Examination Survey, 1999 to 2004.

Participants: 5140 noninstitutionalized adults age 20 to 69 years who had audiometric testing.

Measurements: Hearing impairment was assessed from the pure tone average of thresholds over low or mid-frequencies (500, 1000, and 2000 Hz) and high frequencies (3000, 4000, 6000, and 8000 Hz) and was defined as mild or greater severity (pure tone average >25 decibels hearing level [dB HL]) and moderate or greater severity (pure tone average >40 dB HL).

Results: Hearing impairment was more prevalent among adults with diabetes. Age-adjusted prevalence of low- or mid-frequency hearing impairment of mild or greater severity in the worse ear was 21.3% (95% CI, 15.0% to 27.5%) among 399 adults with diabetes compared with 9.4% (CI, 8.2% to 10.5%) among 4741 adults without diabetes. Similarly, age-adjusted prevalence of high-frequency hearing impairment of mild or greater severity in the worse ear was 54.1% (CI, 45.9% to 62.3%) among those with diabetes compared with 32.0% (CI, 30.5% to 33.5%) among those without diabetes. The association between diabetes and hearing impairment was independent of known risk factors for hearing impairment, such as noise exposure, ototoxic medication use, and smoking (adjusted odds ratios for low- or mid-frequency and high-frequency hearing impairment were 1.82 [CI, 1.27 to 2.60] and 2.16 [CI, 1.47 to 3.18], respectively).

Limitations: The diagnosis of diabetes was based on self-report. The investigators could not distinguish between type 1 and type 2 diabetes. Noise exposure was based on participant recall.

Conclusion: Hearing impairment is common in adults with diabetes, and diabetes seems to be an independent risk factor for the condition.

Ann Intern Med. 2008;149:1-10. www.annals.org
For author affiliations, see end of text.

Hearing loss, reported by more than 17% of the U.S. adult population, is a major public health concern affecting more than 36 million people (1). Risk for hearing impairment is associated with male sex, lower education, industrial or military occupation, and leisure time noise exposure (2–4), and prevalent hearing impairment has been correlated with smoking (5). Prevalence varies substantially by age, sex, and race, and estimates exceed 30% among those age 65 years or older (1). In 1 community-based study, 46% of the population age 43 to 84 years was classified as hearing-impaired on the basis of audiometric examination (6). These high-prevalence estimates imply that many people are at risk for functional and psychosocial limitations associated with hearing impairment (7, 8).

Diabetes mellitus affects an estimated 9.6% of the U.S. adult population (9, 10) and is associated with microvascular and neuropathic complications affecting the retina, kidney, peripheral arteries, and peripheral nerves (11). The pathologic changes that accompany diabetes could injure the vasculature or the neural system of the inner ear, resulting in sensorineural hearing impairment. Two studies (12, 13) described evidence of such pathologic changes, including sclerosis of the internal auditory artery, thickened capillaries of the stria vascularis, atrophy of the spiral ganglion, and demyelination of the eighth cranial nerve among patients with diabetes in whom autopsy was done. Clinical evidence supporting an association between diabetes and hearing impairment is limited to several small studies (14–18) or noise-exposed samples (19). Epidemiologic evidence from 1 population-based cohort study suggested a modest association (20). We used recent national survey data to examine the relationship between diabetes and hearing impairment. Specifically, we designed this analysis to determine whether hearing impairment is more prevalent among U.S. adults who report a diagnosis of diabetes than those who report no diagnosis and whether differences in prevalence by diabetes status occur predominantly in specific U.S. population subgroups.

See also:

Print
Editors' Notes 2
Editorial comment 54
Summary for Patients I-20

Web-Only
Appendix
Appendix Tables
Conversion of graphics into slides

Context

Previous studies have hinted at an association between diabetes mellitus and hearing impairment.

Contribution

Using data from a national survey, the investigators found a higher prevalence of hearing impairment among persons with diabetes than in those without diabetes (21% vs. 9%).

Caution

Diabetes was self-reported and was verified in only a small proportion of participants. The investigators did not distinguish between type 1 and type 2 diabetes.

Implication

Hearing impairment is common among adults with diabetes.

—The Editors

METHODS

Participants

Data from NHANES (National Health and Nutrition Examination Survey) were collected by the National Center for Health Statistics from 1999 to 2004 by using a complex, multistage, probability sample designed to represent the civilian, noninstitutionalized U.S. population. Half of the study participants (n = 11 405) age 20 to 69 years were randomly assigned to audiometric testing. Of the 5742 assigned, we included 5140 (89.5%) persons who completed the audiometric examination and the diabetes questionnaire in this analysis. Major reasons for not completing an examination included time limitation (n = 128 [2.2%]), physical limitation (n = 60 [1.0%]), communication problem (n = 42 [0.7%]), refusal (n = 81 [1.4%]), and equipment failure (n = 47 [0.8%]). Included among the 60 participants with a physical limitation is an unknown number of participants who were not tested because they could not remove their hearing aids; 7 of these participants reported diabetes.

Measures

As part of the NHANES survey, pure tone air conduction hearing thresholds were obtained for each ear at frequencies of 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Higher frequencies are perceived as higher pitches. Audiologists usually consider tones of 500 Hz or less to be low frequency, tones from 1000 to 2000 Hz to be of mid-range frequency, and tones of 3000 Hz or greater to be high frequency. The measurements were collected by trained audiometric technicians by using a calibrated audiometer that met accepted standards (**Appendix**, available at www.annals.org).

We derived measures of hearing impairment for 2 ranges of frequency (low or mid and high) and 2 categories of severity (mild or greater and moderate or greater). To produce low- or mid-frequency pure tone averages, we averaged pure tone thresholds (the signal intensities needed to perceive the tones) measured at 500, 1000, and 2000 Hz for each individual and ear (21). We averaged pure tone thresholds measured at 3000, 4000, 6000, and 8000 Hz (22, 23) for each individual and ear to produce high-frequency pure tone averages. For each frequency range, a pure tone average greater than 25 decibels hearing level (dB HL) defined hearing impairment of mild or greater severity, whereas a pure tone average greater than 40 dB HL defined hearing impairment of moderate or greater severity (24). For each combination of frequency range and severity, we defined hearing impairment in terms of the pure tone average in the worse ear, which designates persons with impairment in at least 1 ear. We also defined hearing impairment in terms of the better ear, which designates persons with impairment in both ears (a subset of the persons impaired in at least 1 ear). **Table 1** shows functional descriptions of hearing impairment, by frequency range and severity. In addition, we classified participants as having self-reported hearing impairment if they reported having a little trouble hearing, having a lot of trouble hearing, or being deaf without a hearing aid (1).

Among the 5140 participants, the National Center for Health Statistics identified 24 participants with at least 1 audiometric nonresponse (that is, participants did not perceive the pure tone at any level of intensity). We classified these cases as impaired for a frequency range if the audiometric nonresponse occurred within the range. An examination of these participants' available pure tone thresholds corroborated their classification as impaired at both levels of severity.

Table 1. **Functional Description of Hearing Impairment, by Severity of Impairment and Frequency Range**

Frequency Range	Severity of Impairment	
	Pure Tone Average Threshold >25 to 40 dB HL	Pure Tone Average Threshold >40 dB HL
Low or mid	Slight difficulty with understanding speech under ideal listening conditions	Considerable difficulty with understanding speech under ideal listening conditions
High	Slight difficulty with understanding speech under unfavorable listening conditions	Considerable difficulty with understanding speech under unfavorable listening conditions

dB HL = decibels hearing level.

Information on demographic characteristics, diagnosed diabetes, noise exposure, medication use, and smoking was obtained during in-home interviews. Education was assessed as the highest grade level or degree attained. Income–poverty ratio was defined as the ratio of reported total family income to the U.S. Census Bureau poverty threshold, which varies by family size and age of family members. Diagnosed diabetes was assessed with the question, "Other than during pregnancy (for women), have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?" Of the 5140 participants, 2259 received an additional random assignment to a fasting protocol and subsequent blood draw. Of the 2259 participants, 146 reported a diagnosis of diabetes. Of the remainder, 73 participants were classified as having undiagnosed diabetes (fasting plasma glucose level ≥7 mmol/L [≥126 mg/dL]) and 539 were classified as having impaired fasting glucose (fasting plasma glucose level ≥5.6 mmol/L [≥100 mg/dL], but <7 mmol/L [<126 mg/dL]). The remaining 1501 participants were defined as having normal glycemic status.

Occupational noise exposure was defined as reporting a history of loud noise at work that required speaking in a loud voice to be heard. Leisure-time noise exposure was based on participant recall of noise from firearms (outside of work) or other sources (such as loud music or power tools) for an average of at least once a month for 1 year. History of military service was determined from a question asking about ever having served in the U.S. Armed Forces. Use of ototoxic medications was assessed by a review of medication containers. Because the small proportion of adults reporting use of aminoglycoside antibiotics (0.03%), loop diuretics (1.5%), antineoplastic drugs (5.0%), and nonsteroidal anti-inflammatory drugs (7.3%) precluded analysis of these medications individually, we defined use of ototoxic medication as use in the past 30 days of any of these 4 drug classes.

Statistical Analysis

Differences in the distribution of sociodemographic characteristics, military history, noise exposure (leisure time and occupational), ototoxic medication use, smoking, and diagnosed diabetes were tested by using the *t* test (for continuous characteristics) or chi-square test (for categorical characteristics). Unadjusted prevalence estimates and 95% CIs for the hearing impairment outcomes were assessed by diagnosed diabetes status. Prevalence estimates were additionally stratified by sociodemographic characteristics, military history, leisure-time noise exposure, occupational noise exposure, ototoxic medication use, and smoking to identify population subgroups that may be particularly vulnerable to diabetes-related hearing impairment. Age-adjusted prevalence estimates were computed by direct standardization to the 2000 U.S. Census population by using age categories of 20 to 49 years, 50 to 59 years, and 60 to 69 years. Statistical significance of the difference between unadjusted estimates was determined from chi-square test statistics for a general association, and the Cochran–Mantel–Haenszel chi-square test was used to determine the statistical significance of the difference between age-adjusted estimates. For the 2259 participants who had been randomly assigned to the fasting protocol, age-adjusted prevalence estimates of high-frequency hearing impairment were generated by glycemic status (diagnosed diabetes, undiagnosed diabetes, impaired fasting glucose, or normal). Odds ratios (with 95% CIs) for the independent association of diabetes with hearing impairment were estimated by using multiple logistic regression models, adjusting for age, sex, race or ethnicity, education, income–poverty ratio, leisure-time noise exposure, occupational noise exposure, history of military service, use of ototoxic medications, and smoking. Age was treated as a continuous variable in all regression models. Nonlinear effects of age on the logit of each outcome were examined by testing the addition of an age squared term to each model but were not statistically significant. By using the concordance index, we assessed predictive accuracy, which ranged from 80% to 90% for each of the 8 audiometrically assessed outcomes and was 72% for self-reported hearing impairment. Six of the 9 models passed the Hosmer–Lemeshow goodness-of-fit tests. Finally, the frequency-specific pure tone thresholds were examined graphically by averaging within-person thresholds over both ears and plotting the age-adjusted and age-specific mean thresholds stratified by diagnosed diabetes status.

We used SAS software, version 9.1 (SAS Institute, Cary, North Carolina), and SUDAAN, version 9.0.1 (Research Triangle Institute, Research Triangle Park, North Carolina), for all analyses and incorporated 6-year sample weights that were adjusted for oversampling of ethnic minorities, elderly persons, and those of low income; eligibility of half of the sample for audiometric testing; and nonresponse of eligible individuals who were not tested. We computed 6-year audiometric sample weights by assigning two thirds of the 4-year audiometric weight for persons sampled from 1999 to 2002 and one third of the 2-year audiometric weight for persons sampled from 2003 to 2004.

Role of the Funding Source

The U.S. Department of Health and Human Services funds NHANES and oversees the conduct and reporting of the NHANES. As employees or contractors of the U.S. Department of Health and Human Services, the authors had a direct role in the reporting and analysis of data and the decision to submit the manuscript for publication.

RESULTS

Table 2 shows characteristics of the U.S. population, stratified by low- or mid-frequency hearing impairment of mild or greater severity assessed in the worse ear. People with hearing impairment were older than those without

Table 2. **Characteristics of the U.S. Population Age 20 to 69 Years, by Low- or Mid-Frequency Hearing Impairment of Mild or Greater Severity in the Worse Ear***

Characteristic	Hearing Impaired (n = 587)	Not Hearing Impaired (n = 4553)	*P* Value
Mean age (SD†), *y*	53.2 (11.7)	40.6 (12.7)	<0.001
Race or ethnicity, %			
Non-Hispanic white	75.8	69.7	–
Non-Hispanic black	7.6	12.0	–
Mexican American	4.8	8.3	–
Other (including multiracial)	11.8	10.0	<0.001
Sex, %			
Men	53.8	48.3	–
Women	46.2	51.7	0.065
Education, %			
Less than high school	27.3	17.2	–
High school	27.6	25.0	–
More than high school	45.1	57.8	<0.001
Income–poverty ratio, %			
≤1.0	16.5	13.9	–
>1.0	83.5	86.1	0.23
History of military service, %	20.4	11.5	<0.001
Leisure-time noise exposure, %	31.1	29.0	0.43
Occupational noise exposure, %	39.7	33.8	0.033
Ototoxic drug use, %	21.0	11.7	0.001
Current smoker, %	27.8	28.3	0.81
Diagnosed diabetes, %	16.6	4.8	<0.001

* Data from the National Health and Nutrition Examination Survey, 1999–2004 (n = 5140). *Hearing impairment* is defined as a pure tone average >25 decibels hearing level of thresholds assessed at 500, 1000, and 2000 Hz.
† Standard deviation does not account for the complex sample design of the survey.

hearing impairment by an average of 13 years, more likely to be non-Hispanic white, and more likely to have less than a high school level of education. People with hearing impairment were also more likely to report having served in the military, experienced occupational noise exposure, and used ototoxic medications. The effects of military history and ototoxic medications were explained by the older age of participants with these characteristics. People with hearing impairment were no more likely than those without hearing impairment to report an income–poverty ratio of 1.0 or less, leisure-time noise exposure, or current smoking, although associations with income–poverty ratio and leisure-time noise exposure were observed when we corrected for age. Finally, people with hearing impairment were more likely to report diabetes, an effect not explained by age in preliminary analyses. All other characteristics were associated with diagnosed diabetes in preliminary analyses (data not shown), suggesting that they should be treated as likely confounders when assessing the potential relationship between hearing impairment and diabetes.

Table 3 shows unadjusted and age-adjusted prevalence estimates of hearing impairment in the United States, by diagnosed diabetes status. The unadjusted prevalence estimates for all 9 outcomes were statistically higher among individuals with diabetes than those without diabetes. Differences in prevalence were attenuated but remained statistically significant after adjustment for age.

The **Figure** shows age-adjusted and age-specific mean pure tone thresholds (averaged first within participants over both ears), by diagnosed diabetes status. Persons with diabetes had higher thresholds at all frequencies than persons without diabetes, and the difference seemed to widen at frequencies greater than 2000 Hz (**Figure,** *A*). Although these curves represent population averages, 2 individuals with these profiles would have clinically significant differences in hearing impairment. Age-specific analyses (**Figure**, *B* through *F*) demonstrate the consistency of higher pure tone thresholds across the entire frequency range and across all age groups for people with diabetes. The curve for people with diabetes age 20 to 29 years (**Figure**, *B*) should be interpreted with caution because it is based on only 10 people (most of whom probably have type 1 diabetes), and an examination of the age distribution within this age group suggests that age differs between those with diabetes and those without.

Table 4 shows the prevalence of low- or mid-frequency hearing impairment of mild or greater severity assessed in the worse ear in specific subgroups. The prevalence of hearing impairment among people with diagnosed diabetes statistically exceeded the prevalence among those without diabetes in all groups except persons age 60 to 69 years. Statistically significant differences by diabetes status remained after age adjustment within most subgroups. **Appendix Tables 1** to **8** (available at www.annals.org) show the results for the other audiometric outcomes and self-reported hearing impairment. Findings were similar for all 4 high-frequency hearing impairment outcomes (**Appendix Tables 1**, **3**, **5**, and 7, available at www.annals

.org). The low prevalence of low- or mid-frequency hearing impairment of moderate or greater severity assessed in the worse ear (**Appendix Table 2**, available at www.annals.org) or better ear (**Appendix Table 6**, available at www.annals.org) resulted in insufficient statistical power to detect statistically significant differences in subgroup specific prevalence by diabetes status.

Table 5 shows the age-adjusted prevalence of high-frequency hearing impairment, by glycemic status (normal, impaired fasting glucose, or diabetes). The prevalence of hearing impairment was statistically higher for those with impaired fasting glucose than those with normal fasting glucose for 3 of the 4 outcomes and was statistically higher for all 4 outcomes among persons with diabetes than those with normal fasting glucose levels. There was no difference in prevalence between persons with diagnosed diabetes and those with undiagnosed diabetes.

In multivariable analyses, people with diabetes had statistically significant increased odds of hearing impairment in worse and better ears at all levels of severity and frequency (**Table 6**). Estimates were generally similar across frequencies except those for hearing impairment of moderate or greater severity assessed in the better ear, in which the odds ratio estimate of low- or mid-frequency hearing impairment was higher, and that of high-frequency hearing impairment was lower than all the others. Additional adjustment for hypertension and cardiovascular disease did not substantively change the odds ratio estimates (data not shown).

Discussion

We evaluated the association between diabetes and audiometrically assessed hearing impairment in the U.S. noninstitutionalized population by using nationally representative data. We estimate a prevalence of low- or mid-frequency hearing impairment of mild or greater severity of 28.0% among people with diabetes. The prevalence of hearing impairment was higher among individuals with diabetes in both sexes; all groups of race or ethnicity, education, and income–poverty ratio; and all age groups but the oldest (those 60 to 69 years). The higher prevalence was not limited to possibly predisposed subgroups, such as those who smoke, those with occupational or leisure-time noise exposure, or those taking ototoxic medications. The association between diabetes and hearing impairment remained in analyses that adjusted for other factors that may contribute to impairment.

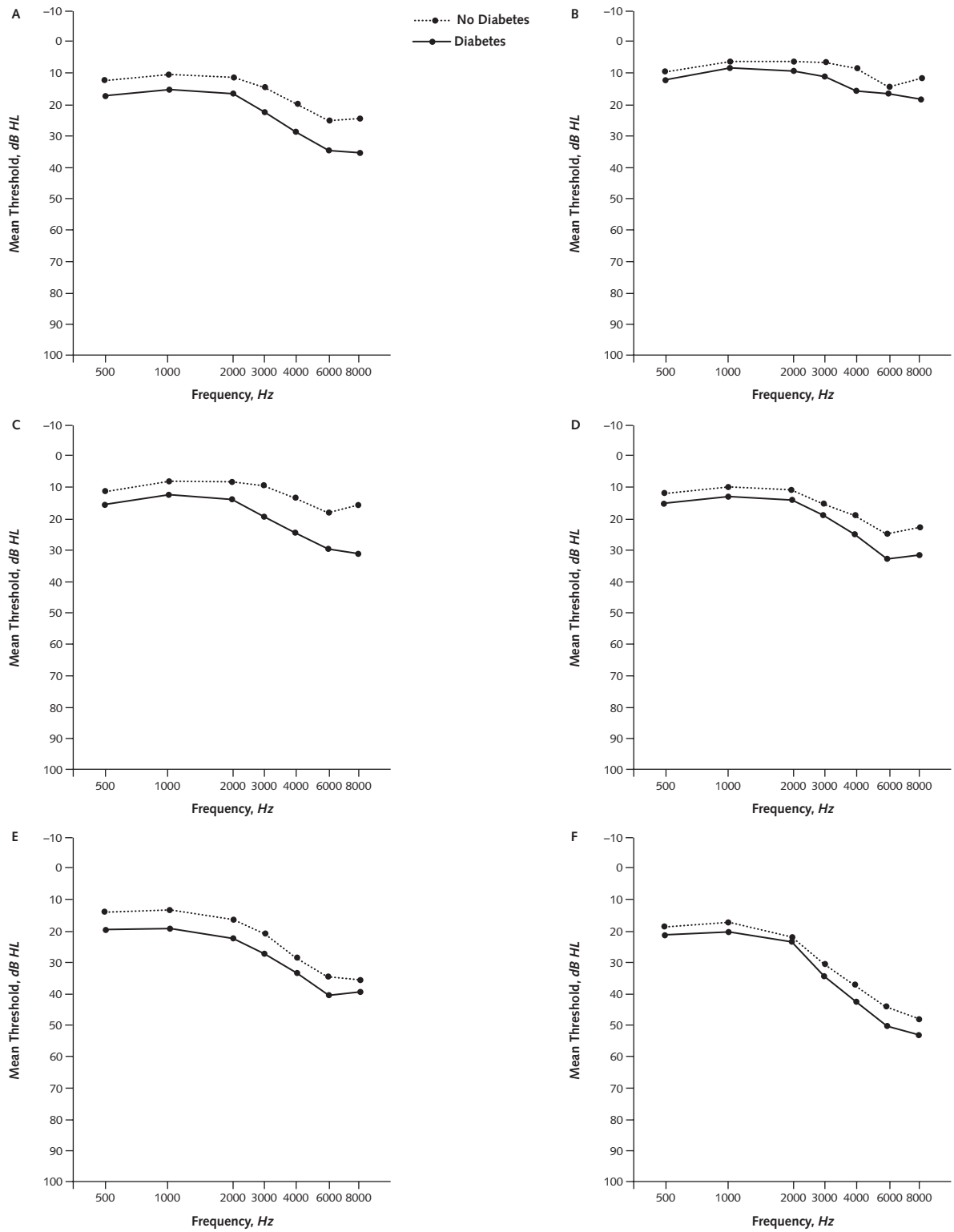
The strength of the association of diabetes with hearing impairment that we observed is similar to that in 2 previous population-based studies (20, 21). We report an odds ratio of 1.82 (CI, 1.27 to 2.60) for low- or mid-frequency hearing impairment of mild or greater severity assessed in the worse ear, whereas Helzner and colleagues (21) and Dalton and coworkers (20) reported odds ratios of 1.41 (95% CI, 1.05 to 1.88) and 1.42 (CI, 1.10 to 1.83), respectively, although the outcome of the latter study was based on a pure tone average in the worse ear of greater than 25 dB HL over frequencies of 500, 1000, 2000, and 4000 Hz. For the purposes of comparison, we replicated the definition of hearing impairment used by

Table 3. **Prevalence of Hearing Impairment in U.S. Adults Age 20 to 69 Years, by Diagnosed Diabetes Status***

Hearing Impairment	Participants, *n*	Prevalence (95% CI), %			Age-Adjusted Prevalence (95% CI), %†		
		Diabetes (*n* = 399)	No Diabetes (*n* = 4741)	*P* Value	Diabetes (*n* = 399)	No Diabetes (*n* = 4741)	*P* Value
Worse ear							
Mild or greater severity (PTA threshold >25 dB HL)							
Low or mid-frequency	587	28.0 (22.7–33.3)	9.0 (7.9–10.1)	<0.001	21.3 (15.0–27.5)	9.4 (8.2–10.5)	<0.001
High frequency	1787	67.8 (62.0–73.5)	31.1 (29.5–32.8)	<0.001	54.1 (45.9–62.3)	32.0 (30.5–33.5)	<0.001
Moderate or greater severity (PTA threshold >40 dB HL)							
Low or mid-frequency	185	9.3 (6.0–12.6)	2.5 (1.9–3.1)	<0.001	4.7 (2.9–6.5)	2.6 (2.0–3.2)	0.011
High frequency	953	45.6 (39.8–51.4)	15.8 (14.5–17.2)	<0.001	37.0 (27.9–46.2)	16.5 (15.2–17.7)	<0.001
Better ear							
Mild or greater severity (PTA threshold >25 dB HL)							
Low or mid-frequency	252	12.6 (8.7–16.5)	3.4 (2.7–4.0)	<0.001	8.4 (4.3–12.6)	3.5 (2.9–4.2)	0.006
High frequency	1194	54.0 (47.9–60.2)	19.4 (18.0–20.7)	<0.001	41.1 (33.5–48.6)	20.1 (18.9–21.3)	<0.001
Moderate or greater severity (PTA threshold >40 dB HL)							
Low or mid-frequency	55	3.3 (1.4–5.2)	0.6 (0.3–0.8)	0.008	1.5 (0.6–2.4)	0.6 (0.3–0.8)	0.014
High frequency	561	27.1 (22.4–31.8)	8.7 (7.7–9.8)	<0.001	18.3 (13.2–23.4)	9.2 (8.3–10.1)	0.002
Self-reported	1087	42.3 (36.5–48.0)	21.5 (20.0–23.0)	<0.001	38.9 (30.1–47.7)	21.7 (20.2–23.2)	<0.001

dB HL = decibels hearing level; PTA = pure tone average.
* Data from the National Health and Nutrition Examination Survey, 1999–2004 (*n* = 5140).
† Age-adjusted to 2000 U.S. Census.

Figure. **Age-adjusted and age-specific mean within-person pure tone thresholds.**



Values are averaged over both ears and presented by diagnosed diabetes status among U.S. adults, National Health and Nutrition Examination Survey, 1999–2004. dB HL = decibels hearing level. **A.** Participants age 20 to 69 years (n = 5140), age-adjusted to the 2000 U.S. Census. **B.** Participants age 20 to 29 years (n = 1209). This panel should be interpreted with caution; the data are based on only 10 people (most of whom probably have type 1 diabetes), and age differed between participants with diabetes and those without. **C.** Participants age 30 to 39 years (n = 1084). **D.** Participants age 40 to 49 years (n = 1036). **E.** Participants age 50 to 59 years (n = 838). **F.** Participants age 60 to 69 years (n = 973).

Dalton and coworkers (20) and observed an odds ratio of 1.89 (CI, 1.27 to 2.81). Our definition of diabetes differed from that used by Dalton and coworkers, who included cases of undiagnosed diabetes and attempted to exclude individuals with type 1 diabetes. Our analysis focused on people reporting a diabetes diagnosis. Because of the self-reported nature of our assessment, we could not restrict our analyses to people with type 2 diabetes, although 90% to 95% of diabetes in our nationally representative sample of adults with diabetes was probably type 2 (9).

Differences in age composition might account for the modest differences in the strength of association among these population-based studies. The adults in Helzner and colleagues' study (21) were 73 to 84 years of age, and those studied by Dalton and coworkers (20) were between 43 and 84 years of age. The relative contribution of diabetes to hearing impairment may be stronger among our substantially younger sample (age 20 to 69 years) before the cumulative effects of aging, noise exposure, and other factors have made substantial contributions to hearing impairment. Our graphical analysis of mean pure tone thresholds suggested that the separation in pure tone thresholds by diabetes status was less in those age 60 to 69 years. In addition, the ratio of the age-specific prevalence estimates for older versus younger participants appears to be smaller (**Table 4**), suggesting that the relative contribution of dia-

Table 4. **Prevalence of Low- or Mid-Frequency Hearing Impairment of Mild or Greater Severity in the Worse Ear***

Characteristic	Prevalence					Age-Adjusted Prevalence (95% CI), %†		
	Diabetes (*n* = 399)		No Diabetes (*n* = 4741)		*P* Value	Diabetes (*n* = 399)	No Diabetes (*n* = 4741)	*P* Value
	Participants, *n*‡	Prevalence (95% CI), %	Participants, *n*‡	Prevalence (95% CI), %				
Age								
20–49 y	97	16.1 (7.7–24.5)	3232	4.7 (3.8–5.6)	0.019	–	–	–
50–59 y	111	32.3 (21.5–43.2)	727	14.2 (10.8–17.5)	0.004	–	–	–
60–69 y	191	36.0 (26.9–45.1)	782	30.4 (25.9–34.8)	0.30	–	–	–
Race or ethnicity								
Non-Hispanic white	139	27.8 (21.8–33.7)	2311	10.0 (8.6–11.5)	<0.001	19.5 (10.3–28.6)	9.8 (8.5–11.1)	0.007
Non-Hispanic black	97	18.1 (11.0–25.2)	956	5.8 (4.2–7.5)	0.010	10.7 (4.1–17.4)	6.8 (4.9–8.8)	0.158
Mexican American	118	17.2 (10.8–23.6)	1090	5.5 (4.3–6.6)	0.002	8.5 (5.8–11.1)	8.1 (6.6–9.7)	0.25
Other§	45	42.6 (26.4–58.7)	384	8.4 (4.8–12.0)	0.002	40.3 (19.3–61.3)	9.6 (6.0–13.2)	0.007
Sex								
Male	192	27.2 (19.6–34.8)	2223	10.1 (8.5–11.7)	<0.001	22.9 (13.7–32.0)	10.8 (9.2–12.3)	0.050
Female	207	28.9 (19.6–38.2)	2518	8.0 (6.6–9.4)	<0.001	19.0 (9.7–28.3)	8.2 (6.8–9.5)	0.005
Education								
Less than high school	166	39.4 (28.3–50.4)	1323	12.8 (9.9–15.6)	<0.001	31.9 (20.0–43.9)	12.1 (9.8–14.4)	0.020
High school	91	25.5 (13.5–37.4)	1090	10.2 (8.1–12.2)	0.026	18.5 (5.8–31.1)	10.5 (8.4–12.6)	0.22
More than high school	142	22.6 (14.7–30.5)	2326	7.4 (6.1–8.7)	0.002	17.0 (8.2–25.8)	7.9 (6.5–9.2)	0.020
Income–poverty ratio								
≤1.0	88	31.3 (20.1–42.5)	796	9.7 (6.9–12.5)	0.003	24.6 (11.4–37.8)	12.7 (9.4–15.9)	0.08
>1.0	273	25.2 (18.8–31.5)	3535	8.6 (7.3–9.9)	<0.001	18.1 (10.5–25.7)	8.8 (7.6–10.0)	0.006
Military history								
Yes	68	36.2 (23.0–49.4)	517	14.4 (11.0–17.8)	0.005	30.1 (6.3–54.0)	9.9 (7.2–12.6)	0.073
No	330	25.7 (19.9–31.5)	4224	8.3 (7.2–9.4)	<0.001	19.6 (13.7–25.5)	9.2 (8.1–10.3)	<0.001
Leisure-time noise exposure								
Yes	87	32.2 (23.0–41.4)	1227	9.6 (7.8–11.4)	<0.001	25.3 (12.9–37.6)	11.5 (9.6–13.4)	0.020
No	312	26.5 (20.8–32.2)	3511	8.8 (7.3–10.3)	<0.001	20.1 (13.5–26.3)	8.6 (7.2–10.0)	0.002
Occupational noise exposure								
Yes	117	29.7 (21.4–37.9)	1475	10.3 (8.6–12.1)	0.001	24.3 (15.1–33.5)	11.2 (9.6–12.8)	0.018
No	254	26.9 (19.5–34.3)	3048	8.1 (6.7–9.5)	<0.001	17.7 (9.7–25.7)	8.3 (7.0–9.7)	0.005
Ototoxic medication use								
Yes	101	38.1 (27.1–49.1)	514	14.0 (9.7–18.2)	<0.001	17.3 (8.8–25.7)	11.1 (7.6–14.5)	0.001
No	298	24.6 (18.2–30.9)	4227	8.4 (7.3–9.4)	<0.001	21.1 (13.5–28.6)	9.2 (8.1–10.3)	0.009
Current smoker								
Yes	94	32.2 (21.7–42.8)	1251	8.8 (7.3–10.3)	<0.001	28.9 (17.3–40.5)	10.0 (8.3–11.7)	0.005
No	305	26.6 (19.9–33.3)	3485	9.1 (7.7–10.5)	<0.001	17.7 (9.9–25.4)	9.0 (7.7–10.3)	0.013

* In U.S. adults age 20–69 years, by diagnosed diabetes status and participant characteristics (data from the National Health and Nutrition Examination Survey, 1999–2004 [*n* = 5140]). *Hearing impairment* is defined as a pure tone average >25 decibels hearing level of thresholds assessed at 500, 1000, and 2000 Hz.
† Age-adjusted to 2000 U.S. Census.
‡ Column totals may not sum to the total number of participants because of missing data on the covariates.
§ Includes multiracial participants.

Table 5. **Age-Adjusted Prevalence of High-Frequency Hearing Impairment, by Glycemic Status***

Glycemic Status	Participants, *n*	Prevalence (95% CI), by Severity of Hearing Impairment, %							
		Worse Ear				Better Ear			
		Mild or Greater (*n* = 811)†	*P* Value‡	Moderate or Greater (*n* = 428)§	*P* Value	Mild or Greater (*n* = 541)	*P* Value	Moderate or Greater (*n* = 265)	*P* Value
Normal	1501	30.4 (28.2–32.6)	–	15.2 (12.8–17.5)	–	19.4 (17.1–21.7)	–	9.8 (7.9–11.7)	–
Impaired fasting glucose	539	40.5 (35.4–45.5)	0.001	22.7 (18.3–27.0)	0.004	25.0 (21.1–28.9)	0.034	10.7 (7.9–13.4)	0.59
Diabetes	219	48.4 (37.1–59.7)	0.003	35.6 (24.4–46.8)	<0.001	36.1 (25.0–47.1)	0.006	19.8 (12.1–27.6)	0.023
Diagnosed	146	48.4 (34.6–62.2)	0.013	35.8 (22.6–49.0)	0.003	37.0 (23.6–50.4)	0.014	19.4 (10.6–28.1)	0.049
Undiagnosed	73	48.2 (29.8–66.5)	0.056	35.5 (17.2–53.8)	0.036	33.3 (16.2–50.4)	0.118	20.8 (6.0–35.5)	0.156

* In U.S. adults age 20–69 years (n = 2259); data from the National Health and Nutrition Examination Survey, 1999–2004. *Hearing impairment* was based on a pure tone average of thresholds averaged over 3000, 4000, 6000, and 8000 Hz.
† Pure tone average threshold >25 decibels hearing level.
‡ For the contrast with normal glycemic status.
§ Pure tone average threshold >40 decibels hearing level.

betes may be less as one ages. Evidence from another relatively young sample of Japanese men in the military demonstrated an 87% increased odds of impairment (using the definition by Dalton and coworkers [20]) for those reporting diabetes, which is consistent with our findings (25).

Gates and colleagues (26) did not find a statistically significant difference in pure tone average (over 250, 500, and 1000 Hz or over 4000, 6000, and 8000 Hz) by diabetes status; however, the mean age of their study cohort was 73 years, and effects of diabetes may be less likely to be observed in a sample of this age. Ma and coworkers (27) examined mean pure tone thresholds at 500, 1000, 2000, and 4000 Hz by using data from the Hispanic Health and Nutrition Examination Survey and observed a higher mean threshold for Mexican-American adults with diabetes, but only at 500 Hz.

Diabetes-related hearing loss has been described as progressive, bilateral, sensorineural impairment with gradual onset predominantly affecting the higher frequencies (15). We observed generally stronger associations between diabetes and high-frequency hearing impairment than between diabetes and low- or mid-frequency hearing impairment. No consistently stronger associations were observed with hearing impairment assessed in the better ear (bilateral impairment) or when assessing greater severity. When we examined hearing thresholds at specific frequencies, thresholds at every frequency were higher for people with diabetes than for people without diabetes. This pattern

Table 6. **Multivariable-Adjusted Odds Ratios***

Hearing Impairment	Participants, *n*	Odds Ratio (95% CI)
Worse ear		
Mild or greater severity (PTA threshold >25 dB HL)		
Low or mid-frequency†	491	1.82 (1.27–2.60)
High frequency†	1537	2.16 (1.47–3.18)
Moderate or greater severity (PTA threshold >40 dB HL)		
Low or mid-frequency	154	1.81 (1.09–3.02)
High frequency†	815	2.29 (1.52–3.44)
Better ear		
Mild or greater severity (PTA threshold >25 dB HL)		
Low or mid-frequency	203	1.80 (1.14–2.85)
High frequency	1025	2.44 (1.65–3.61)
Moderate or greater severity (PTA threshold >40 dB HL)		
Low or mid-frequency	44	3.21 (1.63–6.29)
High frequency	475	1.64 (1.04–2.57)
Self-reported	949	1.76 (1.30–2.38)

dB HL = decibels hearing level; PTA = pure tone average.
* For the association of diagnosed diabetes and hearing impairment in U.S. adults age 20–69 years. Data from the National Health and Nutrition Examination Survey, 1999–2004 (n = 4471). Odds ratios are adjusted for age, sex, race or ethnicity, education, income–poverty ratio, leisure-time noise exposure, occupational noise exposure, military history, use of ototoxic medications, and smoking.
† Model did not pass the Hosmer–Lemeshow goodness-of-fit test, but examination of residuals and observed and expected values did not suggest an important departure from model fit.

held across all age groups. These observations are consistent with a report of higher hearing thresholds across all frequencies among patients with diabetes who are age 40 years or younger compared with healthy age-matched control participants, even though the thresholds in either group were not in the range to be considered hearing impaired (28).

Several biological mechanisms might explain an association between diabetes and hearing impairment. Well-established complications of diabetes, such as retinopathy, nephropathy, and peripheral neuropathy, involve pathogenic changes to the microvasculature and sensory nerves (14, 29). These pathologic changes may include the capillaries and sensory neurons of the inner ear, but evidence from human studies is limited. Postmortem observations of diabetic patients include thickening of capillaries in the stria vascularis (13, 30) and demyelination of the eighth cranial nerve, 1 branch of which transmits auditory signals from the cochlea to the brainstem (12). Pathologic changes specific to the cochlea also include thickened walls of the vessels of the basilar membrane and greater loss of outer hair cells in the lower basal turn (30). Compromised cochlear function has been measured by using evoked otoacoustic emissions (a noninvasive method to assess damage to the outer hair cells of the cochlea) among patients with diabetes relative to healthy control participants (31). Other vascular changes include narrowing of the internal auditory artery (32). Certain rare genetic syndromes, such as the Alström syndrome (33), the Wolfram syndrome (34), and maternally inherited diabetes and deafness (35), feature diabetes and hearing impairment as characteristics. It is possible that more common genetic factors predispose to both diabetes and hearing impairment, but these have not been identified yet.

Potential limitations of the analysis include recall-based assessments of leisure time and occupational noise exposure. Self-reported noise exposure is subject to measurement error, so we cannot rule out residual confounding as contributing to some of the association we observed. This limitation may be more of a factor for high-frequency hearing impairment because this outcome incorporates pure tone thresholds observed across 3000 to 6000 Hz, the frequencies at which injury from excessive noise stimulus is most notable (36). Similarly, for most of our analyses, the assessment of diabetes was based on self-report, and persons with undiagnosed diabetes were considered to be nondiabetic. Given the greater prevalence of hearing impairment that we observed with greater dysregulation of glucose, we have probably underestimated the overall measures of association. Also, we cannot distinguish between type 1 and type 2 diabetes; however, almost all participants in this study have type 2 diabetes. In addition, our measure of ototoxic drug use does not incorporate information on dose or use in the past. Finally, we can make inferences only about the U.S. noninstitutionalized adult population. The prevalence of both diabetes and hearing impairment is probably even greater among institutionalized adults.

In summary, our data suggest that hearing impairment may be an underrecognized complication of diabetes. Although this analysis does not focus on possible mechanisms for the association of diabetes and hearing impairment, we have identified an important public health problem that can be addressed. With the high prevalence of hearing impairment among diabetic patients, screening for this condition may be justified (37–39).

From Social & Scientific Systems, Silver Spring, Maryland, and National Institute on Deafness and Other Communication Disorders and National Institute of Diabetes and Digestive and Kidney Diseases, Bethesda, Maryland.

Acknowledgment: The authors thank Danita Byrd-Holt, BBA, and Laura Fang, MS, for statistical programming support; Keith Rust, PhD, for statistical expertise and helpful comments; and Christa Themann, MS, for helpful comments on the manuscript and involvement in the design and management of the audiometric component of NHANES.

Grant Support: By contracts N001 DK12478 and HHSN 26720070000 1G from the National Institute of Diabetes and Digestive and Kidney Diseases (Dr. Bainbridge).

Potential Financial Conflicts of Interest: None disclosed.

Reproducible Research Statement: All NHANES data, analytic guidelines, questionnaires, codebooks, and interview and examination manuals are publicly available at www.cdc.gov/nchs/about/major/nhanes/datalink.htm. Sample statistical code for the analysis of NHANES data is publicly available at www.cdc.gov/nchs/tutorials/Nhanes/index_current.htm.

Requests for Single Reprints: Kathleen E. Bainbridge, PhD, MPH, Social & Scientific Systems, 8757 Georgia Avenue, 12th Floor, Silver Spring, MD 20910; e-mail, kbainbridge@s-3.com.

Current author addresses and author contributions are available at www.annals.org.

References

1. **Pleis JR, Lethbridge-Cejku M.** Summary health statistics for U.S. adults: National Health Interview Survey, 2006. Vital Health Stat 10. 2007:1-153. [PMID: 18361164]

2. **Cruickshanks KJ, Tweed TS, Wiley TL, Klein BE, Klein R, Chappell R, et al.** The 5-year incidence and progression of hearing loss: the epidemiology of hearing loss study. Arch Otolaryngol Head Neck Surg. 2003;129:1041-6. [PMID: 14568784]

3. **Muhr P, Månsson B, Hellström PA.** A study of hearing changes among military conscripts in the Swedish Army. Int J Audiol. 2006;45:247-51. [PMID: 16684706]

4. **Dalton DS, Cruickshanks KJ, Wiley TL, Klein BE, Klein R, Tweed TS.** Association of leisure-time noise exposure and hearing loss. Audiology. 2001;40:1-9. [PMID: 11296936]

5. **Cruickshanks KJ, Klein R, Klein BE, Wiley TL, Nondahl DM, Tweed TS.** Cigarette smoking and hearing loss: the epidemiology of hearing loss study. JAMA. 1998;279:1715-9. [PMID: 9624024]

6. **Cruickshanks KJ, Wiley TL, Tweed TS, et al.** Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin. The Epidemiology of Hearing Loss Study. Am J Epidemiol. 1998;148:879-86. [PMID: 9801018]

7. **Dalton DS, Cruickshanks KJ, Klein BE, Klein R, Wiley TL, Nondahl DM.**

The impact of hearing loss on quality of life in older adults. Gerontologist. 2003;43:661-8. [PMID: 14570962]
8. **Strawbridge WJ, Cohen RD, Shema SJ, Kaplan GA.** Successful aging: predictors and associated activities. Am J Epidemiol. 1996;144:135-41. [PMID: 8678044]
9. **National Institute of Diabetes and Digestive and Kidney Diseases.** National Diabetes Statistics fact sheet: general information and national estimates on diabetes in the United States, 2005. Bethesda, MD: U.S. Department of Health and Human Services, National Institutes of Health; 2005.
10. **Cowie CC, Rust KF, Byrd-Holt DD, Eberhardt MS, Flegal KM, Engelgau MM, et al.** Prevalence of diabetes and impaired fasting glucose in adults in the U.S. population: National Health and Nutrition Examination Survey 1999-2002. Diabetes Care. 2006;29:1263-8. [PMID: 16732006]
11. **National Diabetes Data Group, National Institute of Diabetes and Digestive and Kidney Diseases.** Diabetes in America. 2nd ed. Bethesda, MD: National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases; 1995. NIH publication no. 95-1468.
12. **Makishima K, Tanaka K.** Pathological changes of the inner ear and central auditory pathway in diabetics. Ann Otol Rhinol Laryngol. 1971;80:218-28. [PMID: 5550775]
13. **Jorgensen MB.** The inner ear in diabetes mellitus. Histologic studies. Arch Otolaryngol. 1961;74:373-81.
14. **Friedman SA, Schulman RH, Weiss S.** Hearing and diabetic neuropathy. Arch Intern Med. 1975;135:573-6. [PMID: 1138672]
15. **Axelsson A, Sigroth K, Vertes D.** Hearing in diabetics. Acta Otolaryngol. 1978;356(Suppl):1-23.
16. **Taylor IG, Irwin J.** Some audiological aspects of diabetes mellitus. J Laryngol Otol. 1978;92:99-113. [PMID: 627773]
17. **Kurien M, Thomas K, Bhanu TS.** Hearing threshold in patients with diabetes mellitus. J Laryngol Otol. 1989;103:164-8. [PMID: 2926261]
18. **Erdem T, Ozturan O, Miman MC, Ozturk C, Karatas E.** Exploration of the early auditory effects of hyperlipoproteinemia and diabetes mellitus using otoacoustic emissions. Eur Arch Otorhinolaryngol. 2003;260:62-6. [PMID: 12582780]
19. **Ishii EK, Talbott EO, Findlay RC, D'Antonio JA, Kuller LH.** Is NIDDM a risk factor for noise-induced hearing loss in an occupationally noise exposed cohort? Sci Total Environ. 1992;127:155-65. [PMID: 1480953]
20. **Dalton DS, Cruickshanks KJ, Klein R, Klein BE, Wiley TL.** Association of NIDDM and hearing loss. Diabetes Care. 1998;21:1540-4.
21. **Helzner EP, Cauley JA, Pratt SR, Wisniewski SR, Zmuda JM, Talbott EO, et al.** Race and sex differences in age-related hearing loss: the Health, Aging and Body Composition Study. J Am Geriatr Soc. 2005;53:2119-27. [PMID: 16398896]
22. **Axelsson A, Eliasson A, Israelsson B.** Hearing in pop/rock musicians: a follow-up study. Ear Hear. 1995;16:245-53.
23. **Tambs K, Hoffman HJ, Borchgrevink HM, Holmen J, Samuelsen SO.** Hearing loss induced by noise, ear infections, and head injuries: results from the Nord-Trøndelag Hearing Loss Study. Int J Audiol. 2003;42:89-105. [PMID: 12641392]
24. **Gelfand SA.** Essentials of Audiology. 2nd ed. New York: Thieme; 2001.
25. **Sakuta H, Suzuki T, Yasuda H, Ito T.** Type 2 diabetes and hearing loss in personnel of the Self-Defense Forces. Diabetes Res Clin Pract. 2007;75:229-34. [PMID: 16963152]
26. **Gates GA, Cobb JL, D'Agostino RB, Wolf PA.** The relation of hearing in the elderly to the presence of cardiovascular disease and cardiovascular risk factors. Arch Otolaryngol Head Neck Surg. 1993;119:156-61. [PMID: 8427676]
27. **Ma F, Gómez-Marín O, Lee DJ, Balkany T.** Diabetes and hearing impairment in Mexican American adults: a population-based study. J Laryngol Otol. 1998;112:835-9. [PMID: 9876372]
28. **Kasemsuwan L, Sriwanyong S, Krittiyawong S, Sunetrworakul J, Jiamsuchon K.** Hearing in young diabetic patients. J Med Assoc Thai. 2001;84:1389-94. [PMID: 11804246]
29. **Ciulla TA, Amador AG, Zinman B.** Diabetic retinopathy and diabetic macular edema: pathophysiology, screening, and novel therapies. Diabetes Care. 2003;26:2653-64. [PMID: 12941734]
30. **Fukushima H, Cureoglu S, Schachern PA, Kusunoki T, Oktay MF, Fukushima N, et al.** Cochlear changes in patients with type 1 diabetes mellitus. Otolaryngol Head Neck Surg. 2005;133:100-6. [PMID: 16025061]
31. **Sasso FC, Salvatore T, Tranchino G, Cozzolino D, Caruso AA, Persico M, et al.** Cochlear dysfunction in type 2 diabetes: a complication independent of neuropathy and acute hyperglycemia. Metabolism. 1999;48:1346-50. [PMID: 10582539]
32. **Makishima K.** Arteriolar sclerosis as a cause of presbycusis. Otolaryngology. 1978;86:ORL322-6. [PMID: 113738]
33. **Marshall JD, Beck S, Maffei P, Naggert JK.** Alström syndrome. Eur J Hum Genet. 2007;15:1193-202. [PMID: 17940554]
34. **Minton JA, Rainbow LA, Ricketts C, Barrett TG.** Wolfram syndrome. Rev Endocr Metab Disord. 2003;4:53-9. [PMID: 12618560]
35. **Maassen JA, 'T Hart LM, Van Essen E, Heine RJ, Nijpels G, Jahangir Tafrechi RS, et al.** Mitochondrial diabetes: molecular mechanisms and clinical presentation. Diabetes. 2004;53 Suppl 1:S103-9. [PMID: 14749274]
36. **Gates GA, Schmid P, Kujawa SG, Nam B, D'Agostino R.** Longitudinal threshold changes in older men with audiometric notches. Hear Res. 2000;141:220-8. [PMID: 10713509]
37. **Bagai A, Thavendiranathan P, Detsky AS.** Does this patient have hearing impairment? JAMA. 2006;295:416-28. [PMID: 16434632]
38. **Yueh B, Shapiro N, MacLean CH, Shekelle PG.** Screening and management of adult hearing loss in primary care: scientific review. JAMA. 2003;289:1976-85. [PMID: 12697801]
39. **Bogardus ST Jr, Yueh B, Shekelle PG.** Screening and management of adult hearing loss in primary care: clinical applications. JAMA. 2003;289:1986-90. [PMID: 12697802]

Current Author Addresses: Dr. Bainbridge: Social & Scientific Systems, 8757 Georgia Avenue, 12th Floor, Silver Spring, MD 20910.
Mr. Hoffman: National Institute on Deafness and Other Communication Disorders, Executive Plaza South Building, Suite 400A, 6120 Executive Boulevard, MSC 7180, Bethesda, MD 20892-7180.
Dr. Cowie: National Institute of Diabetes and Digestive and Kidney Diseases, Democracy Plaza II, Room 691, 6707 Democracy Boulevard, MSC 5460, Bethesda, MD 20892-5460.

Author Contributions: Conception and design: K.E. Bainbridge, H.J. Hoffman, C.C. Cowie.
Analysis and interpretation of the data: K.E. Bainbridge, H.J. Hoffman, C.C. Cowie.
Drafting of the article: K.E. Bainbridge.
Critical revision of the article for important intellectual content: K.E. Bainridge, H.J. Hoffman, C.C. Cowie.
Final approval of the article: K.E. Bainbridge, H.J. Hoffman, C.C. Cowie.
Provision of study materials or patients: C.C. Cowie.
Statistical expertise: K.E. Bainbridge, H.J. Hoffman, C.C. Cowie.
Obtaining of funding: H.J. Hoffman, C.C. Cowie.
Administrative, technical, or logistic support: H.J. Hoffman, C.C. Cowie.
Collection and assembly of data: K.E. Bainbridge.

Appendix

Pure tone audiometry is a method of measuring hearing sensitivity across a range of frequencies. For each frequency, a pure tone signal is presented to the ear and the intensity of the signal is varied until the level at which the participant is just able to perceive the tone is identified. This level is the pure tone threshold for a particular frequency. A higher threshold indicates that a more intense signal was needed to perceive the tone and signifies greater hearing impairment. Audiologists express the intensity level of thresholds on a decibels hearing level (dB HL) scale based on the common logarithm of the ratio of the signal's intensity to a reference intensity of 10^{-12} watts/m^2 (22). Zero dB HL represents the threshold of hearing at each frequency for young adults. An average threshold of greater than 25 to 40 dB HL is considered to be mild impairment, greater than 40 to 55 dB HL is considered to be moderate impairment, greater than 55 to 70 dB HL is considered to be moderately severe impairment, and greater than 70 to 90 dB HL is considered to be severe impairment.

Hearing measurements in the study were collected by trained audiometric technicians by using a calibrated Interacoustics audiometer (model AD226, Interacoustics USA, Eden Prairie, Minnesota) while study participants were in a sound-treated booth that met the American National Standard Institute (ANSI) Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms (ANSI S3.1-1991). The audiometer's calibration was confirmed daily by using a Quest Model BA-201-25 (Quest Technologies, Oconomowoc, Wisconsin) bioacoustic simulator to verify the stability of the audiometric signal over time. Audiometers met the specifications of ANSI S3.6-1996 for type 3 audiometers. Standard audiometric headphones were used unless a potential for collapsing ear canals was noted during otoscopic examination, in which case, insert earphones were used.

Appendix Table 1. **Prevalence of High-Frequency Hearing Impairment of Mild or Greater Severity in the Worse Ear***

Characteristic	Prevalence					Age-Adjusted Prevalence (95% CI), %†		
	Diabetes (n = 399)		No Diabetes (n = 4741)		*P* Value	Diabetes (n = 399)	No Diabetes (n = 4741)	*P* Value
	Participants, n‡	Prevalence (95% CI), %	Participants, n‡	Prevalence (95% CI), %				
Age								
20–49 y	97	44.2 (32.8–55.6)	3232	18.6 (16.8–20.3)	<0.001	–	–	–
50–59 y	111	70.5 (61.1–79.9)	727	55.7 (57.7–59.7)	0.003	–	–	–
60–69 y	191	89.9 (84.3–95.5)	782	77.7 (74.2–81.1)	0.003	–	–	–
Race or ethnicity								
Non-Hispanic white	139	72.8 (64.8–80.7)	2311	34.8 (32.8–36.8)	<0.001	58.1 (44.2–71.9)	34.2 (32.4–35.9)	<0.001
Non-Hispanic black	97	46.9 (36.9–57.0)	956	19.7 (17.5–21.9)	<0.001	36.2 (19.5–52.9)	23.2 (21.0–25.3)	0.115
Mexican American	118	53.3 (40.9–65.6)	1090	22.3 (19.9–24.7)	<0.001	39.3 (24.5–54.1)	30.0 (27.2–21.7)	0.170
Other§	45	74.5 (61.8–87.1)	384	25.0 (19.9–30.0)	<0.001	63.5 (43.3–83.7)	28.8 (24.2–33.4)	0.007
Sex								
Male	192	81.2 (73.8–88.5)	2223	42.7 (39.7–45.6)	<0.001	69.0 (57.8–80.2)	44.1 (41.6–46.7)	<0.001
Female	207	53.1 (43.7–62.5)	2518	20.3 (22.4–18.1)	<0.001	35.8 (24.7–46.8)	20.6 (18.8–22.5)	0.002
Education								
Less than high school	166	76.4 (68.1–84.6)	1323	37.4 (33.6–41.1)	<0.001	63.6 (47.9–79.3)	36.6 (33.3–39.8)	0.002
High school	91	66.9 (55.6–71.2)	1090	35.3 (32.6–38.0)	<0.001	54.7 (36.1–73.3)	36.1 (33.5–38.8)	0.063
More than high school	142	63.2 (53.9–72.4)	2326	27.4 (25.5–29.4)	<0.001	49.5 (37.7–61.3)	28.7 (27.0–30.4)	<0.001
Income–poverty ratio								
≤1.0	88	67.9 (55.0–80.7)	796	26.1 (22.4–29.8)	<0.001	56.8 (40.6–72.9)	31.6 (28.2–35.1)	0.002
>1.0	273	67.9 (60.7–75.0)	3535	31.6 (29.7–33.4)	<0.001	53.8 (44.2–63.4)	31.9 (30.3–33.5)	<0.001
Military history								
Yes	68	89.8 (78.2–101.4)	517	56.0 (51.7–60.3)	<0.001	80.3 (56.3–104.3)	42.1 (38.2–45.9)	0.004
No	330	61.6 (55.4–67.7)	4224	27.8 (26.3–29.4)	<0.001	48.7 (40.1–57.3)	30.1 (28.6–31.5)	<0.001
Leisure-time noise exposure								
Yes	87	74.5 (63.2–85.8)	1227	34.0 (30.9–37.1)	<0.001	64.2 (47.0–81.5)	38.6 (36.1–41.1)	0.005
No	312	65.4 (58.7–72.2)	3511	30.0 (28.2–31.7)	<0.001	50.2 (41.4–59.0)	29.4 (27.8–31.0)	<0.001
Occupational noise exposure								
Yes	117	76.2 (66.4–86.1)	1475	40.8 (37.6–44.1)	<0.001	66.1 (52.4–79.9)	42.3(39.6–45.1)	0.001
No	254	62.3 (54.2–70.4)	3048	26.3 (24.5–28.1)	<0.001	44.1 (34.2–54.0)	26.9 (25.2–28.5)	<0.001
Ototoxic medication use								
Yes	101	71.2 (59.8–82.5)	514	39.4 (34.3–44.6)	<0.001	53.7 (30.6–76.8)	30.9 (26.1–35.7)	0.025
No	298	66.6 (59.2–74.1)	4227	30.0 (28.5–31.6)	<0.001	54.4 (44.7–64.1)	32.2 (30.7–33.6)	<0.001
Current smoker								
Yes	94	66.1 (53.8–78.4)	1251	32.8 (29.6–36.1)	<0.001	59.8 (46.0–73.6)	36.4 (33.6–39.3)	0.012
No	305	68.3 (61.4–75.2)	3485	30.5 (28.6–32.4)	<0.001	51.1 (40.8–61.5)	30.2 (28.5–31.8)	<0.001

* Assessed in U.S. adults age 20–69 years (data from the National Health and Nutrition Examination Survey, 1999–2004 [n = 5140]). *Hearing impairment* is defined as a pure tone average >25 decibels hearing level of thresholds assessed at 3000, 4000, 6000, and 8000 Hz.
† Age-adjusted to 2000 U.S. Census.
‡ Column totals may not sum to the total number of participants because of missing data on the covariates.
§ Includes multiracial participants.

Appendix Table 2. **Prevalence of Low- or Mid-Frequency Hearing Impairment of Moderate or Greater Severity in the Worse Ear***

Characteristic	Prevalence					Age-Adjusted Prevalence (95% CI), %†		
	Diabetes (*n* = 399)		No Diabetes (*n* = 4741)		*P* Value	Diabetes (*n* = 399)	No Diabetes (*n* = 4741)	*P* Value
	Participants, *n*‡	Prevalence (95% CI), %	Participants, *n*‡	Prevalence (95% CI), %				
Age								
20–49 y	97	0.8 (0.0 to 2.4)	3232	1.1 (0.6 to 1.5)	0.78	–	–	–
50–59 y	111	15.8 (8.0 to 23.6)	727	4.2 (2.3 to 6.1)	0.013	–	–	–
60–69 y	191	11.4 (5.4 to 17.5)	782	9.4 (7.1 to 11.7)	0.52	–	–	–
Race or ethnicity								
Non-Hispanic white	139	10.1 (5.3 to 15.0)	2311	2.6 (1.9 to 3.3)	0.008	5.5 (2.6 to 8.3)	2.5 (1.8 to 3.2)	0.052
Non-Hispanic black	97	6.2 (1.2 to 11.2)	956	1.5 (1.0 to 2.0)	0.091	2.7 (0.6 to 4.8)	1.8 (1.1 to 2.4)	0.26
Mexican American	118	9.5 (2.2 to 16.7)	1090	2.0 (1.2 to 2.7)	0.066	4.7 (1.3 to 8.2)	2.9 (1.7 to 4.1)	0.24
Other§	45	8.9 (0.5 to 17.3)	384	3.2 (1.7 to 4.8)	0.172	4.1 (0.6 to 7.6)	3.8 (2.0 to 5.7)	0.51
Sex								
Male	192	9.0 (3.7 to 14.2)	2223	2.8 (1.9 to 3.6)	0.032	4.4 (1.7 to 7.0)	3.0 (2.1 to 3.8)	0.156
Female	207	9.7 (4.8 to 14.5)	2518	2.2 (1.5 to 2.9)	0.005	5.2 (1.9 to 8.5)	2.2 (1.5 to 3.0)	0.038
Education								
Less than high school	166	12.3 (4.7 to 20.0)	1323	3.9 (2.7 to 5.2)	0.036	5.6 (2.4 to 8.9)	3.7 (2.6 to 4.7)	0.20
High school	91	11.5 (4.1 to 18.9)	1090	2.6 (1.5 to 3.7)	0.024	6.8 (0.6 to 13.0)	2.7 (1.6 to 3.8)	0.151
More than high school	142	6.2 (2.0 to 10.5)	2326	2.0 (1.3 to 2.7)	0.060	3.0 (1.0 to 5.0)	2.1 (1.4 to 2.8)	0.186
Income–poverty ratio								
≤1.0	88	11.3 (3.6 to 19.0)	796	4.0 (2.4 to 5.6)	0.062	7.7 (1.6 to 13.9)	5.1 (3.4 to 6.7)	0.28
>1.0	273	8.6 (4.3 to 12.8)	3535	2.2 (1.6 to 2.8)	0.009	3.9 (2.1 to 5.6)	2.3 (1.7 to 2.8)	0.066
Military history								
Yes	68	10.9 (0.0 to 22.2)	517	3.4 (1.6 to 5.2)	0.196	5.0 (0.0 to 10.4)	2.2 (1.1 to 3.4)	0.30
No	330	8.9 (5.2 to 12.5)	4224	2.4 (1.8 to 2.9)	0.001	4.6 (2.5 to 6.7)	2.7 (2.1 to 3.3)	0.028
Leisure-time noise exposure								
Yes	87	9.4 (3.3 to 15.5)	1227	2.7 (1.5 to 3.9)	0.036	4.6 (1.6 to 7.7)	3.3 (1.9 to 4.7)	0.26
No	312	9.3 (5.4 to 13.2)	3511	2.4 (1.7 to 3.0)	0.002	4.8 (2.4 to 7.1)	2.3 (1.7 to 2.9)	0.024
Occupational noise exposure								
Yes	117	10.4 (3.2 to 17.6)	1475	2.8 (1.7 to 3.8)	0.057	6.3 (2.1 to 10.5)	3.1 (2.0 to 4.1)	0.132
No	254	8.7 (4.4 to 13.0)	3048	2.3 (1.6 to 2.9)	0.005	3.7 (1.8 to 5.5)	2.3 (1.7 to 3.0)	0.065
Ototoxic medication use								
Yes	101	9.0 (2.8 to 15.3)	514	4.5 (2.6 to 6.3)	0.183	7.1 (−0.9 to 15.1)	3.2 (1.7 to 4.6)	0.545
No	298	9.4 (4.9 to 13.9)	4227	2.2 (1.6 to 2.8)	0.003	4.5 (2.6 to 6.5)	2.5 (1.9 to 3.1)	0.025
Current smoker								
Yes	94	8.9 (1.7 to 16.1)	1251	2.5 (1.4 to 3.5)	0.084	6.2 (1.2 to 11.1)	3.0 (1.9 to 4.2)	0.203
No	305	9.4 (5.6 to 13.2)	3485	2.5 (1.9 to 3.0)	<0.001	4.0 (2.3 to 5.7)	2.4 (1.9 to 3.0)	0.023

* Assessed in U.S. adults age 20–69 years (data from the National Health and Nutrition Examination Survey, 1999–2004 [*n* = 5140]). *Hearing impairment* is defined as a pure tone average >40 decibels hearing level of thresholds assessed at 500, 1000, and 2000 Hz.
† Age-adjusted to 2000 U.S. Census.
‡ Column totals may not sum to the total number of participants because of missing data on the covariates.
§ Includes multiracial participants.

Appendix Table 3. **Prevalence of High-Frequency Hearing Impairment of Moderate or Greater Severity in the Worse Ear***

Characteristic	Prevalence					Age-Adjusted Prevalence (95% CI), %†		
	Diabetes (n = 399)		No Diabetes (n = 4741)		*P* Value	Diabetes (n = 399)	No Diabetes (n = 4741)	*P* Value
	Participants, n‡	Prevalence (95% CI), %	Participants, n‡	Prevalence (95% CI), %				
Age								
20–49 y	97	31.1 (18.1–44.1)	3232	7.3 (6.3–8.2)	0.004	–	–	–
50–59 y	111	43.5 (33.3–53.7)	727	31.2 (26.4–36.0)	0.036	–	–	–
60–69 y	191	63.2 (54.0–72.4)	782	50.0 (46.2–53.8)	0.016	–	–	–
Race or ethnicity								
Non-Hispanic white	139	53.4 (45.8–60.9)	2311	18.6 (16.9–20.3)	<0.001	42.0 (27.1–56.8)	18.1 (16.7–19.6)	<0.001
Non-Hispanic black	97	20.4 (13.6–27.2)	956	6.7 (5.3–8.2)	0.003	13.5 (5.8–21.2)	8.2 (6.6–9.7)	0.163
Mexican American	118	23.3 (15.2–31.5)	1090	10.9 (9.0–12.8)	0.010	14.0 (8.3–19.7)	15.7 (13.5–17.9)	0.76
Other§	45	49.6 (34.0–65.1)	384	10.3 (6.8–13.9)	0.003	49.1 (28.8–69.4)	12.4 (8.9–15.8)	0.016
Sex								
Male	192	58.8 (49.3–68.3)	2223	24.5 (22.2–26.7)	<0.001	48.7 (35.9–61.4)	25.8 (23.9–27.8)	0.007
Female	207	31.2 (22.4–39.9)	2518	7.7 (6.3–9.1)	<0.001	23.1 (12.5–33.8)	7.9 (6.6–9.2)	0.003
Education								
Less than high school	166	54.0 (41.9–66.1)	1323	21.4 (18.2–24.6)	<0.001	48.9 (31.5–66.4)	20.7 (18.0–23.4)	0.017
High school	91	47.5 (33.9–61.2)	1090	19.1 (16.8–21.3)	0.002	38.6 (18.3–58.8)	19.8 (17.6–22.1)	0.100
More than high school	142	39.5 (29.7–49.3)	2326	12.7 (11.3–14.1)	<0.001	30.8 (18.4–43.2)	13.6 (12.2–15.0)	0.010
Income–poverty ratio								
≤1.0	88	40.0 (27.4–52.6)	796	10.0 (7.8–12.2)	<0.001	33.2 (17.6–48.9)	14.5 (11.9–17.0)	0.029
>1.0	273	45.7 (38.4–53.1)	3535	16.5 (15.0–18.1)	<0.001	36.9 (26.3–47.6)	16.8 (15.5–18.1)	<0.001
Military history								
Yes	68	68.1 (53.3–82.9)	517	39.2 (35.4–43.0)	0.003	62.8 (37.9–87.7)	27.2 (24.3–30.1)	0.096
No	330	39.2 (33.2–45.2)	4224	12.7 (11.4–14.0)	<0.001	31.5 (22.4–40.7)	14.1 (12.8–15.4)	<0.001
Leisure-time noise exposure								
Yes	87	62.5 (50.1–75.0)	1227	18.8 (16.6–20.9)	<0.001	52.0 (33.8–70.1)	22.9 (21.1–24.7)	0.002
No	312	39.8 (33.7–45.8)	3511	14.6 (13.1–16.1)	<0.001	31.5 (22.7–40.2)	14.3 (12.9–15.6)	<0.001
Occupational noise exposure								
Yes	117	58.4 (46.2–70.5)	1475	22.7 (20.0–25.3)	<0.001	50.9 (35.8–66.0)	24.0 (21.7–26.3)	0.003
No	254	38.5 (31.2–45.9)	3048	12.4 (11.0–13.8)	<0.001	26.7 (17.7–35.7)	12.8 (11.6–14.0)	0.004
Ototoxic medication use								
Yes	101	53.3 (40.9–65.6)	514	20.3 (16.4–24.1)	<0.001	29.9 (13.0–46.8)	14.7 (11.9–17.6)	0.004
No	298	43.0 (36.9–49.2)	4227	15.3 (14.0–16.5)	<0.001	37.6 (27.9–47.4)	16.8 (15.6–18.0)	<0.001
Current smoker								
Yes	94	48.8 (34.8–62.8)	1251	16.5 (13.9–19.0)	0.001	46.9 (30.3–63.8)	19.3 (16.7–21.8)	0.017
No	305	44.6 (37.1–52.1)	3485	15.6 (14.1–17.2)	<0.001	31.8 (21.1–42.5)	15.4 (14.1–16.7)	<0.001

* Assessed in U.S. adults age 20–69 years (data from the National Health and Nutrition Examination Survey, 1999–2004 [n = 5140]). *Hearing impairment* is defined as a pure tone average >40 decibels hearing level of thresholds assessed at 3000, 4000, 6000, and 8000 Hz.
† Age-adjusted to 2000 U.S. Census.
‡ Column totals may not sum to the total number of participants because of missing data on the covariates.
§ Includes multiracial participants.

Appendix Table 4. Prevalence of Low- or Mid-Frequency Hearing Impairment of Mild or Greater Severity in the Better Ear*

Characteristic	Prevalence					Age-Adjusted Prevalence (95% CI), %†		
	Diabetes (n = 399)		No Diabetes (n = 4741)		P Value	Diabetes (n = 399)	No Diabetes (n = 4741)	P Value
	Participants, n‡	Prevalence (95% CI), %	Participants, n‡	Prevalence (95% CI), %				
Age								
20–49 y	97	5.2 (0.0–10.8)	3232	1.3 (0.7–1.9)	0.20	–	–	–
50–59 y	111	15.9 (8.0–23.7)	727	4.9 (3.1–6.8)	0.021	–	–	–
60–69 y	191	17.0 (10.8–23.2)	782	15.0 (11.4–18.5)	0.56	–	–	–
Race or ethnicity								
Non-Hispanic white	139	12.0 (6.8–17.3)	2311	3.7 (2.8–4.5)	0.007	6.9 (2.4–11.4)	3.6 (2.8–4.4)	0.114
Non-Hispanic black	97	5.9 (0.8–10.9)	956	1.9 (1.1–2.7)	0.144	2.6 (0.5–4.7)	3.3 (1.4–3.2)	0.55
Mexican American	118	11.7 (7.7–15.7)	1090	2.7 (1.7–3.5)	<0.001	5.8 (3.9–7.6)	4.3 (2.7–5.9)	0.079
Other§	45	20.9 (9.3–32.5)	384	3.4 (1.5–5.3)	0.014	18.8 (2.8–34.8)	4.4 (2.1–6.6)	0.047
Sex								
Male	192	11.5 (5.9–17.1)	2223	3.4 (2.5–4.4)	0.010	6.9 (2.3–11.5)	3.8 (2.9–4.7)	0.192
Female	207	13.8 (7.6–20.0)	2518	3.3 (2.4–4.1)	0.004	10.6 (2.3–18.9)	3.4 (2.5–4.2)	0.028
Education								
Less than high school	166	19.5 (10.5–28.5)	1323	5.8 (4.2–7.4)	0.010	16.0 (4.3–27.7)	5.3 (4.1–6.6)	0.113
High school	91	10.7 (3.4–18.0)	1090	3.6 (2.3–4.9)	0.061	3.5 (0.5–6.5)	3.7 (2.4–5.0)	0.38
More than high school	142	9.5 (4.0–14.9)	2326	2.5 (1.7–3.3)	0.024	6.4 (1.6–11.2)	2.8 (2.0–3.5)	0.106
Income–poverty ratio								
≤1.0	88	12.8 (4.6–20.9)	796	3.9 (2.6–5.1)	0.046	6.4 (3.1–9.6)	6.0 (3.9–8.0)	0.46
>1.0	273	12.4 (7.7–17.1)	3535	3.0 (2.4–3.7)	0.001	8.1 (3.2–13.1)	3.2 (2.5–3.8)	0.018
Military history								
Yes	68	15.3 (3.3–27.3)	517	6.3 (3.8–8.8)	0.162	6.0 (0.7–11.4)	4.1 (2.3–6.0)	0.45
No	330	11.8 (7.5–16.1)	4224	3.0 (2.4–3.6)	<0.001	8.8 (4.2–13.4)	3.4 (2.8–4.1)	0.012
Leisure-time noise exposure								
Yes	87	15.6 (8.3–23.0)	1227	3.5 (2.3–4.6)	0.004	10.4 (2.8–17.9)	4.7 (3.2–6.1)	0.109
No	312	11.5 (7.0–16.0)	3511	3.3 (2.6–3.9)	0.002	7.9 (2.7–13.0)	3.2 (2.6–3.8)	0.033
Occupational noise exposure								
Yes	117	9.1 (2.2–16.0)	1475	4.1 (2.8–5.3)	0.18	4.5 (1.5–7.6)	4.5 (3.3–5.8)	0.60
No	254	13.5 (8.4–18.6)	3048	2.7 (2.0–3.4)	<0.001	9.5 (2.9–16.1)	2.8 (2.1–3.5)	0.010
Ototoxic medication use								
Yes	101	16.7 (5.4–27.9)	514	7.5 (4.6–10.5)	0.091	6.2 (1.8–10.5)	5.6 (3.3–7.9)	0.35
No	298	11.2 (6.8–15.6)	4227	2.8 (2.3–3.3)	0.001	8.5 (3.6–13.4)	3.2 (2.6.–3.8)	0.028
Current smoker								
Yes	94	14.8 (6.3–23.4)	1251	3.3 (2.3–4.3)	0.018	12.8 (3.5–22.0)	3.9 (2.8–5.0)	0.056
No	305	11.9 (6.8–16.9)	3485	3.4 (2.6–4.1)	0.002	6.4 (2.1–10.6)	3.3 (2.6–4.0)	0.074

* Assessed in U.S. adults age 20–69 years (data from the National Health and Nutrition Examination Survey, 1999–2004 [n = 5140]). *Hearing impairment* is defined as a pure tone average >25 decibels hearing level of thresholds assessed at 500, 1000, and 2000 Hz.
† Age-adjusted to 2000 U.S. Census.
‡ Column totals may not sum to the total number of participants because of data on the covariates.
§ Includes multiracial participants.

Appendix Table 5. Prevalence of High-Frequency Hearing Impairment of Mild or Greater Severity in the Better Ear*

Characteristic	Prevalence					Age-Adjusted Prevalence (95% CI), %†		
	Diabetes (*n* = 399)		No Diabetes (*n* = 4741)		*P* Value	Diabetes (*n* = 399)	No Diabetes (*n* = 4741)	*P* Value
	Participants, *n*‡	Prevalence (95% CI), %	Participants, *n*‡	Prevalence (95% CI), %				
Age								
20–49 y	97	31.6 (21.2–42.1)	3232	8.8 (7.6–10.0)	0.001	–	–	–
50–59 y	111	56.0 (45.4–66.5)	727	37.9 (33.7–42.1)	0.003	–	–	–
60–69 y	191	75.7 (67.6–83.8)	782	62.2 (57.7–66.7)	0.011	–	–	–
Race or ethnicity								
Non-Hispanic white	139	58.4 (50.4–66.4)	2311	22.7 (21.1–24.4)	<0.001	42.9 (31.4–54.3)	22.2 (20.7–23.6)	<0.001
Non-Hispanic black	97	29.3 (21.2–37.4)	956	10.0 (8.2–11.7)	<0.001	20.6 (9.7–31.4)	12.5 (10.7–14.4)	0.178
Mexican American	118	39.9 (30.7–49.2)	1090	12.4 (10.6–14.2)	<0.001	23.9 (16.1–31.8)	18.7 (16.5–20.9)	0.036
Other§	45	66.3 (50.7–81.9)	384	11.7 (8.2–15.3)	<0.001	58.9 (37.7–80.2)	14.3 (11.2–17.4)	0.002
Sex								
Male	192	69.0 (60.8–77.2)	2223	27.7 (25.4–29.9)	<0.001	54.3 (43.9–64.8)	29.2 (27.3–31.0)	<0.001
Female	207	37.7 (27.4–48.0)	2518	11.5 (10.0–13.0)	<0.001	25.8 (14.9–36.7)	11.8 (10.4–13.2)	0.013
Education								
Less than high school	166	63.4 (52.3–74.4)	1323	24.9 (21.3–28.5)	<0.001	53.5 (38.2–68.7)	24.0 (20.9–27.1)	0.003
High school	91	56.1 (43.7–68.4)	1090	22.3 (19.8–24.8)	<0.001	40.8 (21.0–60.6)	23.1 (20.5–25.6)	0.037
More than high school	142	47.3 (37.9–56.8)	2326	16.4 (14.9–17.9)	<0.001	34.9 (22.8–46.9)	17.6 (16.1–19.1)	0.004
Income–poverty ratio								
≤1.0	88	50.0 (34.2–65.7)	796	12.9 (10.7–15.1)	0.001	32.8 (22.1–43.5)	17.5 (14.8–20.3)	0.006
>1.0	273	55.0 (47.9–62.0)	3535	20.1 (18.8–21.5)	<0.001	43.2 (33.5–52.9)	20.5 (19.3–21.7)	<0.001
Military history								
Yes	68	80.6 (68.7–92.5)	517	45.1 (40.6–49.6)	<0.001	77.5 (53.3–101.7)	32.7 (29.0–36.5)	0.005
No	330	46.5 (39.1–53.9)	4224	16.0 (14.8–17.1)	<0.001	33.7 (25.4–42.0)	17.8 (16.7–19.0)	<0.001
Leisure-time noise exposure								
Yes	87	68.7 (58.0–79.4)	1227	21.8 (19.1–24.5)	<0.001	60.2 (43.2–77.3)	26.0 (23.4–28.5)	<0.001
No	312	49.0 (41.8–56.1)	3511	18.4 (16.8–20.0)	<0.001	33.4 (25.3–41.6)	17.9 (16.5–19.3)	<0.001
Occupational noise exposure								
Yes	117	58.6 (47.2–69.9)	1475	27.8 (25.3–30.3)	<0.001	50.0 (37.2–62.8)	29.3 (27.2–31.4)	0.011
No	254	51.0 (43.6–58.4)	3048	15.1 (13.7–16.7)	<0.001	33.5 (24.4–42.5)	15.7 (14.3–17.0)	<0.001
Ototoxic medication use								
Yes	101	61.0 (48.7–73.3)	514	27.7 (32.5–23.0)	<0.001	43.3 (20.5–66.0)	19.8 (16.1–23.4)	0.020
No	298	51.7 (44.5–59.0)	4227	18.3 (17.1–19.5)	<0.001	40.6 (31.2–49.9)	20.1 (19.0–21.2)	<0.001
Current smoker								
Yes	94	54.1 (39.7–68.5)	1251	21.2 (18.4–23.9)	0.001	47.4 (31.5–63.2)	24.5 (21.8–27.2)	0.027
No	305	54.0 (46.4–61.6)	3485	18.7 (17.2–20.2)	<0.001	38.0 (29.1–46.9)	18.4 (17.2–19.7)	<0.001

* Assessed in U.S. adults age 20–69 years (data from the National Health and Nutrition Examination Survey, 1999–2004 [*n* = 5140]). *Hearing impairment* is defined as a pure tone average >25 decibels hearing level of thresholds assessed at 3000, 4000, 6000, and 8000 Hz.
† Age-adjusted to 2000 U.S. Census.
‡ Column totals may not sum to the total number of participants because of missing data on the covariates.
§ Includes multiracial participants.

Appendix Table 6. **Prevalence of Low- or Mid-Frequency Hearing Impairment of Moderate or Greater Severity in the Better Ear***

Characteristic	Prevalence					Age-Adjusted Prevalence (95% CI), %†		
	Diabetes (*n* = 399)		No Diabetes (*n* = 4741)		*P* Value	Diabetes (*n* = 399)	No Diabetes (*n* = 4741)	*P* Value
	Participants, *n*‡	Prevalence (95% CI), %	Participants, *n*‡	Prevalence (95% CI), %				
Age								
20–49 y	97	0.0 (0.0 to 0.0)	3232	0.3 (0.1 to 0.5)	0.004	–	–	–
50–59 y	111	5.5 (0.5 to 10.5)	727	0.8 (0.2 to 1.4)	0.076	–	–	–
60–69 y	191	4.5 (0.6 to 8.5)	782	1.9 (0.6 to 3.1)	0.155	–	–	–
Race or ethnicity								
Non-Hispanic white	139	3.8 (0.9 to 6.7)	2311	0.6 (0.3 to 0.9)	0.043	1.6 (0.3 to 3.0)	0.6 (0.3 to 0.8)	0.060
Non-Hispanic black	97	4.1 (−0.6 to 8.7)	956	0.6 (0.2 to 1.0)	0.171	1.8 (−0.2 to 3.8)	0.7 (0.2 to 1.2)	0.24
Mexican American	118	5.1 (−0.9 to 11.0)	1090	0.6 (0.3 to 0.9)	0.157	2.6 (−0.5 to 5.6)	0.9 (0.3 to 1.4)	0.25
Other§	45	0.0 (0.0 to 0.0)	384	0.6 (−0.1 to 1.3)	0.193	0.0 (0.0 to 0.0)	0.5 (−0.2 to 1.3)	0.25
Sex								
Male	192	3.0 (0.2 to 5.8)	2223	0.7 (0.3 to 1.1)	0.112	1.4 (−0.1 to 2.8)	0.7 (0.3 to 1.1)	0.185
Female	207	3.7 (0.8 to 6.5)	2518	0.4 (0.1 to 0.7)	0.033	1.6 (0.4 to 2.8)	0.5 (0.2 to 0.8)	0.052
Education								
Less than high school	166	2.7 (0.1 to 5.4)	1323	1.3 (0.4 to 2.1)	0.31	1.0 (0.2 to 1.9)	1.2 (0.4 to 1.9)	0.92
High school	91	5.0 (−0.2 to 10.2)	1090	0.6 (0.1 to 1.1)	0.105	2.0 (−0.4 to 4.4)	0.6 (0.1 to 1.2)	0.103
More than high school	142	2.7 (−0.1 to 5.6)	2326	0.3 (0.1 to 0.6)	0.118	1.3 (−0.1 to 2.7)	0.4 (0.1 to 0.6)	0.137
Income–poverty ratio								
≤1.0	88	4.4 (−0.1 to 8.9)	796	1.3 (0.6 to 2.1)	0.22	2.3 (−0.1 to 4.8)	1.6 (0.7 to 2.5)	0.37
>1.0	273	3.2 (0.8 to 5.7)	3535	0.4 (0.2 to 0.6)	0.03	1.4 (0.3 to 2.5)	0.4 (0.2 to 0.6)	0.050
Military history								
Yes	68	4.1 (−0.9 to 9.1)	517	0.4 (0.0 to 0.7)	0.157	1.0 (−0.3 to 2.2)	0.4 (−0.1 to 0.9)	0.162
No	330	3.1 (0.9 to 5.3)	4224	0.6 (0.3 to 0.9)	0.034	1.5 (0.4 to 2.6)	0.7 (0.4 to 1.0)	0.085
Leisure-time noise exposure								
Yes	87	3.3 (−0.3 to 6.9)	1227	0.7 (0.2 to 1.2)	0.180	1.5 (−0.1 to 3.1)	0.8 (0.2 to 1.4)	0.29
No	312	3.3 (1.0 to 5.7)	3511	0.5 (0.2 to 0.8)	0.029	1.5 (0.4 to 2.6)	0.5 (0.2 to 0.8)	0.063
Occupational noise exposure								
Yes	117	4.1 (−0.1 to 8.2)	1475	0.9 (0.3 to 1.5)	0.14	2.0 (0.0 to 4.0)	0.9 (0.3 to 1.6)	0.17
No	254	2.7 (0.4 to 4.9)	3048	0.4 (0.1 to 0.6)	0.05	1.2 (0.2 to 2.2)	0.4 (0.2 to 0.6)	0.11
Ototoxic medication use								
Yes	101	4.1 (−1.3 to 9.4)	514	1.1 (0.2 to 2.1)	0.27	1.6 (−0.7 to 3.9)	0.9 (0.1 to 1.7)	0.40
No	298	3.1 (1.0 to 5.1)	4227	0.5 (0.3 to 0.7)	0.020	1.5 (0.5 to 2.4)	0.5 (0.3 to 0.7)	0.030
Current smoker								
Yes	94	2.3 (−0.4 to 5.1)	1251	0.9 (0.3 to 1.4)	0.31	1.3 (−0.1 to 2.7)	0.9 (0.4 to 1.5)	0.41
No	305	3.6 (1.2 to 6.1)	3485	0.4 (0.2 to 0.6)	0.019	1.6 (0.5 to 2.7)	0.4 (0.2 to 0.6)	0.033

* Assessed in U.S. adults age 20–69 years (data from the National Health and Nutrition Examination Survey, 1999–2004 [*n* = 5140]). *Hearing impairment* is defined as a pure tone average >40 decibels hearing level of thresholds assessed at 500, 1000, and 2000 Hz.
† Age-adjusted to 2000 U.S. Census.
‡ Column totals may not sum to the total number of participants because of missing data on the covariates.
§ Includes multiracial participants.

Appendix Table 7. **Prevalence of High-Frequency Hearing Impairment of Moderate or Greater Severity in the Better Ear***

Characteristic	Prevalence					Age-Adjusted Prevalence (95% CI), %†		
	Diabetes (n = 399)		No Diabetes (n = 4741)		P Value	Diabetes (n = 399)	No Diabetes (n = 4741)	P Value
	Participants, n‡	Prevalence (95% CI), %	Participants, n‡	Prevalence (95% CI), %				
Age								
20–49 y	97	12.6 (5.5–19.7)	3232	2.7 (1.9–3.4)	0.019	–	–	–
50–59 y	111	22.0 (13.7–30.4)	727	17.2 (13.5–21.0)	0.31	–	–	–
60–69 y	191	47.8 (37.7–57.8)	782	36.7 (32.9–40.4)	0.052	–	–	–
Race or ethnicity								
Non-Hispanic white	139	29.6 (23.1–36.1)	2311	10.7 (9.4–12.0)	<0.001	15.5 (9.3–21.7)	10.3 (9.3–11.4)	0.025
Non-Hispanic black	97	9.8 (4.4–15.3)	956	3.0 (2.2–3.8)	0.038	4.2 (2.1–6.3)	3.7 (2.8–4.6)	0.37
Mexican American	118	16.8 (9.6–23.9)	1090	4.6 (3.6–5.6)	0.008	10.7 (5.0–16.4)	8.0 (6.4–9.5)	0.55
Other§	45	37.6 (23.8–51.4)	384	4.5 (2.4–6.6)	<0.001	38.9 (19.4–58.5)	5.9 (3.7–8.2)	0.005
Sex								
Male	192	40.1 (32.5–47.6)	2223	13.9 (12.1–15.7)	<0.001	27.4 (19.1–35.8)	15.0 (13.74–16.6)	0.007
Female	207	12.8 (6.8–18.9)	2518	3.8 (3.0–4.7)	0.010	8.0 (1.7–14.4)	3.9 (3.2–4.7)	0.20
Education								
Less than high school	166	27.1 (18.1–36.1)	1323	13.0 (10.3–15.6)	0.011	15.4 (6.4–24.3)	12.1 (10.3–13.9)	0.77
High school	91	26.8 (16.4–37.2)	1090	10.5 (8.7–12.4)	0.012	15.6 (4.4–26.7)	11.0 (9.0–13.1)	0.52
More than high school	142	27.2 (19.0–35.5)	2326	6.6 (5.5–7.7)	<0.001	20.9 (12.0–29.8)	7.2 (6.1–8.3)	0.007
Income–poverty ratio								
≤1.0	88	17.4 (6.3–28.4)	796	5.2 (3.7–6.7)	0.061	8.6 (4.7–12.6)	8.2 (6.1–10.3)	0.68
>1.0	273	28.7 (22.6–34.8)	3535	9.1 (7.9–10.2)	<0.001	20.5 (13.2–27.8)	9.3 (8.4–10.3)	0.009
Military history								
Yes	68	51.2 (36.3–66.1)	517	25.3 (21.6–29.0)	0.008	42.5 (20.8–64.2)	16.2 (13.4–19.1)	0.151
No	330	20.2 (14.8–25.6)	4224	6.5 (5.6–7.4)	<0.001	13.0 (9.5–16.6)	7.5 (6.6–8.4)	0.025
Leisure-time noise exposure								
Yes	87	43.9 (32.8–55.0)	1227	10.1 (8.3–11.9)	<0.001	30.7 (16.2–45.2)	13.3 (11.6–15.0)	0.007
No	312	21.3 (16.3–26.3)	3511	8.1 (6.9–9.3)	<0.001	13.9 (8.2–19.6)	7.9 (6.9–8.8)	0.089
Occupational noise exposure								
Yes	117	30.7 (20.0–41.3)	1475	13.6 (11.7–15.4)	0.005	21.9 (11.2–32.6)	14.7 (13.1–16.4)	0.21
No	254	24.4 (19.0–29.8)	3048	6.2 (5.1–7.2)	<0.001	14.9 (8.2–21.5)	6.4 (5.4–7.4)	0.005
Ototoxic medication use								
Yes	101	30.7 (19.7–41.7)	514	12.2 (9.2–15.2)	0.002	10.2 (6.4–14.0)	8.3 (6.2–10.4)	0.067
No	298	25.9 (20.7–31.0)	4227	8.2 (7.3–9.2)	<0.001	19.6 (13.3–25.8)	9.4 (8.4–10.4)	0.006
Current smoker								
Yes	94	28.2 (18.5–37.8)	1251	9.0 (7.3–10.8)	0.002	24.3 (15.2–33.4)	11.6 (9.9–13.2)	0.045
No	305	26.7 (20.1–33.3)	3485	8.6 (7.5–9.7)	<0.001	15.4 (8.3–22.5)	8.4 (7.5–9.4)	0.021

* Assessed in U.S. adults age 20–69 years (data from the National Health and Nutrition Examination Survey, 1999–2004 [n = 5140]). *Hearing impairment* is defined as a pure tone average >40 decibels hearing level of thresholds assessed at 3000, 4000, 6000, and 8000 Hz.
† Age-adjusted to 2000 U.S. Census.
‡ Column totals may not sum to the total number of participants because of missing data on the covariates.
§ Includes multiracial participants.

Appendix Table 8. Prevalence of Self-Reported Hearing Impairment*

Characteristic	Prevalence					Age-Adjusted Prevalence (95% CI), %†		
	Diabetes (n = 399)		No Diabetes (n = 4741)		P Value	Diabetes (n = 399)	No Diabetes (n = 4741)	P Value
	Participants, n‡	Prevalence (95% CI), %	Participants, n‡	Prevalence (95% CI), %				
Age								
20–49 y	97	36.5 (24.8–48.3)	3232	17.3 (16.2–19.3)	0.007	–	–	–
50–59 y	111	41.1 (31.9–50.3)	727	28.8 (24.4–33.1)	0.024	–	–	–
60–69 y	191	49.6 (39.6–59.6)	782	35.4 (30.6–40.2)	0.012	–	–	–
Race or ethnicity								
Non-Hispanic white	139	48.2 (40.0–56.3)	2311	24.4 (22.5–26.3)	<0.001	46.7 (33.2–60.1)	24.2 (22.3–26.1)	0.001
Non-Hispanic black	97	23.3 (14.9–31.6)	956	12.6 (10.5–14.7)	0.030	18.0 (6.9–29.1)	13.2 (11.0–15.3)	0.156
Mexican American	118	30.1 (18.6–41.7)	1090	15.1 (12.7–17.6)	0.034	28.7 (13.5–44.0)	17.5 (14.9–20.2)	0.176
Other§	45	42.9 (29.4–56.4)	384	15.7 (11.4–20.0)	0.001	36.4 (17.8–54.9)	16.0 (11.9–20.1)	0.004
Sex								
Male	192	52.3 (44.4–60.3)	2223	26.2 (23.6–28.8)	<0.001	48.1 (37.6–58.5)	26.8 (24.3–29.3)	<0.001
Female	207	31.3 (21.8–40.7)	2518	17.0 (14.9–19.1)	0.011	28.2 (14.6–41.8)	17.1 (15.0–19.1)	0.064
Education								
Less than high school	166	39.8 (29.4–50.2)	1323	23.3 (19.0–27.6)	0.011	35.3 (20.0–50.7)	22.9 (18.8–26.9)	0.143
High school	91	45.0 (31.3–58.7)	1090	24.1 (21.2–27.1)	0.014	39.0 (20.1–58.0)	24.4 (21.4–27.4)	0.032
More than high school	142	42.3 (32.2–52.3)	2326	19.8 (17.8–21.7)	<0.001	40.5 (27.3–53.6)	20.1 (18.3–22.0)	0.004
Income–poverty ratio								
≤1.0	88	41.0 (26.8–55.2)	796	22.2 (17.7–26.7)	0.038	39.6 (21.2–57.9)	23.5 (18.8–28.1)	0.121
>1.0	273	40.0 (32.3–47.6)	3535	21.3 (19.8–22.9)	<0.001	35.2 (23.6–46.8)	21.5 (20.0–23.0)	0.005
Military history								
Yes	68	52.4 (36.9–67.8)	517	35.2 (30.9–39.4)	0.064	49.0 (26.8–71.1)	31.3 (26.7–35.8)	0.134
No	330	39.5 (32.1–46.9)	4224	19.7 (18.2–21.2)	<0.001	36.9 (27.0–46.8)	20.3 (18.7–21.8)	<0.001
Leisure-time noise exposure								
Yes	87	57.2 (44.5–69.9)	1227	31.5 (28.0–35.0)	<0.001	51.4 (35.1–67.6)	33.4 (30.1–36.8)	0.029
No	312	37.1 (30.6–43.6)	3511	17.3 (15.8–18.8)	<0.001	34.6 (25.2–44.0)	17.2 (15.7–18.6)	<0.001
Occupational noise exposure								
Yes	117	57.7 (45.9–69.4)	1475	32.3 (29.0–35.6)	0.001	51.4 (36.5–66.4)	33.0 (29.6–36.4)	0.010
No	254	34.7 (27.4–41.9)	3048	16.0 (14.4–17.7)	<0.001	30.4 (19.6–41.1)	16.2 (14.6–17.8)	0.001
Ototoxic medication use								
Yes	101	40.7 (29.2–52.1)	514	27.3 (22.6–32.0)	0.031	17.7 (9.0–26.4)	25.0 (20.2–29.8)	0.153
No	298	42.8 (36.2–49.4)	4227	20.7 (19.3–22.1)	<0.001	42.3 (32.7–51.9)	21.3 (19.9–22.8)	<0.001
Current smoker								
Yes	94	52.7 (41.9–63.5)	1251	23.2 (19.9–26.5)	<0.001	56.5 (43.5–69.4)	24.2 (20.9–27.4)	0.002
No	305	38.9 (31.9–45.8)	3485	20.8 (19.2–22.4)	<0.001	29.3 (18.6–40.0)	20.7 (19.1–22.3)	0.003

* In U.S. adults age 20–69 years (data from the National Health and Nutrition Examination Survey, 1999–2004 [n = 5140]).
† Age-adjusted to 2000 U.S. Census.
‡ Column totals may not sum to the total number of participants because of missing data on the covariates.
§ Includes multiracial participants.