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Three decade change in the prevalence of hearing impairment and its association with diabetes in the United States ☆

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ABSTRACT

Objective. To examine the secular change of the prevalence of hearing impairment over three decades in U.S. adults with and without diabetes.

Methods. The cross-sectional National Health and Nutrition Examination Surveys (NHANES, the 1971–1973 [NHANES I] and the 1999–2004 [NHANES 1999–2004]) were used. Average pure-tone audiometry thresholds in decibels (dB) at 1, 2, 3, and 4 kHz frequencies of the worse ear were used to represent the participants' hearing status. Any hearing impairment was defined as average pure-tone audiometry threshold of the worse ear >25 dB.

Results. From 1971 to 2004, among adults without diabetes aged 25 to 69 years, the unadjusted prevalence of hearing impairment decreased from 27.9% to 19.1% ($P<0.001$), but among adults with diabetes there was no significant change (46.4% to 48.5%). After adjustment for age, sex, race, and education, the prevalence of hearing impairment in the NHANES I and NHANES 1999–2004, respectively, was 24.4% (95% confidence interval [CI], 22.3–26.6%) and 22.3% (95% CI, 20.4–24.2) for adults without diabetes and 28.5% (95% CI, 20.4–36.6%) and 34.4 (95% CI, 29.1–39.7%) for adults with diabetes. The adjusted prevalence ratios of hearing impairment for persons with diabetes vs. those without diabetes was 1.17 (95% CI, 0.87–1.57) for the NHANES I and 1.53 (95% CI, 1.28–1.83) for NHANES 1999–2004.

Conclusions. Persons with diabetes have a higher prevalence of hearing impairment, and they have not achieved the same reductions in hearing impairment over time as have persons without diabetes.

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Hearing impairment (HI) is the third most commonly reported chronic condition in US adults aged ≥65 years after hypertension and arthritis (Yueh et al., 2003). The major risk factors for HI include aging, exposure to noise, ototoxic drugs, and infectious disease (Niskar et al., 2001). There is evidence that diabetes is associated with HI (Bainbridge et al., 2008). The prevalence of diabetes mellitus has grown substantially in recent decades (Cowie et al., 2006), meanwhile US adults' lifestyle and occupational environment have changed. In the U. S. noninstitutionalized civilian population, the prevalence of self-reported HI increased by ~25% (Ries, 1994) between 1971 and 1990. However, a prevalence of HI based on self-reports is likely to be different from a prevalence of HI based on clinic measurement (Roberts, 1968). We are unaware, however, of any national reports on a change of prevalence in objectively measured HI.

We present here the first examination of changes in measured HI between the early 1970s and the late 1990s/early 2000s among U.S. adults aged 25 to 69 years by diabetes status.

Research design and methods

Study population

The National Health and Nutrition Examination Survey (NHANES) using a complex sampling design is an ongoing US representative survey designed to measure the health and nutritional status of the civilian noninstitutionalized U.S. population.

In NHANES I (year 1971 to 1973), all 3854 participants aged 25 to 74 years selected for pure-tone audiometric test; we limited our sample to those who were asked their history of diabetes and were in the same age range as NHANES 1999–2004 (year 1999 to 2004), 25 to 69 years ($n=3524$). Of those, we excluded 332 participants because of equipment defects ($n=308$), or medical condition ($n=24$).

In NHANES 1999–2004, half of the participants aged 20 to 69 years were randomly assigned to an audiometry examination. Participants were excluded if they used irremovable hearing aids, had ear pain, or did not tolerate headphones.

In the NHANES 1999–2004, of the 5418 participants selected randomly, we excluded 663 participants aged less than 25 years and 269 participants

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with incomplete audiometric exam because of lack of time, a communication problem, equipment failure, refusal, exclusion for safety, physical limitation, illness, or other reasons.

In the final analytic population aged 25 to 69 years, NHANES I had 3192 persons (women: 52.7%), and NHANES 1999–2004 had 4486 persons (women: 50.9%). Diabetes was reported by 3.5% of participants in NHANES I and 6.7% of participants in NHANES 1999–2004.

NHANES 1999–2004 received approval from the institutional review board and written informed consents were obtained from participants. NHANES I received internal human subjects review conducted according to the standards in place at that time.

Measures of hearing condition

Pure-tone audiometry thresholds were tested at several frequencies in a dedicated, sound-isolating room. The audiometers used were calibrated in accordance with the 1969 specifications of American National Standards Institute for NHANES I (ANSI S3.6-1969) (NCHS, 1973), and the 1989 specifications for NHANES 1999–2004 (ANSI S3.6-1989) (NCHS, 2001). The threshold recorded for each frequency was the lowest decibel (dB) level at which 50% or more of the responses were obtained. Both NHANES I and NHANES 1999–2004 employed a modified Hughson–Westlake technique for threshold.

Participants were tested at 4 frequencies [0.5, 1, 2, 4 kHz] in NHANES I and at 7 frequencies [0.5, 1, 2, 3, 4, 6, 8 kHz] in NHANES 1999–2004. The average pure-tone audiometry threshold of 1, 2, 3, and 4 kHz covered most of the frequencies of conversational speech between 0.5 and 2 kHz (Carhart, 1971; NCHS, 2001). Since NHANES I did not measure the threshold at 3 kHz, the threshold at 3 kHz of both NHANES I and NHANES 1999–2004 was estimated by the average of thresholds at 2 kHz and 4 kHz. The kappa agreement analysis for levels of hearing status between measured and estimated thresholds using NHANES 1999–2004 was 0.93 (95% confidence interval [CI]: 0.92 to 0.94) (Landis and Koch, 1977). The following categories of average pure-tone audiometry threshold were used to represent the participants' hearing status: hearing within normal limits (−10 to 25 dB), mild hearing loss (26 to 40 dB), moderate hearing loss (41 to 55 dB), moderately severe hearing loss (56 to 70 dB), severe hearing loss (71 to 90 dB), and profound hearing loss (>90 dB). A person was considered to have HI if average pure-tone audiometry threshold of the worse ear of 1, 2, 3, and 4 kHz was worse than normal limits (>25 dB). Average frequency-specified HI was defined as average levels of average pure-tone audiometry threshold of left and right ears of specific average pure-tone audiometry threshold at 1, 2, 3, or 4 kHz worse than normal limits (>25 dB).

Diabetes and demographic variables

Participants who reported having been told having diabetes by a doctor or health care professional were classified as having diagnosed diabetes. Age (year), race/ethnicity (white, African American, and all others), and education (less than high school, high school graduate, and more than high school) were assessed by questionnaire.

The income level was estimated by poverty-income ratio (PIR) which is the ratio of self-reported income to the family's appropriate poverty threshold (U.S.Census Bureau, 2007). Following PIR cutpoints established by the U.S. Department of Agriculture's food assistance program, participants were divided into 3 groups: low income (<1.3), middle income (1.3 to 3.5), and high income (>3.5).

Statistical analysis

All statistical analyses were performed with SAS-Callable SUDAAN software (Version 9.0.3, Research Triangle Institute, Research Triangle Park, NC) to obtain point estimates and standard errors that accounted for the complex sampling design (NCHS, 1982, 2004). Audiometry weights were used for computing estimates of US prevalence. Logistic regression was used to calculate the adjusted predicted marginal prevalence and standard error (SE) of HI and prevalence ratios (PRs) was calculated as the predicted prevalence of hearing status at a category of a risk factor divided by prevalence of hearing status at the referent category of that risk factor. The standard error of ln(PR) were estimated as $[(SE_{\text{Prevalence A}})^2/(\text{Prevalence A})^2 + (SE_{\text{Prevalence B}})^2/(\text{Prevalence B})^2]^{0.5}$ using delta method (Oehlert, 1992). Difference in prevalences of hearing status between surveys was calculated as prevalence from NHANES 1999–2004 minus prevalence from NHANES I. We standardized estimates to the average distribution of age–sex–race of NHANES I and NHANES 1999–2004. The population attributable risk percentage was calculated as $[100 \times \text{prevalence of diabetes} \times (PR-1)/(\text{prevalence of diabetes} \times (PR-1)+1)]$. The percent change in excess PR of HI from the adjusted model included intercept, survey years, and other covariate(s), while the base model included intercept and survey years only, which calculated as $[100 \times (\text{PR from base model} - \text{PR from adjusted model})/(\text{PR from base model} - 1)]$ (Gregg et al., 2000). The percent change in excess PR was used for evaluating the effect of an adjusted variable on the secular change of HI prevalence from NHANES I to NHANES 1999–2004.

Results

Between NHANES I and NHANES 1999–2004, among persons with diabetes, the proportion of women ($P=0.004$) and whites ($P<0.001$) decreased. Similar changes were observed for persons without diabetes, except for sex ($P=0.389$) (Table 1). The prevalence of self-reported diabetes was higher in NHANES 1999–2004 (6.8%) than in NHANES I (3.7%) ($P<0.001$). The median duration of diabetes changed from 4.8 years in NHANES I to 6.1 years in NHANES 1999–2004 ($P<0.001$). The mean age (years) were 44.9 and 44.3 for NHANES I and NHANES 1999–2004, respectively ($P=0.12$).

Substantial gains were seen between the 2 surveys in the educational level among both the population with diabetes and those without the disease (Table 1). The prevalence of educational level less than high school among persons with diabetes declined from 60.7% to 28.2%; among persons without diabetes, it changed from 33.5% to 17.5% (all $P<0.010$). However, persons with diabetes still had a much higher prevalence of education less than high school than persons without diabetes ($P<0.001$) during the later survey years.

In the comparison with NHANES I, the unadjusted prevalence of hearing within normal limits decreased by 2.1 percentage points (from 53.6% to 51.5%) among persons with diabetes ($P>0.75$); however, among person without diabetes, the unadjusted prevalence of hearing within normal limits in NHANES 1999–2004 increased 8.8 percentage points (from 72.1 to 80.9%) ($P<0.001$). The age–sex–race standardized prevalence of hearing status by survey and diabetes status are displayed in Table 2.

In both surveys, persons with diabetes had a much higher prevalence of HI than persons without diabetes. Persons with diabetes in NHANES 1999–2004 had worse hearing status than their counterparts in NHANES I at 0.5 kHz frequency ($P<0.001$). None of the other frequency-specific differences in prevalence in total population were statistically significant. Using persons without diabetes as the reference, the age–sex–race–education adjusted prevalence ratio (PR) of HI for persons with diabetes increased from 1.17 (95% CI, 0.87–1.57) in NHANES I to 1.53 (95% CI, 1.28–1.83) in NHANES 1999–2004 ($P<0.001$). The prevalence of HI was generally higher among the older, male, white, lower education/income population for both surveys (Table 3). All age groups had a lower prevalence of HI in NHANES 1999–2004 than in NHANES I. Men had greater improvement in hearing than women ($P=0.024$). For U.S. adults aged 25 to 69 years, the population attributable risk (%) of HI due to self-reported diabetes for the NHANES I and the NHANES 1999–2004 increased significantly from 0.6% to 3.4% ($P<0.001$).

The prevalence of HI decreased among whites and African Americans, persons with lower levels of education, and among all income levels (Table 3). Among those without diabetes the difference of prevalences between the 2 surveys was −8.8 percentage points ($P<0.001$). After adjustment for age, sex, and race, this difference of prevalences was reduced to −6.7 percentage points ($P<0.001$). In the final multivariate logistic model adjusted for age, sex, race, and educational levels, the difference of prevalences was −2.1 percentage points ($P=0.115$). Among those with diabetes, after adjustment for duration of diabetes, age, sex, race, and education, the prevalence (%)

Table 1
Characteristics of NHANES participants according to self-reported diabetes mellitus status.

Characteristic	NHANES I (n = 3192)				NHANES 1999–2004 (n = 4486)			
	Participants	Total % (SE)[a]	With DM % (SE)	Without DM % (SE)	Participants	Total % (SE)	With DM % (SE)	Without DM % (SE)
Age, y								
25–39	933	38.4 (1.1)	8.3 (2.8)	39.5 (1.1)	1657	38.4 (1.1)	12.0 (2.7)	40.3 (1.1)
40–49	680	22.9 (0.8)	15.5 (3.5)	23.2 (0.8)	1035	27.9 (0.9)	21.4 (3.4)	28.3 (0.9)
50–59	804	22.6 (0.9)	34.0 (4.4)	22.2 (0.9)	832	20.8 (0.8)	34.0 (3.1)	19.8 (0.8)
60–69	775	16.1 (0.8)	42.2 (5.3)	15.1 (0.9)	962	13.0 (0.6)	32.6 (2.8)	11.6 (0.6)
Sex								
Male	1521	47.3 (0.9)	35.2 (5.2)	47.7 (0.9)	2132	49.1 (0.8)	52.7 (2.9)	48.8 (0.9)
Female	1671	52.7 (0.9)	64.8 (5.2)	52.3 (0.9)	2354	50.9 (0.8)	47.3 (2.9)	51.2 (0.9)
Race								
White	2654	89.1 (0.8)	85.5 (2.8)	89.3 (0.8)	2186	71.6 (1.8)	61.3 (4.6)	72.3 (1.7)
African American	508	10.0 (0.8)	14.1 (2.8)	9.8 (0.8)	907	11.1 (1.0)	14.1 (2.4)	10.9 (1.0)
Other	30	0.9 (0.3)	0.4 (0.3)	0.9 (0.3)	1393	17.3 (1.8)	24.5 (4.2)	16.7 (1.7)
Education								
<High school	1401	34.5 (1.5)	60.7 (5.7)	33.5 (1.5)	1307	18.2 (0.8)	28.2 (3.1)	17.5 (0.7)
High school	1090	38.4 (1.2)	24.7 (4.6)	38.9 (1.2)	1003	24.8 (0.9)	25.7 (2.8)	24.7 (1.0)
>High school	701	27.2 (1.2)	14.6 (4.6)	27.6 (1.3)	2176	57.0 (1.1)	46.1 (3.4)	57.8 (1.2)
Income poverty index								
<1.3 (low income)	627	16.1 (1.1)	29.5 (3.9)	15.7 (1.1)	1065	18.8 (1.1)	25.5 (2.9)	18.3 (1.1)
1.3–3.5 (middle income)	1475	51.1 (1.3)	46.7 (5.9)	51.3 (1.3)	1495	34.1 (1.3)	39.9 (3.6)	33.7 (1.3)
>3.5 (high income)	900	32.7 (1.4)	23.7 (3.9)	33.0 (1.4)	1543	47.1 (1.8)	34.6 (3.7)	48.0 (1.8)
Self-reported diabetes								
No	3042	96.5 (0.3)	–	–	4095	93.3 (0.5)	–	–
DM duration <6 y	80	1.9 (0.2)	–	–	171	3.2 (0.4)	–	–
DM duration ≥6 y	70	1.6 (0.2)	–	–	220	3.5 (0.3)	–	–

Abbreviations: SE, standard error; DM, diabetes mellitus.
[a] Weighted percentage.

of HI in NHANES I was 28.5 (95% CI, 20.4 to 36.6), and in NHANES 1999–2004 it was 34.4 (95% CI, 29.1 to 39.7). The difference of prevalences in percentage points was 5.9 (95% CI: −3.6 to 15.4).

Compared with the base model, education was the most predictive factor related to the decrease in HI prevalence (Table 4), while diabetes status was the most important factor related to the increase in HI prevalence. There was no significant interaction between diabetes status and educational level ($P = 0.46$).

Discussion

Our study demonstrates that in 1999–2004, of US noninstitutionalized civilians aged 25 to 69 years, 21.1% had audiometrically detected HI; this was a 25.6% decrease in prevalence of HI from 1971–1973 (28.5%). Most of this decrease was associated with increased education, which likely served as a proxy for decreased occupational noise, and demographic changes in the US population (in age, sex, and race). However, there was no improvement of hearing status among persons with diabetes.

Diabetes has been established as a risk factor for HI in epidemiologic and pathologic studies (Parving et al., 1990; Sasso et al., 1999; Varkonyi et al., 2002; Ologe and Okoro, 2005; Vaughan et al., 2006; Sakuta et al., 2007). The mechanism by which diabetes could result in HI is not clear. Diabetes may be associated with microangiopathy in the inner ear (Smith et al., 1995), or it might be tied to neuronal degeneration (Tomlinson et al., 1996; Ristow, 2004).

Only a few studies have examined HI in the U.S. population. Lee et al. (2004), using the National Health Interview Survey, observed

Table 2
Age–sex–race standardized proportions by measured hearing status by survey years and diabetes status.

Hearing status	n	NHANES I N = 3192 % (95% CI)[a]	n	NHANES 1999–2004 N = 4486 % (95% CI)	Difference in prevalence in percentage points (95% CI)
Total					
Hearing within normal limits (−10–25)	2144	73.5 (70.7–76.2)	3448	78.4 (76.4–80.2)	4.8 (1.5–8.1)
Mild hearing loss (26–40)	637	17.3 (14.9–20.0)	651	13.9 (12.6–15.2)	−3.4 (−6.3–−0.6)
Moderate hearing loss (41–70)	348	7.8 (6.9–8.8)	361	7.3 (6.2–8.6)	−0.5 (−2.1–1.0)
Severe or profound hearing loss (71+)	63	1.3 (1.0–1.7)	26	0.5 (0.3–0.7)	−0.8 (−1.2–−0.4)
Persons with DM					
Hearing within normal limits (−10–25)	81	66.4 (52.9–77.7)	208	63.9 (57.0–70.3)	−2.5 (−16.8–11.8)
Mild hearing loss (26–40)	45	23.8 (14.6–36.4)	107	19.5 (14.8–25.4)	−4.3 (−16.5–7.9)
Moderate hearing loss (41–70)	21	9.2 (4.8–17.0)	72	16.1 (9.6–25.7)	6.9 (−3.0–16.8)
Severe or profound hearing loss (71+)	3[b]	0.6 (0.1–2.2)	4[b]	0.4 (0.2–1.2)	−0.1 (−1.0–0.8)
Persons without DM					
Hearing within normal limits (−10–25)	2063	73.7 (70.9–76.4)	3240	79.4 (77.6–81.1)	5.7 (2.4–9.0)
Mild hearing loss (26–40)	592	17.1 (14.8–19.8)	544	13.3 (12.1–14.5)	−3.9 (−6.7–−1.1)
Moderate hearing loss (41–70)	327	7.8 (6.9–8.8)	289	6.8 (5.7–8.1)	−1.0 (−2.5–0.6)
Severe or profound hearing loss (71+)	60	1.3 (1.0–1.7)	22	0.5 (0.3–0.7)	−0.9 (−1.3–−0.5)

Abbreviations: CI, confidence interval; DM, diabetes mellitus.
[a] Weighted % and 95% confidence interval.
[b] The confidence intervals are based on large sample theory and are not necessarily valid for small numbers of cases.

Table 3
Prevalence of hearing impairment and prevalence ratio by survey years and other covariates.

Variable	NHANES I N = 3192		NHANES 1999–2004 N = 4486		Difference in prevalence in percentage points
	% (95% CI)	PR (95% CI)	% (95% CI)	PR (95% CI)	(95% CI)
Model 1, univariate					
Age, y					
25–39	11.4 (8.5–14.3)	1.0 (Reference)	6.2 (4.8–7.5)	1.0 (Reference)	−5.2 (−8.4–−2.0)
40–49	23.4 (19.2–27.5)	2.05 (1.50–2.80)	17.6 (14.6–20.6)	2.85 (2.17–3.76)	−5.8 (−10.9–−0.7)
50–59	40.1 (34.9–45.4)	3.53 (2.64–4.71)	32.5 (27.5–37.4)	5.27 (4.04–6.86)	−7.7 (−14.9–−0.4)
60–69	60.4 (56.3–64.5)	5.30 (4.07–6.92)	54.4 (50.6–58.2)	8.82 (7.03–11.07)	−6.0 (−11.6–−0.4)
Sex					
Male	41.8 (37.6–46.1)	1.0 (Reference)	30.6 (27.1–34.1)	1.0 (Reference)	−11.3 (−16.8–−5.7)
Female	16.5 (14.6–18.6)	0.40 (0.34–0.46)	11.9 (10.0–13.8)	0.39 (0.32–0.47)	−4.6 (−7.4–−1.8)
Race					
White	29.4 (26.7–32.1)	1.0 (Reference)	23.3 (20.6–26.0)	1.0 (Reference)	−6.1 (−9.9–−2.3)
African American	22.1 (17.8–26.4)	0.75 (0.61–0.93)	12.2 (9.9–4.4)	0.52 (0.42–0.65)	−9.9 (−14.7–−5.0)
Other	11.8 (2.5–41.0)	0.40 (0.09–1.72)	17.5 (14.6–20.3)	0.75 (0.61–0.91)	5.7 (−11.7–23.0)
Diabetes					
No	27.9 (25.3–30.4)	1.0 (Reference)	19.1 (17.2–21.0)	1.0 (Reference)	−8.8 (−12.0–−5.6)
Duration <6 y	37.4 (25.0–49.7)	1.34 (0.95–1.89)	44.8 (34.5–55.1)	2.35 (1.83–3.01)	7.4 (−8.7–23.6)
Duration ≥6 y	56.8 (38.9–74.7)	2.04 (1.47–2.83)	51.9 (43.2–60.5)	2.72 (2.24–3.29)	−4.9 (−24.8–14.9)
Education					
<High school	43.1 (39.8–46.4)	1.0 (Reference)	30.7 (26.4–35.0)	1.0 (Reference)	−12.4 (−17.8–−7.0)
High school	24.5 (21.0–28.0)	0.57 (0.48–0.67)	23.0 (20.5–25.4)	0.75 (0.63–0.89)	−1.5 (−5.8–2.8)
>High school	15.7 (12.8–18.5)	0.36 (0.30–0.44)	17.2 (14.9–19.5)	0.56 (0.46–0.68)	1.5 (−2.2–5.2)
Income poverty index					
<1.3 (low income)	33.4 (29.0–37.9)	1.0 (Reference)	21.0 (17.9–24.0)	1.0 (Reference)	−12.4 (−17.8–−7.0)
1.3–3.5 (middle income)	28.9 (25.1–32.7)	0.87 (0.72–1.04)	21.2 (17.8–24.5)	1.01 (0.81–1.25)	−7.8 (−12.8–−2.7)
>3.5 (high income)	25.1 (22.4–27.9)	0.75 (0.63–0.89)	19.9 (17.4–22.4)	0.95 (0.78–1.15)	−5.2 (−8.9–−1.5)
Total	28.4 (25.9–31.1)	–	21.1 (19.0–23.2)	–	−7.4 (−10.7–−4.1)
Model 2, adjusted for age, sex, and race					
Diabetes					
No	27.2 (24.9–29.5)	1.0 (Reference)	20.5 (18.6–22.5)	1.0 (Reference)	−6.7 (−9.5–−3.8)
Duration <6 y	26.9 (19.2–34.7)	0.99 (0.73–1.34)	34.1 (25.8–42.4)	1.66 (1.28–2.15)	7.2 (−3.7–18.2)
Duration ≥6 y	39.4 (22.3–56.6)	1.45 (0.93–2.26)	35.0 (27.6–42.4)	1.71 (1.35–2.15)	−4.5 (−23.1–14.1)
Total	27.5 (25.2–29.8)	–	21.7 (19.6–23.7)	–	−5.8 (−8.7–−2.9)
Model 3, adjusted for age, sex, race, and education					
Diabetes					
No	24.4 (22.3–26.6)	1.0 (Reference)	22.3 (20.4–24.2)	1.0 (Reference)	−2.1 (−4.8–0.5)
Duration <6 y	23.6 (15.8–31.5)	0.97 (0.69–1.36)	34.7 (27.0–42.5)	1.56 (1.23–1.98)	11.2 (0.3–22.1)
Duration ≥6 y	34.4 (18.9–49.9)	1.41 (0.89–2.23)	35.2 (28.4–42.0)	1.58 (1.28–1.95)	0.8 (−16.0–17.6)
Total	24.7 (22.5–26.9)	–	23.3 (21.3–25.4)	–	−1.2 (−4.0–1.5)

Abbreviations: PR: prevalence ratio; CI, confidence interval.
NHANES I is the reference for each category of variables.

that the self-reported prevalence of HI remained relatively stable in the US noninstitutionalized population from 1986 to 1995. However, the agreement between self-reported HI and HI defined by average pure-tone audiometry threshold is not consistent, which makes self-reported HI a weak method for detecting mild HI (Bagai et al., 2006).

Table 4
Effect of separately controlling for other covariates on reduction in the association of survey year and HI.

Variables in model	PR (95% CI) of NHANES 1999–2004[a]	Change in excess PR (%)[b]
Survey (base model)	0.74 (0.65–0.85)	0 (Referent)
Survey, sex	0.73 (0.64–0.83)	−4
Survey, age	0.79 (0.69–0.89)	19
Survey, race	0.78 (0.68–0.89)	15
Survey, education	0.87 (0.76–0.99)	50
Survey, diabetes	0.72 (0.63–0.82)	−8
Survey, income poverty index	0.74 (0.64–0.84)	0
Survey, education, diabetes	0.84 (0.73–0.95)	38
Survey, sex, age, race	0.79 (0.70–0.90)	19
Survey, sex, age, race, education	0.95 (0.84–1.07)	81
Survey, sex, age, race, diabetes	0.78 (0.69–0.88)	15
Survey, sex, age, race, education, diabetes	0.93 (0.82–1.05)	73

Abbreviations: PR, prevalence ratio; CI, confidence interval.
[a] Prevalence of HI (hearing impairment) in NHANES I as referent.
[b] Percent change in excess prevalence ratio of hearing impairment by survey year compared with base model of survey years, which is calculated as [100× (PR_base − PR_adjusted) / (PR_base − 1)].

Having an educational level of less than high school, which is related to exposure to a noisy occupational environment, was highly related to the risk of HI in this study. Although the improvement in educational level was higher among persons with diabetes than among person without diabetes, the prevalence of HI among persons with diabetes was still relatively stable or even slightly increased ($P>0.05$). This might be because the mechanisms of HI differ between persons with and without diabetes or because the improvement in education among persons with diabetes was not sufficient. Tay et al. (1995) demonstrated that persons with diabetes have worse hearing threshold levels, especially at low and middle frequencies ($P<0.001$), and HI was reported more frequently in persons with type 1 diabetes than in persons with type 2 diabetes. A prospective cohort study concluded that persons with diabetes who are aged ≤60 years may show early high-frequency hearing loss similar to early presbycusis; however, after age 60, this difference in hearing loss between persons with diabetes and those without the disorder was diminished (Vaughan et al., 2006). In our study, persons with diabetes in the NHANES 1999–2004 had a younger age at diabetes diagnosis and a longer duration of diabetes. Further study is needed to determine whether an early onset of diabetes increases the risk of HI, effectively outweighing the benefits accrued by reduced environmental risks in recent decades. We also found that persons with diabetes had a significant increment in the prevalence of HI at lower frequency (0.5 kHz) during the last 30 years; meanwhile, persons without diabetes had a significant decrement of the prevalence of HI at higher frequency (3.0 kHz). These findings might imply a difference in the mechanisms influencing HI among people with and without diabetes. Diabetic HI may have a risk factor profile similar to that for diabetic neuropathy, diabetic nephropathy, or diabetic retinopathy.

Average pure-tone audiometry threshold can detect impairment at various levels of the sensorineural hearing system. The major limitation of our study is its cross-sectional design, which may not support causal analysis. The second is the measurement condition and sampling structure changed during the last decades. Exclusion of persons with irremovable hearing aids or sufficient ear pain in NHANES 1999–2004 might underestimate the prevalence of HI. Also, diabetes status was identified through self-report; although self-report is a good measure of diagnosed diabetes, it would not detect undiagnosed diabetes (Cowie et al., 2006). It is plausible that the self-reported diabetes cases in NHANES 1999–2004 could be less severe than those of NHANES I, because the diagnostic threshold for diabetes, based on blood glucose concentration, was lowered during the more recent study period (i.e., NHANES 1999–2004).

Conclusions

Our study demonstrated that HI remains an important public health condition in the US. While the prevalence of HI among U.S. adults has been decreasing in the last 30 years, the increasing prevalence of diabetes continues to bring added risk of diverse vascular and neuropathic complications. These findings suggest that it will be important to track HI and explore ways to reduce its risk among the diabetic population.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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