Risk Factors for Hearing Impairment Among U.S. Adults With Diabetes

National Health and Nutrition Examination Survey 1999–2004

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OBJECTIVE—The objective of this study was to examine the risk factors of low/mid-frequency and high-frequency hearing impairment among a nationally representative sample of diabetic adults.

RESEARCH DESIGN AND METHODS—Data came from 536 participants, aged 20–69 years, with diagnosed or undiagnosed diabetes who completed audiometric testing during 1999–2004 in the National Health and Nutrition Examination Survey (NHANES). We defined hearing impairment as the pure-tone average >25 dB hearing level of pure-tone thresholds at low/mid-frequencies (500; 1,000; and 2,000 Hz) and high frequencies (3,000; 4,000; 6,000; and 8,000 Hz) and identified independent risk factors using logistic regression.

RESULTS—Controlling for age, race/ethnicity, and marital status, odds ratios for associations with low/mid-frequency hearing impairment were 2.20 (95% CI 1.28–3.79) for HDL <40 mg/dL and 3.55 (1.57–8.03) for poor health. Controlling for age, race/ethnicity, sex, and income-to-poverty ratio, odds ratios for associations with high-frequency hearing impairment were 4.39 (1.26–15.26) for history of coronary heart disease and 4.42 (1.26–15.45) for peripheral neuropathy.

CONCLUSIONS—Low HDL, coronary heart disease, peripheral neuropathy, and having poor health are potentially preventable correlates of hearing impairment for people with diabetes. Glycemic control, years since diagnosis, and type of glycemic medication were not associated with hearing impairment.

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Some degree of hearing impairment affects over two-thirds of diabetic adults, about twofold higher than that of the nondiabetic population (1), yet little is known about the characteristics of those experiencing this disability. Reports (2,3) indicating that audiometric hearing thresholds are correlated with diabetes complications, poor glycemic control, or diabetes duration are often not corroborated (4–6). Although cardiovascular disease and its risk factors, including smoking, have been linked to hearing impairment in the general population (7,8), these associations are unsubstantiated among people with diabetes. One investigation (9) of diabetes complications among a population-based sample demonstrated that hearing impairment was associated with nephropathy but not with retinopathy, diabetes duration, or hemoglobin A_{1c} (A1C). Thus, the evidence that diabetes severity is associated with the likelihood of hearing impairment is inconclusive.

Recent national survey data provide an opportunity to examine the correlates of hearing impairment in a representative sample of diabetic adults. The aim of the current study is to examine whether, among people with diabetes, hearing impairment is associated with diabetes duration, insulin use, glycemic control, cardiovascular disease risk factors, or the presence of diabetes complications.

RESEARCH DESIGN AND METHODS

Data, collected during 1999–2004, came from the National Health and Nutrition Examination Survey (NHANES), which used a complex, multistage, probability sample representative of the civilian, noninstitutionalized U.S. population. Of 5,418 study participants aged 20–69 years who were randomly assigned to audiometric testing, 5,147 (95.0%) completed the audiometric examination, and of those, 399 reported diagnosed diabetes when asked the question, "Other than during pregnancy (for women), have you ever been told by a doctor or health professional that you have diabetes?" Of the remaining 4,748 participants, 2,116 were randomly assigned to a fasting blood draw and were evaluated for undiagnosed diabetes using the criterion of a fasting blood glucose ≥126 mg/dL. Seventy-five participants with undiagnosed diabetes were identified with fasting blood glucose. Of 4,673 participants not identified from the interview or fasting blood glucose as having diabetes, 62 had A1C ≥6.5% and also were classified as having undiagnosed diabetes, yielding an analytical sample of 536 individuals with diabetes.

Pure-tone audiometry signals were presented to each ear at varying intensities until the threshold at which the participant was just able to perceive the tone was identified. Air-conduction hearing thresholds in decibels hearing level (dB HL) were obtained for each ear at 500; 1,000; 2,000; 3,000; 4,000; 6,000; and 8,000 Hz by trained audiometric technicians using a calibrated Interacoustics Model AD226 audiometer with study participants in a sound-treated booth, which met the American National Standard Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms (ANSI S3.1-1991).

Participants were classified as having low/mid-frequency hearing impairment if the average of the pure-tone thresholds

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(hereafter referred to as the pure-tone average [PTA]) measured at 500; 1,000; and 2,000 Hz in either ear exceeded 25 dB HL. If the PTA of thresholds measured at 3,000; 4,000; 6,000; and 8,000 Hz in either ear exceeded 25 dB HL, participants were classified as having high-frequency hearing impairment. A PTA of at least 25 dB HL is considered to be impairment of sufficient severity to present difficulties with understanding speech (10). Item-missing threshold data were considered as audiometric nonresponse (tone not perceived). After verifying that the average of their available pure-tone thresholds exceeded 25 dB HL, participants with audiometric nonresponse within a frequency range were classified as impaired for that range. For graphical purposes, the worse ear was defined as the ear with the greater PTA of all seven thresholds.

Demographic characteristics, including age, race/ethnicity, sex, marital status, and educational attainment were obtained during interviews. Current smoking status and history of smoking also were obtained by interview. The income-to-poverty ratio was defined as the ratio of reported total family income to the U.S. Census Bureau poverty threshold. We defined leisure-time noise exposure as a positive response to either of two questions assessing noise exposure from firearms (outside of work) or other noise sources, for an average of at least once per month for a year. Occupational noise exposure was defined as a history of loud noise at work that required speaking in a raised voice to be heard. Coronary heart disease was defined as a positive response to any of three questions asking whether a doctor had told the participant that they have coronary heart disease, angina, or had a heart attack. Participants rated their general health status during a computer-assisted interview. Questions about the current use of insulin and oral agents, and years since diabetes diagnosis, were asked of those with diagnosed diabetes.

Anthropometric and clinical measures were obtained during physical examinations that included a blood draw and clean-catch urine collection (11). BMI was calculated as weight in kilograms divided by the square of height in meters. We defined central adiposity as a waist measurement of ≥102 cm for men or ≥88 cm for women. We defined hypertension as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg, or report of current antihypertensive medication use. Ankle brachial index, the ratio of systolic blood pressure in the brachial artery to that in the posterior tibial artery in the right or left ankle, was measured in participants aged ≥40 years. We defined peripheral arterial disease as an ankle brachial index <0.9. Albuminuria was defined as a ratio of urinary albumin to urinary creatinine ≥30 mg/g. Monofilament testing was administered to participants aged 40–69 years. Peripheral neuropathy was defined as having at least one insensate area of six metatarsal sites tested (three on each foot) using a standard 10-g monofilament. High cholesterol was defined as total cholesterol ≥200 mg/dL, a positive response to a question of whether a health professional had ever told the participant that they have high cholesterol, or reported current use of lipid-lowering medications. Low HDL was defined as HDL <40 mg/dL. A1C was assessed by Boronate Affinity High-Performance Liquid Chromatography using Primus CLC330 and Primus CLC 385 (Primus, Kansas City, MO), and values were standardized to the method of the Diabetes Control and Complications Trial, yielding interassay coefficients of variation <3.0% (12). Suboptimal glycemic control was defined as A1C ≥7%. Plasma glucose was measured using a hexokinase enzymatic method with a coefficient of variation of 1.3–2.2% (11).

Data analysis

The proportions of our sample with hearing impairment at high frequencies, at low/mid-frequencies, at both frequency ranges, and not hearing-impaired were computed. Statistical differences in the distribution of sociodemographic and anthropometric characteristics, noise exposure, smoking, comorbidities, and characteristics of diabetes were examined with t tests (for continuous characteristics) and χ^2 tests (for categorical characteristics). For the t test, values for years since diabetes diagnosis were transformed by taking their natural logarithm to better approximate the assumption of normality. The level of significance was $\alpha = 0.05$. Characteristics independently associated with a greater prevalence of low/mid- and high-frequency hearing impairment were identified from odds ratios and 95% CIs were estimated using logistic regression. Models tested with peripheral neuropathy, or peripheral arterial disease, were limited to participants aged 40–69 years. Differences in the effects of covariates on the odds of hearing impairment by whether diabetes was previously diagnosed were tested with interaction terms. Analyses were performed using SAS version 9.2 (SAS Institute, Cary, NC) and SUDAAN version 10.0.0 (Research Triangle Institute, Research Triangle Park, NC), incorporating 6-year sample weights, which accounted for the probabilities of being assigned to audiometry and/or to fasting plasma glucose testing.

RESULTS—Two-thirds of subjects with diabetes had high-frequency hearing impairment (Table 1). Twenty-six percent also had low/mid-frequency hearing impairment. Less than 1% of subjects with diabetes had a low/mid-frequency hearing impairment without high-frequency involvement. Characteristics of the U.S. population with diabetes (diagnosed and undiagnosed), aged 20–69 years, are presented in Table 2 and stratified by low/mid- and high-frequency hearing impairment. Diabetic subjects with hearing impairment had a mean age of 56–57 years, which was significantly older than those without hearing impairment. Among those with hearing impairment, a lesser proportion was non-Hispanic black or Mexican American. No sex differences in

Table 1—*Prevalence of hearing impairment at high frequencies among the U.S. population with diabetes (diagnosed or undiagnosed) aged 20–69 years stratified by hearing impairment status at low/mid-frequencies, NHANES 1999–2004* (n = 536)

	n	Weighted prevalence (%)
Hearing-impaired at high frequencies	353	65.5
Hearing-impaired at low/mid-frequencies	134	25.9
Not hearing-impaired at low/mid-frequencies	219	39.6
Not hearing-impaired at high frequencies	183	34.6
Hearing-impaired at low/mid-frequencies	3	0.5
Not hearing-impaired at low/mid-frequencies	180	34.1

Table 2—*Sociodemographic, noise exposure, and health characteristics of the U.S. population with diabetes (diagnosed or undiagnosed) aged 20–69 years stratified by hearing impairment status at low/mid-frequencies and high frequencies, NHANES 1999–2004* (n = 536)

	Low/mid-frequencies*			High frequencies†		
	Hearing-impaired	Not hearing-impaired	*P*	Hearing-impaired	Not hearing-impaired	*P*
n (%)	137 (26.3)	399 (73.7)		353 (65.5)	183 (34.6)	
Sociodemographic characteristics						
Age (years)	56.9 (1.3)	51.2 (0.7)	<0.001	56.3 (0.7)	46.0 (1.0)	<0.001
Race/ethnicity (%)						
Non-Hispanic white	64.3	61.2		67.2	52.2	
Non-Hispanic black	7.0	17.0		9.7	23.1	
Mexican American	4.9	8.8		6.0	11.2	
Other, including multiracial	23.9	13.0	<0.001	17.1	13.6	0.001
Male sex (%)	58.0	57.0	0.90	67.6	37.7	<0.001
Unmarried (%)	44.5	29.7	<0.01	32.3	35.9	0.56
Less than high school education (%)	40.3	26.6	0.04	33.2	24.4	0.09
Income to poverty ratio ≤1 (%)	22.5	14.6	0.08	16.6	16.3	0.95
Noise exposure (%)						
Leisure-time noise exposure	22.4	24.2	0.72	24.3	22.6	0.72
Occupational noise exposure	39.5	36.4	0.60	41.0	30.3	0.13
Health characteristics						
Low HDL (%)	44.5	28.9	0.01	36.6	26.4	0.11
High cholesterol (%)	78.4	71.8	0.26	80.2	60.9	<0.001
Hypertension (%)	60.4	57.6	0.70	61.9	51.6	0.14
Currently smokes (%)	25.5	24.1	0.82	24.8	23.9	0.88
Coronary heart disease (%)	24.2	11.3	<0.01	20.3	4.3	<0.001
BMI (kg/m^2)	33.0 (1.0)	33.0 (0.7)	0.95	32.2 (0.56)	34.6 (1.4)	0.12
Central adiposity (%)	78.6	74.1	0.39	72.3	80.8	0.12
Peripheral neuropathy (%)‡	22.7	19.1	0.57	25.6	5.8	<0.001
Peripheral arterial disease (%)‡	12.1	5.6	0.24	9.2	2.4	0.02
Albuminuria (%)	37.4	24.4	0.04	30.8	22.4	0.11
A1C ≥7%	44.5	47.1	0.71	46.6	45.8	0.91
Self-reported poor health (%)	17.8	7.6	0.01	11.9	7.2	0.14
For diagnosed diabetes (*n* = 399)						
Years since diagnosis‖	14.3 (1.8)	9.2 (0.8)	0.07	12.4 (1.1)	7.0 (0.8)	0.003
Type of medication (%)			0.08			0.38
Insulin use (with or without oral agents)	36.2	22.0		28.0	21.6	
Oral agents only	43.3	55.1		51.6	52.4	
None	20.5	22.9		20.5	26.0	

Data are means (SE), unless otherwise indicated. *$PTA_{(500;\ 1,000;\ 2,000\ Hz)}$ >25 dB in either ear. †$PTA_{(3,000;\ 4,000;\ 6,000;\ 8,000\ Hz)}$ >25 dB in either ear. ‡Measured among 428 participants aged 40–69 years. ‖*P* value for test of difference in mean log-transformed years since diagnosis.

low/mid-frequency hearing impairment were observed, but there was a markedly higher percentage of male subjects among the hearing-impaired at high frequencies. Diabetic adults with low/mid-frequency hearing impairment were more likely to be unmarried and to have less than a high school education, whereas no significant differences in marital or education status were found by high-frequency hearing impairment status. We found no significant differences in the proportions with hearing impairment by leisure time or occupational noise exposure.

Among subjects with diabetes, prevalence of low HDL was significantly greater in those who were hearing-impaired at the low/mid-frequency range, whereas the prevalence of high total cholesterol was significantly higher in those who were hearing-impaired at the high-frequency range. We observed no differences in hearing impairment by the prevalence of hypertension or current smoking status. Coronary heart disease was twice as prevalent among diabetic subjects with low/mid-frequency hearing impairment and over four times as prevalent among those with high-frequency hearing impairment compared with those without hearing impairment. Comparing diabetic subjects with high-frequency hearing impairment to those without impairment, estimates for mean BMI and the proportion with central adiposity were not in the expected direction but were not significantly different ($P = 0.12$). Peripheral neuropathy was experienced by 25% and peripheral arterial disease by 9% of those with high-frequency hearing impairment, about four times the prevalence of these complications among those not impaired. Higher prevalence estimates of albuminuria were observed among those with hearing impairment at both frequency ranges, although this was statistically significant at the low/mid-frequency range only. We observed no difference in the proportion with A1C ≥7%. The proportion of subjects with low/mid-frequency hearing impairment who reported being in poor health was over two times that of those without low/mid-frequency hearing impairment.

Among 399 participants with diagnosed diabetes, mean diabetes duration in those with hearing impairment was 5 years greater than in those without hearing impairment but was statistically significant only at the high-frequency range. Participants with low/mid-frequency hearing impairment used insulin more frequently and oral medications less frequently (marginally significant, $P = 0.08$).

Adjusting for sociodemographic factors, we found that low HDL levels increased the odds of low/mid-frequency hearing impairment by 2.2-fold (Table 3). Those who reported poor health were over three times as likely to have low/mid-frequency hearing impairment. Subjects who reported coronary heart disease or peripheral neuropathy had over four times the odds of high-frequency hearing impairment. We found no evidence of effect modification of any covariate by diagnosed versus undiagnosed diabetes. Suboptimal glycemic control, years since diagnosis, type of glycemic medication, BMI, and high total cholesterol were not significantly related to hearing impairment at either frequency range. Age-adjusted mean pure-tone thresholds from the worse ear are presented by the presence or absence of low HDL (Fig. 1*A*), coronary heart disease (Fig. 1*B*), peripheral neuropathy (Fig. 1*C*), and poor self-reported health (Fig. 1*D*). Subjects with low HDL and coronary heart disease and those who reported poor health had higher thresholds at all frequencies than subjects without these conditions. Subjects with peripheral neuropathy had higher thresholds at frequencies >1,000 Hz.

CONCLUSIONS—Diabetes-related hearing loss has been described as a progressive, sensorineural impairment (5) affecting audiometric thresholds between 500 and 8,000 Hz (1). Presbycusis, or age-related hearing loss, typically begins in the higher frequencies and progresses to the middle and then lower frequencies as people age. Correlates of high-frequency hearing loss may indicate characteristics of those in an earlier stage of presbycusis, and subjects who additionally have low/mid-frequency hearing impairment are more likely to have had hearing impairment for a longer period of time. Thus, we evaluated correlates of low/mid- and high-frequency hearing impairment in a nationally representative sample of diabetic adults aged 20–69 years.

We observed strong associations with age and race at both frequency ranges that are consistent with evidence from the general population (13). Despite the higher prevalence of diabetes complications, such as retinopathy and nephropathy, among non-Hispanic blacks and Mexican Americans (14,15), these groups had lower prevalence of hearing impairment compared with non-Hispanic whites or people from other minority race/ethnicity groups. The higher odds of high-frequency hearing impairment among male subjects than female subjects is possibly attributed to residual confounding by industrial and/or recreational noise exposure, for which self-reported measures often are inadequate. Excessive noise commonly affects hair cells sensitive to signals of 4,000–6,000 Hz, and elevated thresholds in this range are more commonly observed among male subjects (16). We observed greater prevalence of high- frequency hearing impairment among those with a lower income-to-poverty ratio, consistent with previously described socioeconomic inequalities (17). In addition to exposure to noisy environmental conditions (18), subjects of lower socioeconomic status may have a history of inadequate glycemic control, for which we are unable to adjust adequately because we have only one A1C measurement. We observed a greater prevalence of low/mid-frequency hearing impairment among unmarried subjects. Cruickshanks et al. (19) have reported greater risk of hearing impairment among unmarried subjects over 10 years of follow-up, but the role of marital status in the development of hearing impairment remains unknown.

There is debate about whether diabetes affects hearing through angiopathic or neuropathic mechanisms (20). We found hearing impairment in the low/mid- and high-frequency range to be associated with low HDL and coronary heart disease history, respectively. These observations support the hypothesis that diabetes-related hearing loss accompanies an atherosclerotic mechanism affecting the inner ear that also may occur subsequent to an ischemic event. There are no population-based studies of subjects with diabetes with which to compare our findings, but Gates et al. (7) described elevated low/mid-frequency pure-tone thresholds among male subjects (but not female subjects) of the Framingham Cohort Study with confirmed myocardial infarction and reported a greater occurrence of low/mid-frequency hearing impairment among both male and female subjects with confirmed coronary heart disease. Our evidence agrees with observations by Gates et al. (7) who found an inverse relationship between HDL and low/mid-frequency PTA among women. Findings from a study of middle-aged men in military occupations further support an atherosclerotic mechanism based on modest associations of high total cholesterol and high triglycerides with hearing impairment after adjusting for diabetes (21). It is important to note that we observed no association between hearing impairment and albuminuria, an outcome related to microvascular disease. The elevated odds of hearing impairment among non-Hispanic white subjects that we observed compared with non-Hispanic black or Mexican-American subjects also is incongruent with usual race/ethnic patterns of microvascular complications, such as nephropathy or retinopathy (14,15).

We observed a strong association of high-frequency hearing impairment with peripheral neuropathy. Diabetic neuropathy is a well-established complication of uncontrolled hyperglycemia, but there is

Table 3—*Associations between risk factors for low/mid-frequency and high-frequency hearing impairment among the U.S. population with diabetes (diagnosed or undiagnosed) aged 20–69 years (low/mid-frequency model) or aged 40–69 years (high-frequency model)*

	Low/mid-frequency hearing impairment*	High-frequency hearing impairment†
	Odds ratio (95% CI)‡	Odds ratio (95% CI)§
n	485	400
Coronary heart disease	—	4.39 (1.26–15.26)
HDL <40 mg/dL	2.20 (1.28–3.79)	—
Peripheral neuropathy‖	—	4.42 (1.26–15.45)
Self-reported poor health	3.55 (1.57–8.03)	—

*$PTA_{(500;\ 1,000;\ 2,000\ Hz)}$ >25 dB in either ear. †$PTA_{(3,000;\ 4,000;\ 6,000;\ 8,000\ Hz)}$ >25 dB in either ear. ‡Low/mid-frequency model adjusted for age, race/ethnicity, and marital status. §High-frequency model adjusted for sex and income-to-poverty ratio. ‖Peripheral neuropathy was measured in individuals aged ≥40 years.

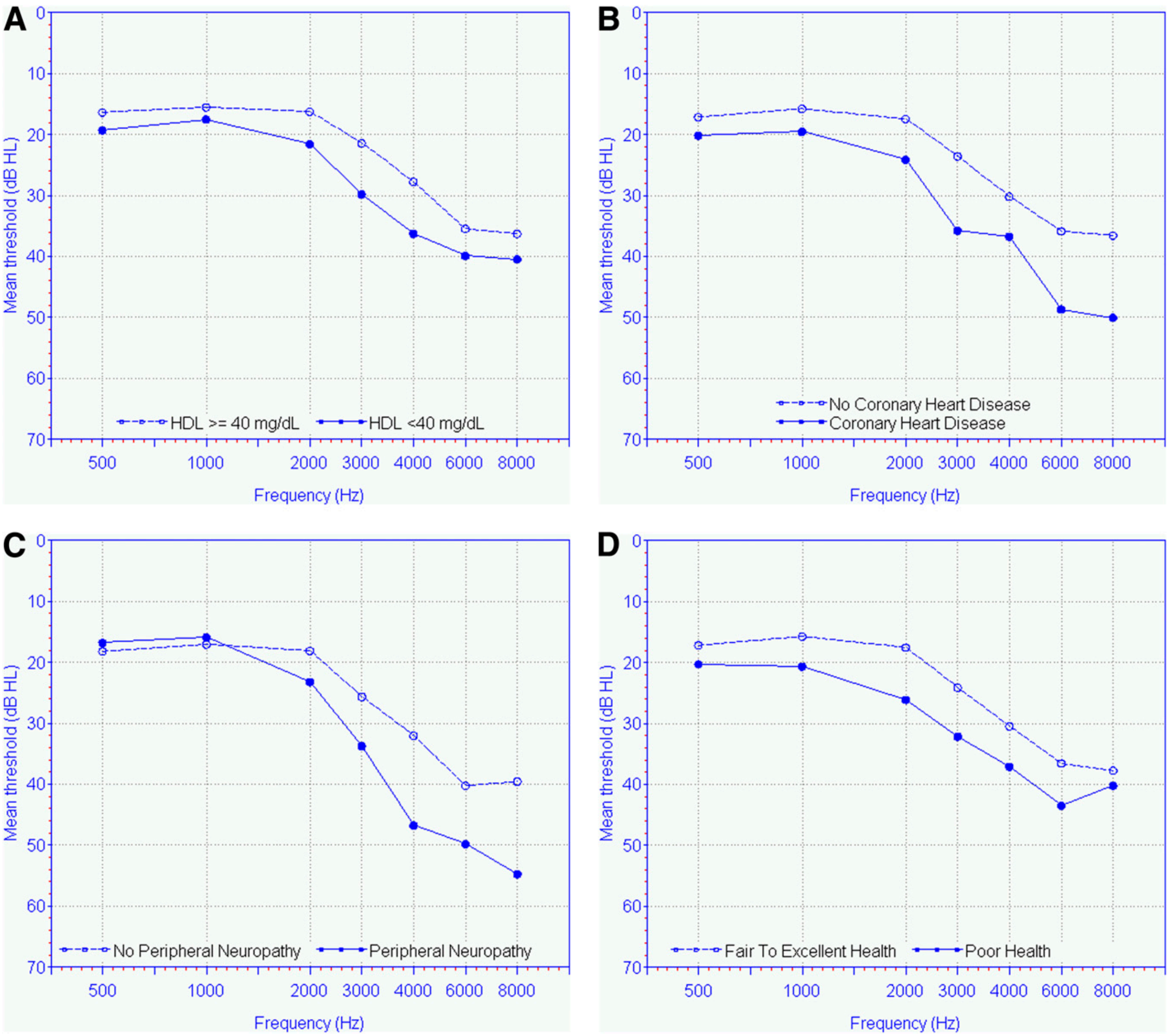

Figure 1—A: *Age-adjusted mean of pure-tone thresholds assessed in the worse ear among U.S. adults aged 20–69 years, by HDL status, NHANES 1999–2004*. B: *Age-adjusted mean of pure-tone thresholds assessed in the worse ear among U.S. adults aged 20–69 years, by coronary heart disease status, NHANES 1999–2004*. C: *Age-adjusted mean of pure-tone thresholds assessed in the worse ear among U.S. adults aged 40–69 years, by peripheral neuropathy status, NHANES 1999–2004*. D: *Age-adjusted mean of pure-tone thresholds assessed in the worse ear among U.S. adults aged 20–69 years, by self-reported health status, NHANES 1999–2004*. *(A high-quality color representation of this figure is available in the online issue.)*

little population-based evidence of a correlation with hearing function despite the hypotheses that diabetes or hyperglycemia may affect the sensory neurons of the inner ear, involve the VIII nerve, or influence central auditory processing (22,23). Several studies have examined the effect of diabetic neuropathy on audiometric threshold levels with small samples of patients with type 1 diabetes, but overall evidence is inconclusive as to the independent effects of neuropathy, other complications, diabetes duration, or glycemic control (2–6). A previous epidemiologic investigation of type 2 diabetes and hearing impairment found no association for either diabetes duration or A1C, findings that our study corroborates (9).

We acknowledge the limitations to this analysis. Our sample is derived from noninstitutionalized adults, so we are unable to generalize to subjects in nursing homes, where more severe disability might be expected. We cannot differentiate subjects with type 1 diabetes from those with type 2 diabetes, but note that 90–95% of the diabetic adults in our nationally representative sample are likely to have type 2 diabetes (24). Temporal relationships between our covariates and hearing impairment remain ambiguous as a result of the cross-sectional nature of the data. There also may be some errors in the measurement of independent variables. Years since diabetes diagnosis is an imperfect proxy for disease duration, particularly if pathogenic changes accompany hyperglycemic states prior to diabetes diagnosis (25).

In summary, hearing impairment is not widely recognized as a complication of diabetes despite its occurrence in as many as two-thirds of our diabetic sample. Among U.S. adults with diabetes, we identified a greater likelihood of hearing impairment for those who are older, non-Hispanic white, male, or who have lower income. Diabetic subjects with low HDL, a history of coronary heart disease, symptoms of peripheral neuropathy, or those who report poor health also exhibited a greater likelihood of hearing impairment. Longitudinal research will be important in delineating the natural history of hyperglycemia, diabetes duration, and the presence of diabetes complications in the occurrence of hearing impairment.

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K.E.B. researched data and wrote the manuscript. H.J.H. and C.C.C. researched data, contributed to discussion, and reviewed and edited the manuscript.

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