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Hearing Impairment in Relation to Severity of Diabetes in a Veteran Cohort

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Abstract

Objective—Type 2 diabetes is epidemic among veterans, approaching three times the prevalence of the general population. Diabetes leads to devastating complications of vascular and neurologic malfunction and appears to impair auditory function. Hearing loss prevention is a major health-related initiative in the Veterans Health Administration. Thus, this research sought to identify, and quantify with effect sizes, differences in hearing, speech recognition, and hearing-related quality of life (QOL) measures associated with diabetes and to determine whether well-controlled diabetes diminishes the differences.

Design—The authors examined selected cross-sectional data from the baseline (initial) visit of a longitudinal study of Veterans with and without type 2 diabetes designed to assess the possible differences in age-related trajectories of peripheral and central auditory function between the two groups. In addition, the diabetes group was divided into subgroups on the basis of medical diagnosis of diabetes and current glycated hemoglobin (HbA1c) as a metric of disease severity and control. Outcome measures were pure-tone thresholds, word recognition using sentences presented in noise or time-compressed, and an inventory assessing the self-perceived impact of hearing loss on QOL. Data were analyzed from 130 Veterans ages 24 to 73 (mean 48) years with well-controlled (controlled) diabetes, poorly controlled (uncontrolled) diabetes, prediabetes, and no diabetes. Regression was used to identify any group differences in age, noise exposure history, and other sociodemographic factors, and multiple regression was used to model each outcome variable, adjusting for potential confounders. Results were evaluated in relation to diabetes

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duration, use of insulin (yes, no), and presence of selected diabetes complications (neuropathy and retinopathy).

Results—Compared with nondiabetics, Veterans with uncontrolled diabetes had significant differences in hearing at speech frequencies, including poorer hearing by 3 to 3.5 dB for thresholds at 250 Hz and in a clinical pure-tone average, respectively. Compared with nondiabetic controls, individuals with uncontrolled diabetes also significantly more frequently reported that their hearing adversely impacted QOL on one of the three subscales (ability to adapt). Despite this, although they also had slightly poorer mean scores on both word recognition tasks performed, these differences did not reach statistical significance and all subjects performed well on these tasks. Compared with Veterans with controlled diabetes, those with uncontrolled disease tended to have had diabetes longer, be insulin-dependent, and have a greater prevalence of diabetic retinopathy. Results are generally comparable with the literature with regard to the magnitude of threshold differences and the prevalence of hearing impairment but extend prior work by providing threshold difference and hearing loss prevalence effect sizes by category of diabetes control and by including additional functional measures.

Conclusions—In a cohort of Veterans with type 2 diabetes and relatively good hearing, significant effects of disease severity were found for hearing thresholds at a subset of frequencies and for one of the three QOL subscales. Significant differences were concentrated among those with poorly controlled diabetes based on current HbA1c. Results provide evidence that the observed hearing dysfunction in type 2 diabetes might be prevented or delayed through tight metabolic control. Findings need to be corroborated using longitudinal assessments.

Keywords

Aging; Diabetes mellitus; Hearing loss; Pure-tone thresholds; Speech understanding; Veterans

INTRODUCTION

Diabetes mellitus is a metabolic syndrome affecting 1 in 12 adults in the U.S. and 1 in 4 to 5 Veterans receiving care at Veterans Health Administration (VA) (Miller et al. 2004). Poor glycemic control is thought to be responsible for most of the diabetes-related morbidity, which includes devastating complications of vascular and neurologic malfunction, such as heart and kidney disease, stroke, blindness, neuropathy, and loss of limbs. Accumulating evidence suggests that hearing loss is yet another disabling complication of diabetes (e.g., Bainbridge et al. 2008; Mitchell et al. 2009), with potential adverse effects on quality of life (QOL) including impacts on the ability to understand speech, social-emotional well-being (Strawbridge et al. 2000), and mortality (Feeny et al. 2012). Monitoring auditory function may therefore be important for the care of patients with diabetes, and further, if diabetic hearing loss depends on severity or metabolic control, it may be preventable. Nevertheless, characterization of diabetes-related hearing loss and its difference from normal aging are far from complete, as is our understanding of whether, and if so the extent to which, hearing deterioration depends on diabetes severity or metabolic control.

Although studies on diabetes and hearing loss often conclude that an association exists, many experience a number of problems that make interpretation difficult. Problems include

defining diabetes status based on self-report, not differentiating between type 1 and type 2, and primarily focusing on older ages when presbycusis is common (Gates et al. 1993; Dalton et al. 1998; Helzner et al. 2005; Frisina et al. 2006; Mitchell et al. 2009). Yet, recent findings show significantly enhanced risk of macrovascular and microvascular complications in type 2 diabetes compared with type 1 (Kershnar et al. 2006; Maahs et al. 2007; Rodriguez et al. 2010; Constantino et al. 2013), and greater effects of diabetes on hearing may be found among individuals younger than 50 years of age (Dalton et al. 1998; Vaughan et al. 2006; Bainbridge et al. 2008; Agrawal et al. 2009; Austin et al. 2009). Furthermore, some studies find the largest disparities in the low frequencies (<4000 Hz) (Tay et al. 1995; Ma et al. 1998; Frisina et al. 2006), whereas others conclude high frequencies are more likely to be impacted (Diaz de Leon-Morales et al. 2005; Vaughan et al. 2006; Bainbridge et al. 2008; Agrawal et al. 2009; Uchida et al. 2010). Finally, studies are scarce that have included tests of the auditory system beyond establishing pure-tone thresholds for the usual clinical audiogram frequencies (Frisina et al. 2006).

Diabetes severity can be measured in several ways, including duration, ease of control of diabetes, and complications developed. Some investigations have examined the association with ease of control according to whether the diabetes required insulin to control (IDDM) or not (NIDDM). Others have used the level of fasting blood sugar or glycated hemoglobin (HbA1c). While blood glucose measures reflect levels at a single point in time, HbA1c reflects the average glucose level over approximately the past 120 days. Results are mixed with regard to the association between the probability of hearing impairment and the severity of diabetes, based on insulin use or glycemic control. Bainbridge et al. (2011) found that among National Health and Nutrition Examination Survey participating individuals with diabetes, the percentage of insulin use was 36% in those with hearing loss and 22% in those without hearing loss, a “marginally significant”* difference for the low/mid-audiometric frequencies only. However, type of glycemic medication and poor glycemic control were not significant risk factors for hearing loss when examined in logistic regression models used to estimate risk after adjusting for important sociodemographic factors (age, race/ethnicity, and sex). Ma et al. (1998) restricted analysis to those with NIDDM, and after age adjustment found significant differences in hearing at frequencies of 2000 and 4000 only. Dalton et al. (1998) also found no significant association between hearing loss and NIDDM after adjusting for age and other sociodemographic factors; however, an association emerged once they excluded participants with hearing loss not consistent with presbycusis and controlled for potential confounders (odds ratios [OR] = 1.41, 95% confidence interval [CI]: 105 to 1.8). They did not, however, find an effect of diabetes duration or HbA1c level. Neither did Taylor and Irwin (1978) found any association between insulin use and hearing loss nor did Tay et al. (1995) or Vaughan et al. (2006). Sakuta et al. (2007) found an association with results of a 2-hr oral glucose tolerance test but not fasting blood glucose. Gates et al. (1993) reported an association between low-frequency hearing loss and fasting blood sugar only in women. Diaz de Leon-Morales et al. (2005) found no correlation between hearing loss and fasting blood sugar or HbA1c, and Ologe and Okoro (2005) found none with fasting blood sugar. We previously reported that blood glucose was significantly

*Bainbridge et al. (2011), p. 1543.

correlated with pure-tone thresholds at 250 and 500 Hz among Veterans (0.153, $p < 0.039$; and 0.226, $p < 0.002$, respectively). Also, HbA1c was significantly correlated (0.148, $p < 0.048$) with the threshold at 500 Hz. Associations were entirely due to stronger correlations in the youngest age group examined (<50 years) and were not seen in the two older tertiles (Austin et al. 2009). Finally, an association between the duration of diabetes and hearing loss was found in the majority of studies that looked for one (Kurt et al. 2002; Mitchell et al. 2009; Mozaffari et al. 2010). Notably, some large, well-controlled studies did not (Bainbridge et al. 2011; Lerman-Garber et al. 2012).

Information about the magnitude of threshold differences as a function of diabetes severity, that is, the effect size presented with confidence intervals, is useful for determining whether excess hearing loss from diabetes has clinical importance for a particular diabetic patient. We previously reported that among a large Veteran cohort with type 2 diabetes selected to have less than severe hearing loss and include younger ages, excess hearing loss was consistently found among the participants with diabetes (Austin et al. 2009). The presence and size of significant effects depended on diabetes severity and pure-tone frequency. Specifically, participants with IDDM had significantly poorer thresholds in all three age groups examined, but excess hearing loss was found in participants with NIDDM only in the youngest age group (27–49 years). Across age groups, effect sizes for the contrast between IDDM and nondiabetes ranged from about 4 to 6 dB at low/mid-frequencies. Effect sizes at low/mid-frequencies were similar for the NIDDM/control contrast in the youngest age group but were less in older age groups. A possible explanation for these results is that the effects of less severe diabetes were detectable only when not confounded by presbycusis; however, we were not able to explain why younger individuals with NIDDM had excess hearing loss over the entire range of frequencies tested (250 to 14,000 Hz), whereas younger participants with IDDM had excess hearing loss at fewer frequencies. If not a chance finding or due to selection bias, it could be that IDDM is not the more severe subgroup of diabetics compared with NIDDM at younger ages. Given the strong correlations between low-frequency thresholds and blood glucose and HbA1c among the younger Veterans examined in that study (with correlations provided earlier), HbA1c may be a comparatively better measure. Evidence from several large clinical trials, including the Diabetes Control and Complications Trial, demonstrates the usefulness of HbA1c for predicting other microvascular complications in patients with type 1 diabetes mellitus (DCCT 1993). Moreover, the American Diabetes Association promotes the use of HbA1c in the diagnosis and management of diabetes and has set a therapeutic target of 7.0% appropriate for most patients with the disease (ADA 2014). In summary, the limitations in the existing literature lead to a poor understanding of the importance of diabetes control for delaying or preventing diabetic hearing loss.

We undertook a longitudinal study of Veterans with and without diabetes to assess possible differences in age-related trajectories of peripheral and central auditory function between the two groups. We planned the study to include diabetes patients primarily of type 2 and to include younger Veterans and various measures of diabetes severity. We hypothesized that diabetes of greater severity or longer duration, or both, adjusted for noise exposure and patient age, would be associated with higher thresholds for pure tones and that less severe

non-noise hearing loss among diabetes patients would be more easily detected among younger individuals.

This report examines cross-sectional data on hearing, word recognition, and hearing-related QOL measures at the initial (baseline) visit of the study. Aims were to identify and quantify with effect sizes any differences in these outcome measures associated with diabetes and to determine whether well-controlled diabetes diminishes the differences. Results of this report lay the groundwork for analysis of longitudinal assessments in the same participants aimed at detecting onset or progression of hearing impairments and precipitating diabetes factors.

PARTICIPANTS AND METHODS

Participants

Data from 130 Veterans living locally and receiving care at Portland Veterans Affairs Medical Center (PVAMC) were analyzed for this study. Figure 1 is a flowchart of participant recruitment. Participants were identified from two primary sources: (1) an electronic medical record (EMR) query limited to Veterans no more than 49 years old and meeting a priori exclusions (see later); and (2) rosters of participants from two previous diabetes and hearing loss studies conducted at the National Center for Rehabilitative Auditory Research (NCRAR), limited to those who were no more than 57 years old at the time of their earlier participation. To supplement data at younger ages and for certain diabetes severity categories, additional participants were identified through a search of the Diabetes Patient Registry at PVAMC, which includes patients with diabetes and prediabetes (if requested by their physician) and from a pool of patients who contacted us in response to study advertisements placed around PVAMC.

In addition to age restrictions, exclusions included neurologic or psychiatric disorders, cancer, Meniere disease, and conductive, mixed, or severe to profound hearing loss. Potential participants unable to travel to the medical center or be tested over a longtime interval in a sound-proof room were also excluded. Individuals not so excluded were screened for the evidence of active ear disease or conductive hearing loss (participants were required to have normal otoscopy, tympanometry and no clinically significant air-bone gaps based on audiometry), or excessive mid- to high-frequency sensorineural hearing loss (excluded were participants without thresholds <40 dB hearing level [HL] at 2000 Hz and <70 dB HL at 4000 Hz in at least one ear). Participants scoring 24 or less on the Mini-Mental Status Examination were excluded (Folstein et al. 1975). Veterans with type 1 diabetes were removed from the analysis to focus solely on type 2 diabetes, the most common form of diabetes in the general population (WHO 1999) and among Veterans. Of these 130 study participants, 21 without diabetes (28.8%) and 19 with diabetes (33.3%) were in at least one previous NCRAR diabetes study. They accounted for the majority (63.8% or 37/58) of participants over 50 years of age.

Procedures

All testing was completed in a double-walled sound-treated booth by a licensed audiologist. Individuals were consented to participate in the study following the guidelines of the PVAMC Institutional Review Board and were compensated for their time.

Questionnaire—A demographic questionnaire was administered to obtain information about participants' noise exposure history, medical history, and education level and to gather information about their diabetes, including duration, treatment history, and complications.

Diabetes Measures—Participants answered a series of yes/no questions concerning sensations in the feet, including numbness, tingling, and pain (described as burning, itching, or stabbing). The answers were used to construct a peripheral neuropathy index, which ranged from 0 (symptoms denied) to 3 (affirmative answers on all three questions). Participants' reporting at least two symptoms were considered to have peripheral neuropathy for analyses, a likely conservative estimate of the prevalence of diabetic neuropathy in our sample. Separate testing for peripheral foot sensation loss (reported as a percentage) was performed by a research audiologist trained in the procedure, which used a 10-g nylon monofilament applied to each participant's 10 toes. Amputated toes resulting from diabetes complications were included in the calculation and counted as having no sensation. Participants' medical charts were reviewed to capture recent laboratory values and ophthalmological examination findings. Retinopathy was reported as absent, non-proliferative, or proliferative. Presence or absence of clinically significant macular edema was also noted. HbA1c measures were obtained from the EMR for some participants with diabetes. For all nondiabetic participants and when participants with diabetes did not have HbA1c measurement within the previous 30 days, the measure was obtained on the day of testing by the research audiologist using a Bayer DCA 2000+ Analyzer (Bayer HealthCare, Osaka, Japan).

Classification of Diabetes Severity—Participants were divided into four diabetes severity groups based on current HbA1c values constrained by the presence or absence of a medical diagnosis of diabetes: (1) no diabetes (no diagnosis and HbA1c < 5.7%); (2) prediabetes (no diagnosis and HbA1c ≥ 5.7%); (3) controlled diabetes (diagnosis and HbA1c < 7%); and (4) uncontrolled diabetes (diagnosis and HbA1c ≥ 7%).

Quality of Life Inventory—The Psychosocial Impact of Assistive Devices Scale is a standardized, self-rating survey of 26 items (words or phrases) with subscales relating to three areas of psychosocial health: competence, adaptability, and self-esteem (Day & Jutai 1996). It is typically used to assess the self-perceived impact of a medical procedure or assistive device, such as hearing aids on QOL (Saunders & Jutai 2004; Saunders et al. 2009). In this study, the form was adapted to assess impacts of hearing ability on QOL. Participants were asked to indicate the extent that their current hearing ability affected them. For favorable characteristics (e.g., happiness, self-confidence), the rating scale ranged from —3 to 0 such that a lower value was indicative of poorer QOL. For unfavorable characteristics (e.g., confusion, frustration, embarrassment), the rating scale ranged from 0 to +3 such that an increasing value was indicative of decreasing QOL. We opted to dichotomize the outcome as no effect or at least some effect to make the result more interpretable as self-reported scores can be arbitrary. Therefore, any participant with an item that deviated from 0 within a subscale was considered to self-report at least some negative effect of hearing loss on QOL. When all subscale items were 0, the participant was considered to express no effect of hearing loss on QOL. Three participants failed to answer a

question out of 26 and one participant failed to answer three questions out of 26. In all cases, the missing data did not affect the results for any of the subscales. They all had at least one item in a subscale with missing data that deviated from 0.

Hearing Thresholds—Air conduction thresholds were obtained for pulsed tones using a GSI-61 audiometer (Grason-Stadler, Inc.) and ER3A insert earphones (Etymotic Research, Inc.) in frequencies from 250 to 8000 Hz, whereas HDA200 earphones (Sennheiser Electronic Corp.) were used for testing the extended high frequencies (EHFs) above 8000 Hz. Bone conduction thresholds were obtained at octave frequencies 500 to 4000 Hz to establish the nature of the loss, if present. Air conduction thresholds in each ear were averaged across frequencies to yield three distinct pure-tone averages (PTAs) for analysis: (1) clinical PTA of 500, 1000, and 2000 Hz; (2) high-frequency PTA (HF-PTA) of 3000, 4000, 6000, and 8000 Hz; and (3) EHF-PTA of 10,000, 12,500, and 14,000 Hz. Thresholds at 250 Hz were analyzed separately. Any threshold that exceeded the limits of the audiometer was set to 110 dB HL for inclusion in the mean. Only one participant, an older individual with diabetes, had a no-response in the conventional audiometric frequency range that had to be set to 110 dB HL for inclusion in the mean calculation. It was at a single frequency (8000 Hz) in one ear. In the EHF range, “no-response” was obtained in a slightly greater number of subjects with diabetes (14/57 or 25%) than without diabetes (8/50 or 16%), respectively.

Speech Testing—Recorded speech was delivered via insert earphones through the GSI-61 using a calibrated CD player. Speech in noise and time-compressed (rapid) speech were used to increase the difficulty of the task.

Speech in Noise (QuickSIN) Test—The QuickSIN (Etymotic Research, Inc.) is a clinically available measure of speech recognition in noise. Participants were asked to repeat sentences presented in a background of four-talker competing noise presented at 70 dB HL using standardized procedures. Sentences were initially presented 25 dB above background noise, a relatively easy task. The noise level was then increased in 5 dB increments with each successively presented sentence until the final sentence was played at equally loud speech and noise, a much more difficult task. The result, signal to noise ratio “(SNR) loss,” is an estimate of the dB increase in signal required by the person under test to understand speech in noise compared with an average normal-hearing person. Scores could range from —4.5 to 25.5. Scores ≤ 0 indicate speech recognition equal to or better than the average normal-hearing person; increasingly elevated scores >0 indicate increasing difficulty understanding speech in noise and are typically associated with impaired hearing. According to Table 1 of the QuickSIN manual, a 0- to 3-dB SNR loss is considered near-normal; a 3- to 7-dB SNR loss is considered mild; 7 to 15 dB is moderate, and >15 dB is severe.

Time-Compressed Speech—Time-compressed speech testing used Institute of Electrical and Electronic Engineers sentences (IEEE 1969), which are both semantically and syntactically correct and contain five target words. Sentences were compressed with a custom software algorithm (Vaughan & Letowski 1997) at rates faster than normal speech and presented at 40 dB above the PTA in both ears at 2000, 3000, and 4000 Hz, a

comfortably loud level. Participants were instructed to repeat each sentence after presentation. After a practice session with uncompressed and compressed sentences, participants were presented 10 sentences at a 50% compression rate. The number of correctly repeated target words was noted. This process was repeated for sentences compressed at a rate of 60%. Points (2% per word) were awarded based on correct responses on each of the five target words in each of the 10 sentences set for a total possible final score ranging from 0 to 100%. Poorer scores suggest difficultly with speech recognition. Time-compressed speech results were negatively skewed and transformed using a Manly transformation (Wright & Royston 1999) for analyses. However, raw speech data are reported for easier interpretation.

Statistical Analysis

The primary goals of the analyses were to determine whether diabetes severity was associated with hearing and functional outcomes related to hearing (i.e., speech recognition, self-report of hearing-related impacts on QOL) and to quantify the effect size of any observed associations. First, a number of participant characteristics were assessed for their univariate association with diabetes severity using simple linear regression for continuous and logistic regression for categorical variables and post hoc analysis when necessary, which were adjusted using Bonferroni applications. Next, separate multiple linear regression models were fit to each hearing outcome using diabetes severity as a categorical main effect and included as covariates participant characteristics that differed across groups based on a p value of <0.15 in the univariate analyses. Overall, type III p values that test for the presence of a diabetes main effect are reported, after covariates are accounted for, with significance defined at the 0.05 level. All two-way interactions were also assessed for every model using a 0.10 significance level; however, no interactions proved significant and thus interactions are not reported. In addition to overall main effects, we were interested in determining which specific group contrasts were responsible for an association (e.g., participants without diabetes versus participants with uncontrolled diabetes). Therefore, when the type III p value was significant or nearly significant, estimates of each group contrast (i.e., the adjusted effect sizes) were obtained and the contrast p values reported; again with significance defined at the 0.05 level. Model fits were assessed using normal probability plots and histograms of studentized residuals, and influential subjects determined by evaluating likelihood distance (Cook & Weisberg 1982; Collett 1991). Results showed no gross deviations of the fitted models from the data. Two younger participants with prediabetes (nos. 12 and 138) were considered overly influential and removed from the hearing outcome analysis of 250 Hz, and one older participant with uncontrolled diabetes (no. 23) was overly influential in the hearing outcome analysis of the clinical PTA and was removed. Subjects considered overly influential are removed from the analysis to achieve more accurate results that reflect the population under analysis. These three subjects had excessive hearing loss compared with their severity group, and by removing them from the model-based results, we present more conservative estimates of the effect size.

Age and to a lesser extent previous noise exposure and smoking status are considered potential confounders of diabetes-related hearing loss, were found to be associated with diabetes severity group, and therefore were included as covariates in initial multiple

regression models. However, previous noise exposure and smoking status were not statistically significant in any multivariate model (data not shown) and, therefore, was subsequently removed from the final models.

We were also interested in determining whether the prevalence of hearing loss and QOL as it relates to self-reported hearing ability showed significant differences by diabetes severity. This analysis required hearing thresholds to be categorized as normal or impaired. Using standard audiometric cutoff criteria, hearing was categorized as impaired if the average threshold was greater than 20 dB HL. Logistic regression was used to determine the significance of the distribution of the dichotomous outcomes (normal, impaired) between all four diabetes severity groups (control, prediabetes, controlled, and uncontrolled diabetes). In addition, if the overall age-adjusted type III test had a *p* value smaller than 0.15, we conducted planned contrasts between participants with no diabetes and uncontrolled diabetes and between participants with controlled and uncontrolled diabetes and determined effect sizes reported as OR. Models were assessed using goodness of fit statistics.

RESULTS

Overall Sample Characteristics

Characteristics of the 130 study subjects are provided in Table 1. Participants ranged from 24 to 73 years and averaged 47.7 years (SD: 11.1 years). Mean age differed significantly across the four diabetes categories (df = 3, $f = 3.61$, $p = 0.015$), confirming that analyses of hearing and diabetes severity required an age adjustment. Post hoc analysis indicated that the age effect was driven by differences between participants with prediabetes and no diabetes (mean difference = 8.32 years, Bonferroni-adjusted $p = 0.014$). Most participants were male (92.3%) and white (75.4%); neither sex nor race/ethnicity varied significantly across the four groups. Educational achievement and overall noise exposure did not vary significantly across the four groups. Nonmilitary occupational noise exposure differed significantly ($p = 0.028$), and although current smoker status did not differ significantly ($p = 0.664$), differences among the groups in smoking status (ever/never) approached the designated level of significance ($p = 0.061$). These differences were due to participants with controlled diabetes being more likely to report having had greater exposure to nonmilitary occupational noise ($p = 0.024$) and to have ever smoked ($p = 0.058$) compared with participants without diabetes.

Mean HbA1c values[†] were 5.3% (range: 4.8 to 5.6), 5.9% (range: 5.7 to 6.6), 6.3% (range: 5.6 to 6.9), and 8.9% (range: 7.0 to 13.8) among those with no diabetes, prediabetes, controlled diabetes, and uncontrolled diabetes groups, respectively. A much greater percentage of participants were insulin-dependent in the uncontrolled diabetes group (78.1%) compared with the controlled diabetes group (24.0%, $p < 0.001$). Participants with uncontrolled diabetes also had diabetes 3.4 years longer on average ($p = 0.059$).

[†]These values correspond to 34 mmol/mol (29 to 38), 41 mmol/mol (39 to 49), 45 mmol/mol (38 to 52), and 74 mmol/mol (53 to 127), respectively.

Hearing Threshold Outcomes

Figure 2 depicts the mean audiogram for each of the four diabetes severity groups. For better visual clarity, standard deviations are not shown. They are provided in Table 2 along with the mean values for each group. Data are shown separately for the better and worse hearing ear of each participant, as well as for the average across both ears. A reference line is placed at 20 dB HL to mark the boundary between clinically normal hearing (earlier) and impaired hearing (later). Trends appear similar across panels, although substantial threshold asymmetry is evident in this sample of Veterans. Within each group, mean thresholds increased with increasing frequency, consistent with the expected profile based on the age distribution of participants. More specifically, mean thresholds were within the normal range through about 8 kHz in the better hearing ear and through about 2 kHz in the worse hearing ear. Participants without diabetes had the best hearing overall, whereas participants with uncontrolled diabetes had poorer hearing than controls at all frequencies. As shown in Table 2, the unadjusted mean thresholds were poorer by 4 to 10 dB for individuals with uncontrolled diabetes compared with those without diabetes depending on the PTA examined. Participants with controlled diabetes tended to have mean thresholds between these two groups within the conventional audiometric frequency range (i.e., frequencies up to about 8000 Hz). At higher frequencies, mean thresholds for controlled and uncontrolled diabetes groups tended to converge, and those with controlled diabetes were slightly worse. Participants with prediabetes also had mean thresholds that fell between those of the control and uncontrolled diabetes groups through about 3 kHz. At higher frequencies, the prediabetes group had the poorest mean thresholds of all.

To determine whether there was an association between diabetes severity and hearing, each hearing threshold outcome measure was regressed on diabetes severity group and age-adjusted. Results of these multiple regression models are presented in Table 3. Because speech recognition tests were diotic (presented to both ears), we chose to avoid redundancy by presenting these results as the average across both ears. Similar results were obtained in separate analyses of the better and worse hearing ears (data not shown). The regression coefficients (“estimates”) provided in Table 3 are effect sizes, adjusted for age, comparing the estimated mean threshold in the group without diabetes to each other diabetes severity group. Participants with uncontrolled diabetes were found to have significantly poorer hearing thresholds at 250 Hz ($p = 0.022$) and within the clinical PTA ($p = 0.013$) compared with participants without diabetes. Effect sizes for these outcomes were 3.1 and 3.46 dB, respectively. No other contrasts proved significant. Adjusted mean hearing thresholds were not significantly different by diabetes group in the HF-PTA or EHFPTA. In fact, after adjusting for age, predicted mean thresholds for the group with prediabetes were similar to participants without diabetes within 1.5 dB across for each hearing threshold outcome. Using the parameter estimates in Table 3, mean predicted hearing thresholds were plotted in Figure 3 as a function of age for each group. Individual lines visually represent the impact of diabetes severity on the 250 Hz and clinical PTA thresholds (left and right panels, respectively). The lines extend across the age ranges examined; however, model accuracy is greatest for estimates from about 35 to 60 years where the bulk of the data lay. The diabetes severity effect is visible as the intercept differences between the lines in each panel. At any given age, thresholds are over 3 dB poorer among Veterans with uncontrolled diabetes

compared with individuals without diabetes. A smaller but similar disparity exists between thresholds of participants with uncontrolled and controlled diabetes. In contrast, individuals not diagnosed with diabetes, but with prediabetic HbA1c levels, did not have poorer hearing than participants without diabetes at the frequencies depicted in Figure 3.

Multiple regression analysis also allowed estimation of the effect of age on hearing using the slope of the fitted line to predict threshold change in HL per year of life. As indicated in Table 3, age was highly significant for each hearing threshold outcome ($p < 0.01$). Note that slopes are shallow at the frequencies significantly affected by diabetes (0.19 dB per year at 250 Hz; 0.15 dB per year within the clinical PTA). Also note that slopes do not differ by group (meaning that the regression analyses revealed no significant interactions between diabetes severity group and age). These results suggest that once diagnosed, diabetes does not appear to accelerate the pace of age-related hearing loss for the span of ages examined. Rather, individuals with diabetes tended to have poorer hearing at certain frequencies than those without diabetes at any given age examined.

Because the diabetes effect is a shift in the intercept and there is not an interaction between diabetes and age, comparing the age at which individuals with and without diabetes reach any fixed HL reveals an apparent difference (Fig. 3). A horizontal reference line is arbitrarily set at 14 dB HL to further illustrate this point. Using this reference, a 43-year-old patient with uncontrolled diabetes is expected to have hearing similar to a 59-year-old patient without diabetes at 250 Hz, a potential 16-year mean premature auditory aging among patients with uncontrolled disease. Similar results were obtained for the clinical PTA. Patients with uncontrolled diabetes led nondiabetic participants in terms of their clinical PTA decline by about 23 years (e.g., comparable clinical PTA thresholds are expected for a 36-year-old participant with uncontrolled diabetes and a 59-year-old participant without diabetes).

Speech Recognition Outcomes

Descriptive statistics for the speech measures as a function of diabetes severity are provided in Table 2. Low scores on the QuickSIN and high scores for the compressed speech task (done at two time compression rates) indicate better performance. Participants with prediabetes and uncontrolled diabetes tended to perform somewhat worse on all speech tests compared with nondiabetics based on the unadjusted mean scores. However, no significant differences in understanding speech in background noise ($p = 0.76$) or understanding rapid speech were found using multiple regression analysis ($p = 0.70$ at 50% compressed, $p = 0.96$ at 60% compressed). Overall, scores indicated that none of the subject groups were particularly challenged by the speech materials. Group mean QuickSIN scores were all within the range considered near-normal by the manufacturer of the test; mean TCS scores were all at least 85% correct.

Perceived Hearing Loss Impacts on Quality of Life

The QOL inventory was used to evaluate the functional impact of hearing ability on aspects of life centered on the constructs of competence, self-esteem, and adaptability. To improve the interpretability of results, they are shown in Table 4 as the prevalence of hearing-related

QOL impacts by diabetes severity group. As with the other complications, a lower prevalence is favorable. Participants with prediabetes had the lowest crude prevalence of self-reported hearing loss impacts on QOL; however, fewer control participants reported problems than participants with diagnosed diabetes across all subscales. There were no statistically significant differences in competence and self-esteem subscales by diabetes severity group; however, a significant difference was found for the adaptability subscale ($p = 0.019$). Only 14% of participants with prediabetes reported negative impacts of hearing on their adaptability compared with 30% of nondiabetics, 46% of participants with controlled diabetes, and 55% of participants with uncontrolled diabetes. These relationships were investigated further using ORs.

Not surprisingly, based on the data provided in Table 4, significant associations were found involving the prediabetes group. The odds of participants with uncontrolled diabetes reporting difficulty adapting were 7.8 times greater (OR = 7.8, 95% CI: 1.9 to 32.3) than the odds of participants with prediabetes reporting difficulty. Also, the odds of participants with controlled diabetes reporting difficulty adapting were 5.0 times greater (OR = 5.0, 95% CI: 1.2 to 21.2) than the odds of participants with prediabetes reporting difficulty. The significant association between diabetes status and QOL for the adaptability subscale found in the regression analysis (Table 4) was likely not entirely due to the prediabetes group; the odds of participants with uncontrolled diabetes reporting difficulty adapting were 2.8 greater (OR = 2.8; 95% CI: 1.1 to 7.4) than the odds of nondiabetics reporting difficulty adapting. This suggests that participants with uncontrolled diabetes were more likely to feel that their hearing caused them to be less able to adapt to various activities of daily life, including taking chances, trying new things, or taking advantages of opportunities. The adaptability subscale contrast between controlled and uncontrolled diabetes participants was not significant ($p = 0.414$).

Prevalence of Hearing Loss and Diabetes Complications

We also explored how prevalence of hearing impairment compared with other known complications of the disease with results presented in Table 5. For the purpose of determining hearing loss prevalence, thresholds or threshold averages >20 dB HL constituted impairment. Consistent with results presented in Figure 2 and Table 2, the prevalence of hearing impairment increased with increasing pure-tone frequency. Fewer participants in the sample had abnormal hearing within the clinical PTA (7.7 and 22.3%, respectively, in the better and worse ears) than within the HF-PTA (37.7 and 53.8%, respectively, in the better and worse ears). The prevalence of hearing impairment was consistently greater in the group with uncontrolled diabetes compared with controls, although the associated p values indicate a significant difference across groups only within the clinical PTA of the poorer ear ($p = 0.021$). For this outcome, post hoc analyses of planned contrasts revealed significantly higher prevalence among Veterans with uncontrolled diabetes compared with Veterans with no diabetes ($p = 0.012$) and with controlled diabetes ($p = 0.034$). The odds of hearing loss in the clinical PTA region of the poorer ear given uncontrolled diabetes is four times the odds of hearing loss given no diabetes (OR: 4.1, 95% CI: 1.4 to 12.2) and controlled diabetes (OR: 4.1, 95% CI: 1.1 to 15.1). Thus, this is a large effect. The observed trend is compatible across ears and

frequency combinations examined. This trend is also apparent when using different cutoff levels for hearing impairment. For example, over 9% of subjects with uncontrolled diabetes had a clinical PTA greater than 30 dB in the worse ear (and over 6% had greater than 40 dB) compared with none in the group without diabetes.

Table 5 also shows prevalence of diabetes complications obtained from EMR review (clinically significant macular edema, retinopathy), questionnaire data (peripheral neuropathy), and measurements conducted by trained study personnel (foot sensation loss). Participants with uncontrolled diabetes had a greater prevalence of every diabetes complication examined compared with participants with controlled diabetes, although this contrast was significant for diabetic retinopathy only ($p = 0.020$). Prevalence differences in foot sensation loss among those with uncontrolled diabetes approached the designated level of significance ($p = 0.057$). Among individuals with uncontrolled diabetes, foot sensation loss and non-proliferative retinopathy prevalence was close to 40%, which was similar to hearing loss in the clinical PTA of the poorer ear.

DISCUSSION

In a cohort of relatively young Veterans (mean age 47.7 years) without severe hearing loss, poorer hearing was associated with type 2 diabetes only for individuals with uncontrolled disease. The relatively minor threshold loss of 3 to 3.5 dB at 250 Hz and in a clinical PTA (0.5, 1.0, and 2.0 kHz) involved frequencies considered critical for speech understanding. The prevalence of hearing impairment (thresholds >20 dB HL) was four times greater among individuals with uncontrolled disease for the clinical PTA of the poorer ear compared with individuals without disease and with controlled disease. The main diabetes variable of interest was the most recent HbA1c level collected at or just preceding the study visit; however, results showed that compared with Veterans with controlled diabetes, those classified as having uncontrolled disease tended to have diabetes longer, be insulin-dependent, and have a greater prevalence of diabetic retinopathy. Furthermore, prediabetic levels of HbA1c were not associated with hearing decline. We believe these results illustrate that diabetes-related hearing loss is associated with diabetes severity and may be preventable with improved management.

The present cross-sectional results allow us to infer a rate of change of hearing thresholds (in dB HL per year) using the slope of the linear regression models displayed in Figure 3. Change was gradual at 250 Hz and within the clinical PTA, consistent with the literature for healthy Veterans younger than 70 years of age (Echt et al. 2010). The data were well described by a line, and the slope did not vary with diabetes status. This suggests that once diagnosed, diabetes does not accelerate the pace of age-related hearing loss for the span of ages examined. However, at a given age, individuals with diabetes tended to have poorer hearing at certain frequencies than those without. Based on the model results, individuals with diabetes reached a given threshold 1.5 to 2 decades earlier compared with controls at the affected frequencies. If ways could be found to prevent individuals with prediabetes from becoming diabetic or at least to stave off poorly controlled diabetes, better hearing might be maintained into later adulthood. These results need to be confirmed using longitudinal measurements, which are ongoing in this cohort.

In the present study, Veterans with uncontrolled diabetes had 2.8 times the odds as nondiabetics of reporting that their hearing was associated with difficulty adapting to various activities of daily life (OR = 2.8; 95% CI: 1.1 to 7.4). This suggests they perceived that their hearing posed a challenge. Consistent with this finding, the uncontrolled diabetes group demonstrated poorer performance relative to controls for time-compressed (rapid) speech and speech in noise (QuickSIN), although performance did not differ significantly. Moreover, no subjects scored in a range designated in the QuickSIN manual as “impaired.” Our participants were selected to have no more than a moderate hearing loss. The prevalence of hearing impairment was low overall within the frequencies below 3000 Hz, and, although prevalence differences were substantial within the clinical PTA in the worse ear, prevalence did not differ statistically for the better ear. It is probable that a more representative clinical population with type 2 diabetes and/or more challenging speech materials would have shown greater differences (Frisina et al. 2006). Frisina and colleagues (2006) demonstrated that older individuals with diabetes perform more poorly on the hearing in noise test of speech perception compared with control participants, age-matched at the group level.

Comparison With Previous Reports

We found diabetes effects on hearing limited to frequencies through 2000 Hz, whereas some prior reports showed greater differences at higher compared with lower frequencies (e.g., Bainbridge et al. 2008; Agrawal et al. 2009; Uchida et al. 2010). Thresholds at higher frequencies tend to be more variable than lower frequencies even in healthy populations due to effects of aging and noise exposure (see Echt et al. 2010 and results for controls shown in Table 3 of the present study). Thus, a larger sample, fewer diabetes status categories, or a younger cohort may be required, in addition to a population with less noise exposure to reveal potential diabetes-related differences at high frequencies.

Pure-tone thresholds that were significantly affected in the present report showed similar effect sizes (within 2 to 3 dB) to those reported in a recent meta-analysis (Akinpelu et al. 2013), even after we adjusted for age. The odds of hearing loss in the clinical PTA region of the poorer ear given uncontrolled diabetes was four times the odds of hearing loss given no diabetes (OR: 4.1, 95% CI: 1.4 to 12.2) and controlled diabetes (OR: 4.1, 95% CI: 1.1 to 15.1) in our study. This compares well to pooled ORs reported for worse ear data in two recent meta-analysis examining the association between diabetes and hearing impairment, which showed that collapsed across a range of frequencies, hearing impairment among participants with diabetes was double that of controls (Horikawa et al. 2013; Akinpelu et al. 2013).

A major focus of this study was to determine whether evidence supported an association between diabetes severity and hearing loss. We found that the disparity in pure-tone threshold loss and in the prevalence of hearing impairment was concentrated among participants with poorly controlled disease based on current HbA1c. Our previous work entailed using insulin dependence as a measure of ease of diabetes control. In the present study, these two measures of diabetes control capture many of the same participants (see Table 1). Figure 4 was constructed to compare effects on pure-tone thresholds of diabetes severity based on either insulin dependence or HbA1c. Results are shown in the left column

for all participants (excluding those with prediabetes) and in the right panel for participants younger than 50 years for comparison with our earlier report (Austin et al. 2009; Fig. 1 (top) and Table 3). The top row of Figure 4 shows the contrast between participants without diabetes and those with either NIDDM or IDDM. Many participants over age 50 (37/58 or 63.8%) were in both the present and the previous studies, whereas only three participants under age 50 were in both studies (two controls and one NIDDM). For those under age 50, participants with NIDDM had poorer thresholds than those with IDDM at a number of higher frequencies, at least based on the unadjusted means; thus, the same overall pattern of results was found in a largely new sample of younger Veterans. The severity contrasts based on HbA1c that were examined in the present report are replotted in the bottom left panel of Figure 4 (excluding the participants with prediabetes). Above about 8000 Hz, participants with controlled diabetes had poorer unadjusted mean thresholds than uncontrolled diabetes at high frequencies. In the regression analyses performed for all the subjects, these high-frequency differences were not significant after adjusting for age (see Table 3). The comparison illustrates that diabetes severity based on either HbA1c or insulin use provides an indication of hearing loss severity through most of the conventional frequency range, although neither measure is perfect.

Biological Plausibility

Low-frequency hearing loss is relatively uncommon in adults and when present and otologic disease is ruled out, can indicate cochlear blood supply (strial) changes (Schuknecht et al. 1974). The present finding of diabetes affecting hearing in these frequencies is therefore important and may provide insight into at least one diabetic disease process in the auditory system. Degeneration of the cochlear lateral wall and particularly of the stria vascularis is considered a major cause of presbycusis sometimes referred to as “metabolic presbycusis” (Schuknecht & Gacek 1993) and could be occurring prematurely among individuals with diabetes.

The cellular targets of diabetes-related cochlear damage are debated; however, studies on genetically or drug-induced diabetic animal models and postmortem diabetic human temporal bones have some consistent results involving microangiopathy affecting the inner ear. Specific findings include thickening of capillaries in the basilar membrane and stria vascularis (Wackym & Linthicum 1986; Fukushima et al. 2006; also see recent review by Akinpelu et al. 2014). Loss of outer hair cells and atrophy of the stria vascularis are less consistent findings from diabetes and in human temporal bones appear to depend on severity and duration of disease, suggesting they may be late effects (Wackym & Linthicum 1986).

Limitations

Limitations of our study include that our primary measure of diabetes severity/control was current HbA1c. While this measure reflects an average of glucose levels over the past 120 days, it does not provide an indication of how glucose varied over a period of years. Therefore, the fact that it showed a significant association with various hearing outcomes in this report, tells us that it is sufficiently accurate to be used. Furthermore, the imprecision with which it reflects long-term HbA1c values would be random and would bias tests of association toward the null. Thus, the association between the hearing outcomes and the

HbA1c is likely stronger than we are able to measure. A longitudinal approach using measures of hearing and HbA1c over time is needed to more precisely contrast the decline in hearing associated with diabetes severity, to link hearing loss onset with precipitating diabetes factors, and to determine whether effective treatment of diabetes may delay the onset and progression of hearing loss.

The present report concerns a Veteran cohort. The Veteran population is limited to those who have served in the military, so includes fewer women. Also, Veterans are sometimes exposed to high-intensity noise during their training and while performing their military duties. In our baseline questionnaire, we gathered information on military and nonmilitary noise exposure from each participant to account in the model for potential group differences, but we did not find that the groups differed in report of overall noise exposure. We cannot rule out the possibility that military noise exposure may have had a much larger effect than diabetes on high-frequency thresholds, thus obscuring an association. Other large epidemiological studies have shown greater effects at the higher frequencies, which are also more apt to be confounded by the effects of aging (Bainbridge et al. 2008). Thus, our study may have had insufficient power to detect diabetes effects at high frequencies.

Clinical Implications

Some clinical context should be provided for these results. First, the mean pure threshold differences found here will underestimate the clinical effect in some patients with diabetes because our subjects were selected, in part, based on a lack of significant hearing impairment at baseline. This was done to ensure that onset and progression of hearing impairment could be observed and so that electrophysiological measures (not shown) could be obtained in the majority of participants. However, whereas a more representative clinical population with type 2 diabetes and using more challenging speech materials would likely evidence somewhat greater differences, as was found by Frisina et al. (2006), large threshold differences from diabetes are unlikely to be the norm (Akinpelu et al. 2013; Horikawa et al. 2013).

Second, hearing loss is associated with uncontrolled diabetes means that patients with uncontrolled diabetes are at greater risk of hearing impairment than those with controlled diabetes. As a corollary, patients with diabetes are also at greater risk of hearing impairment than those without diabetes. These hearing loss *risk* differences are likely substantial, as found in this study and in many others (see Discussion of Prevalence earlier). This means that even though absolute threshold differences attributable to diabetes may not be large, they do appear to push more individuals outside the clinically normal range. Our participant selection criteria limited the number of participants with severe hearing impairment; however, the clinical impact of even mild diabetes-related hearing loss can be substantial when combined with other conditions that damage the cochlea (Akinpelu et al. 2013).

In addition, diabetic changes to the auditory system extend beyond threshold elevations. Changes in central auditory processing among individuals with diabetes have been documented using auditory brain stem response (Diaz de Leon-Morales et al. 2005; Konrad-Martin et al. 2010; Gupta et al. 2013), and deficits in higher-level central and cognitive impairment have been found using neurocognitive and electrophysiological methods

(Kloppenborg et al. 2008; Knopman et al. 2009; Gould et al. 2013). Because of the insidious nature of even mild hearing threshold loss when combined with central auditory or cognitive decline, and because diabetic retinopathy affects over 21% of patients with type 2 diabetes at the time of diagnosis (Fong et al. 2004) and 40% of patients with diabetes mellitus over age 40 years (Kempen et al. 2004), the Veteran with diabetes faces double-sensory loss, creating a particularly bad combination for communication, social interaction, and realization of their maximum potential for living with their disease. Hearing status and speech understanding ability may therefore be important health outcomes to consider for patients with diabetes.

Finally, if auditory system changes can be demonstrated to develop over time preferentially among participants with uncontrolled diabetes, then a means of prevention exists. Due to the sheer numbers of people affected by diabetes, if ways are found to even modestly reduce the risk factors for diabetes-related auditory system damage, the impact on public health could be major. Yet, auditory dysfunction is neither a commonly known or well-understood diabetes-related health outcome.

CONCLUSION

In a cohort of Veterans with type 2 diabetes and relatively good hearing, significant effects of disease severity were found for hearing thresholds up to and including 2000 Hz, and for one of the three QOL subscales, but not for the speech recognition measures used. The significant deficits were found only among those whose diabetes is poorly controlled. Results provide evidence that the observed hearing dysfunction in type 2 diabetes might be prevented or delayed through tight metabolic control. Findings need to be corroborated using longitudinal assessments.

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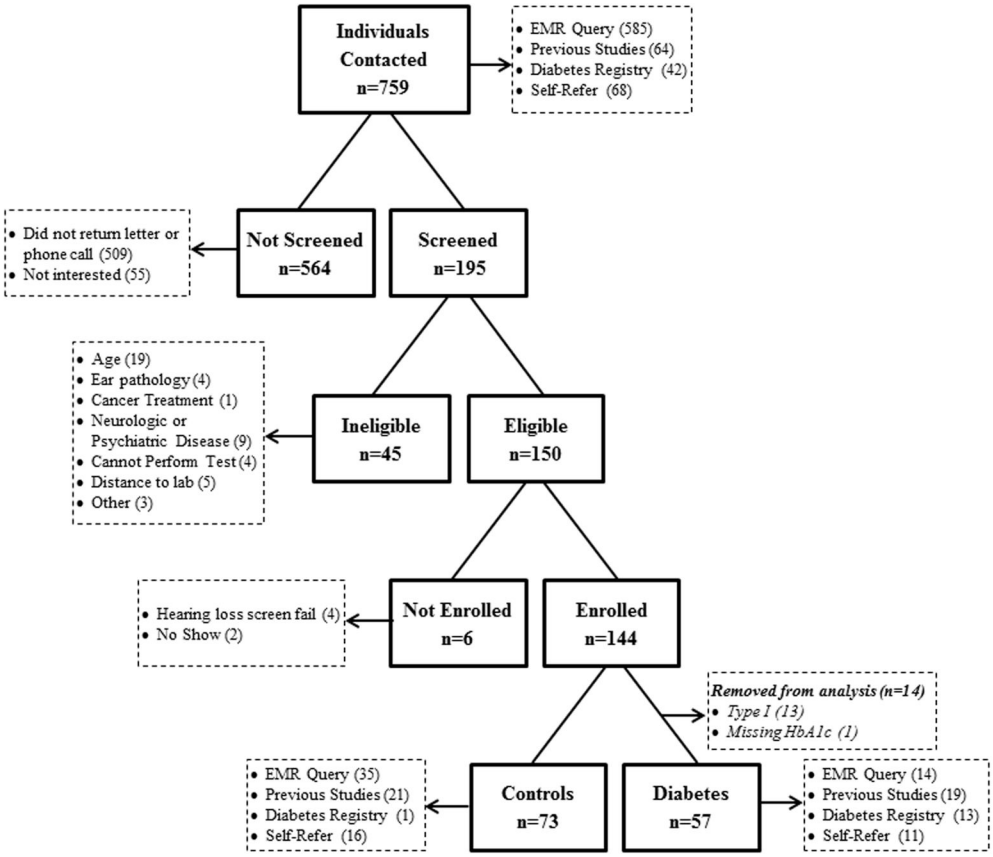

Fig. 1.

Flowchart of participant recruitment showing the number of individuals contacted from each source, those screened and enrolled, and those determined ineligible for participation and not enrolled. From the electronic medical record (EMR) query, 259 Veterans with diabetes and 3799 without diabetes were identified of which 585 recruitment letters were directed to potential participants (111 to those with diabetes and 474 to those without), which led to 31 diabetes and 17 nondiabetes participants being enrolled. In addition, from approximately 1200 participants who participated in either or both the prior VA studies of diabetes and hearing meeting present study inclusion criteria, 64 individuals (26 with diabetes and 38 without) were invited to again participate, which led to 17 participants with diabetes and 24 without. The diabetes registry yielded an additional 17 participants with diabetes and 1 with prediabetes and another 20 participants with diabetes and 18 participants without diabetes self-referred based on word of mouth or seeing a study recruitment flyer. Of the 145 participants enrolled, 13 having late-onset type 1 diabetes were removed from the analysis to focus solely on the disease process resulting from type 2 diabetes, the most common type among the Veteran population. One participant with incomplete data (missing HbA1c value) was also removed. This left 130 participants with (n = 57) and without (n = 73) diabetes for analysis.

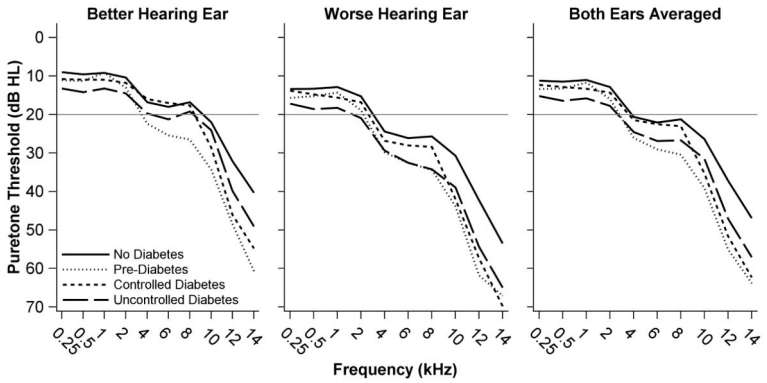

Fig. 2.

Average audiograms for better (left panel) and worse (middle panel) hearing ears and for both ears of each participant averaged (right panel). The parameter in each panel is diabetes severity based on current HbA1c. An audiogram depicts threshold of hearing in decibels of hearing level (dB HL) as a function of frequency (Hz) from low (250 Hz) to high (8000 Hz) for each ear. The 20 dB line demarcates normal hearing. Results on or above this value are considered normal.

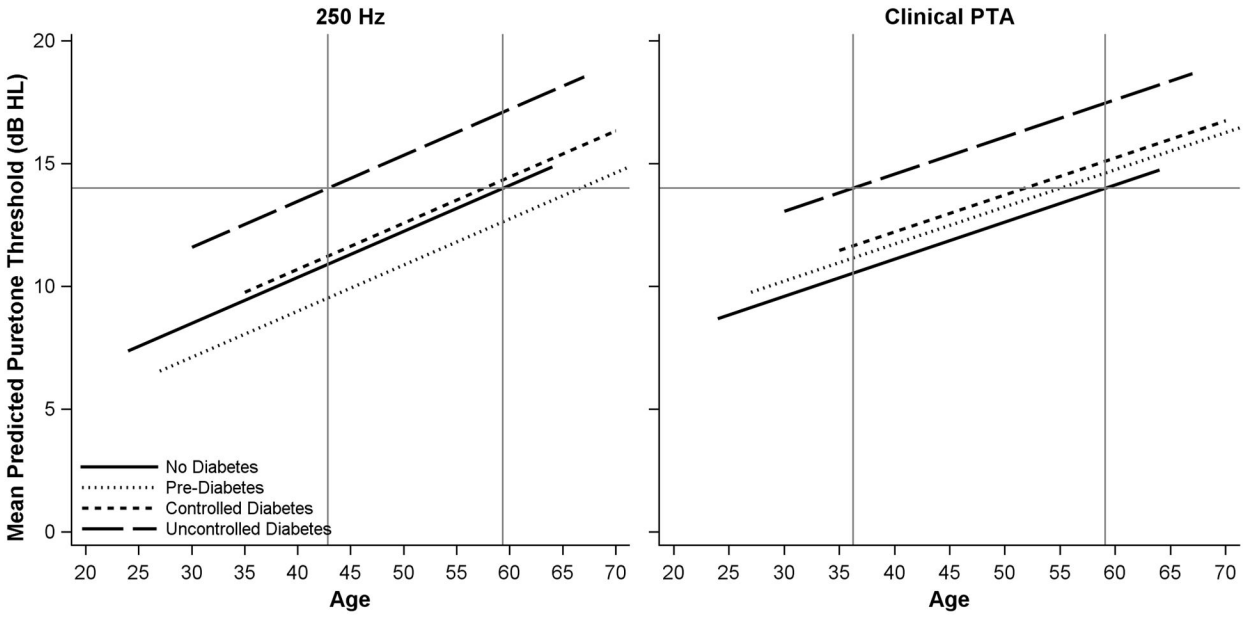

Fig. 3.

Mean predicted hearing thresholds for the speech-frequency region in decibels of hearing level (dB HL) as a function of age from 20 to 70 yr and the four diabetes severity groups. An arbitrary reference line at 14 dB HL is drawn to assist age comparison differences in hearing at this hearing level. Left panel 250 Hz predicted thresholds: All groups had similar slopes (dB HL change per year), but the uncontrolled and controlled groups have higher intercepts. Uncontrolled diabetes reached dB HL values at 250 Hz 23 yr earlier than nondiabetics and 15 yr earlier than participants with controlled diabetes. Right panel clinical pure-tone average (PTA) predicted thresholds: uncontrolled diabetes resulted in threshold values reached 16 yr earlier than the control group and 12 yr earlier than participants with controlled diabetes.

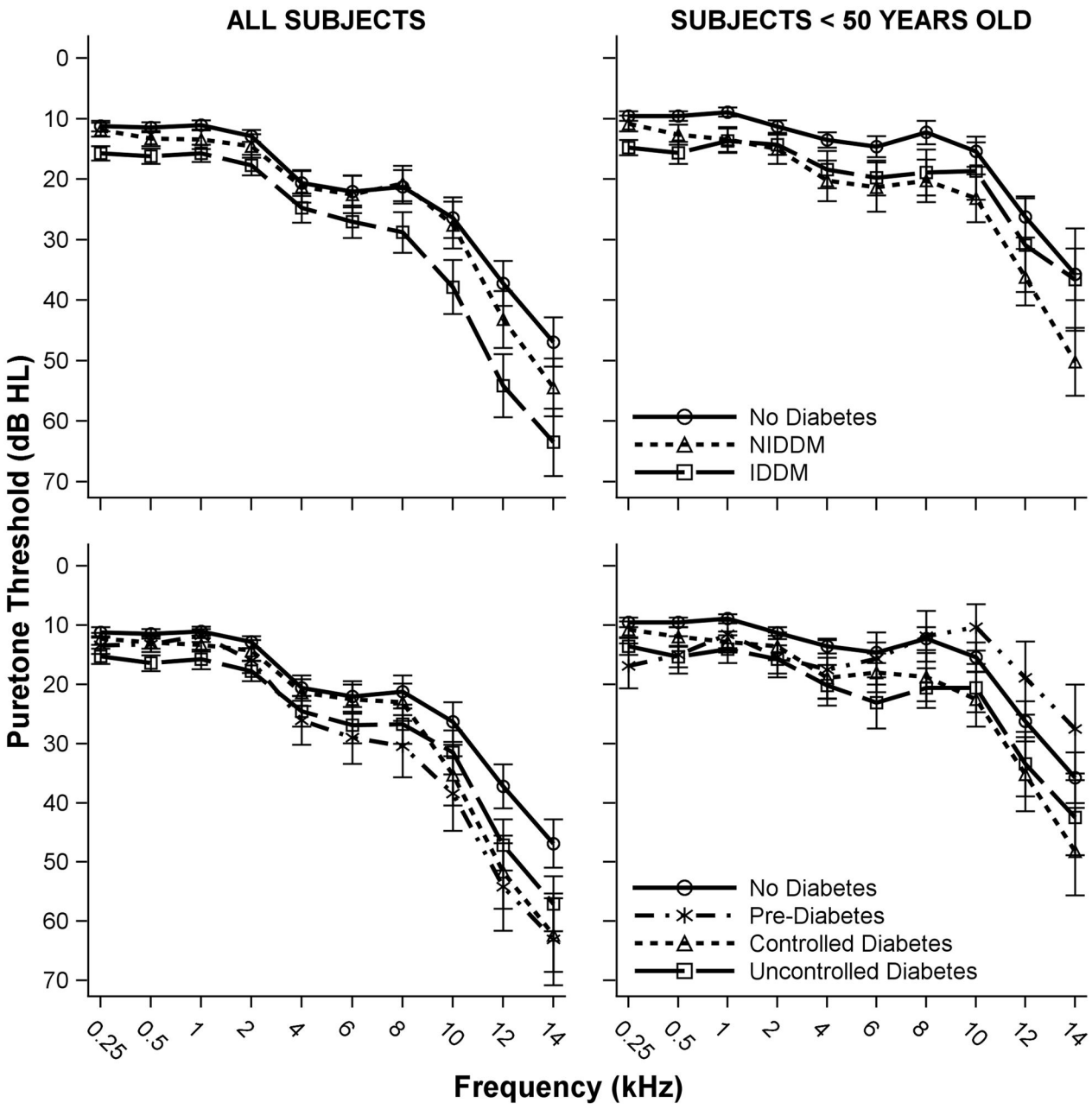

Fig. 4.

Average audiograms for both ears by diabetes severity for all participants (left) and restricted to participants under age 50 yr (right). Top row: Nondiabetic participants vs. participants with non-insulin-dependent diabetes mellitus (NIDDM) or insulin-dependent diabetes mellitus (IDDM). Bottom row: Nondiabetic participants vs. participants with controlled and uncontrolled diabetes. Bars indicate standard errors.

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TABLE 1

Subject characteristics classified by diabetes severity

	Diabetes Severity Group				
Characteristic	**No Diabetes (n = 50)**	**Prediabetes (n = 23)**	**Controlled Diabetes (n = 25)**	**Uncontrolled Diabetes (n = 32)**	***p***
Age, mean (SD), yr	44.4 (11.6)	52.7 (11.4)	48.5 (8.3)	49.4 (9.5)	*0.015*
Sex, N (%)					
Male	47 (94.0)	20 (87.0)	22 (88.0)	31 (96.9)	0.482
Female	3 (6.0)	3 (13.0)	3 (12.0)	1 (3.1)	
Race/ethnicity, N (%)					
Asian	0 (0)	0 (0)	2 (8.0)	2 (6.3)	0.166
Black or African American	2 (4.0)	5 (21.7)	5 (20.0)	2 (6.3)	
White	42 (84.0)	16(69.8)	15 (60.0)	25 (78.1)	
Hispanic or Latino	3 (6.0)	0 (0)	1 (4.0)	1 (3.1)	
Native American	2 (4.0)	1 (4.4)	2 (8.0)	1 (3.1)	
Pacific Islander	0 (0)	0 (0)	0 (0)	1 (3.1)	
Education, N (%)					
Some high school	1 (2.0)	2 (8.7)	1 (4.0)	0 (0.0)	0.689
High school	4 (8.0)	3 (13.0)	4 (16.0)	2 (6.3)	
Vocational training	3 (6.0)	0 (0.0)	1 (4.0)	1 (3.1)	
Some college	20 (40.0)	8 (34.8)	11 (44.0)	19 (59.4)	
Completed college	22 (44.0)	10 (43.5)	8 (32.0)	10 (31.3)	
Smoking status,* N (%)					
Never	21 (45.7)	7 (30.4)	3 (12.5)	12 (41.4)	0.061
Ever	25 (54.3)	16 (69.6)	21 (87.5)	17 (58.6)	
Current smoker,* N (%)					
No	34 (75.6)	17 (73.9)	15 (62.5)	22 (75.9)	0.664
Yes	11 (24.4)	6 (26.1)	9 (37.5)	7 (24.1)	
Noise exposure, mean (SD)					
Military	2.5 (1.1)	2.4 (1.2)	2.9 (0.9)	2.4 (1.1)	0.363
Nonmilitary occupational	1.3 (0.9)	1.8 (1.1)	2.0 (1.0)	1.6 (0.9)	*0.028*
Recreational	1.5 (0.8)	1.3 (0.8)	1.6 (0.8)	1.3 (0.9)	0.245

	Diabetes Severity Group				
Characteristic	**No Diabetes (n = 50)**	**Prediabetes (n = 23)**	**Controlled Diabetes (n = 25)**	**Uncontrolled Diabetes (n = 32)**	***p***
Sudden	1.5 (0.8)	1.3 (0.7)	1.5 (0.7)	1.5 (0.6)	0.423
Overall noise exposure	5.4 (1.8)	5.5 (2.0)	6.5 (2.1)	5.3 (1.9)	0.062
HbA1c, %, Mean (SD)	5.4 (0.2)	5.9 (0.2)	6.3 (0.4)	8.9 (1.6)	*<0.001*
Insulin status, N (%)					
Non-insulin-dependent diabetes mellitus	—	—	19 (76.0)	7 (21.9)	*<0.001*
Insulin-dependent diabetes mellitus	—	—	6 (24.0)	25 (78.1)	
Diabetes duration, mean (SD), yr	—	—	6.4 (7.0)	9.8 (6.5)	0.059

Values given as N (%) or mean (SD).

*Smoking status and current smoker missing data for eight subjects: four no diabetes; one controlled diabetes; three uncontrolled diabetes. In addition, one no diabetes patient did not answer the current smoker question. Statistically significant diabetes severity group contrasts are indicated by italics in this table and also in Tables 3, 4, and 5.

TABLE 2

Unadjusted hearing thresholds (in dB hearing level) and speech understanding by diabetes severity

	Diabetes Severity Group			
	No Diabetes (n = 50)	**Prediabetes (n = 23)***	**Controlled Diabetes (n = 25)**	**Uncontrolled Diabetes (n = 32)**
Hearing outcomes: better hearing ear				
250 Hz threshold	9.0 (5.0)	11.1 (7.1)	10.8 (4.9)	13.3 (7.1)
Clinical PTA	10.1 (5.0)	11.6 (6.3)	11.6 (5.3)	14.3 (8.0)
High-frequency PTA	16.7 (13.9)	24.0 (18.3)	16.7 (9.6)	20.3 (13.8)
Extended high-frequency PTA	32.2 (24.4)	48.0 (31.4)	44.3 (29.2)	38.8 (21.4)
Hearing outcomes: worse hearing ear				
250 Hz threshold	13.4 (9.0)	15.7 (8.6)	13.8 (5.6)	17.2 (7.9)
Clinical PTA	13.5 (5.7)	15.7 (7.2)	15.4 (6.4)	19.0 (9.9)
High-frequency PTA	23.4 (16.9)	29.7 (19.9)	26.2 (14.0)	29.4 (16.7)
Extended high-frequency PTA	41.4 (26.3)	55.8 (33.8)	55.2 (28.4)	51.7 (25.0)
Hearing outcomes: both ears				
250 Hz threshold	11.2 (6.2)	13.4 (7.3)	12.3 (5.1)	15.2 (7.2)
Clinical PTA	11.8 (5.0)	13.7 (6.4)	13.5 (5.7)	16.6 (8.6)
High-frequency PTA	20.0 (14.9)	26.9 (19.0)	21.5 (10.9)	24.9 (14.6)
Extended high-frequency PTA	36.8 (25.0)	51.9 (32.4)	49.8 (28.0)	45.2 (22.4)
Speech outcomes				
QuickSIN Average (signal to noise ratio loss)	0.8 (1.6)	1.2 (1.7)	0.6 (1.2)	1.2 (1.8)
50% TCS (% correct)	94.2 (5.5)	89.1 (15.5)	93.1 (6.5)	91.0 (10.1)
60% TCS (% correct)	90.6 (8.9)	85.6 (12.7)	89.9 (7.4)	86.8 (14.1)

Data are presented as mean (SD).

* Missing data in one subject for extended high-frequency PTA and for all speech measures due to equipment failure.

PTA, pure-tone average.

TABLE 3

Separate models regressing each hearing outcome on diabetes severity group, adjusted for age

Hearing Outcomes Average of Both Ears	Model Effects	Estimates	Standard Error	*p*
250 Hz threshold*	Intercept	2.86	2.34	0.225
	Age (yr)	0.19	0.05	<0.001
	No diabetes	0.00		
	Prediabetes (dB HL)	—1.38	1.58	0.384
	Controlled diabetes (dB HL)	0.33	1.43	0.818
	Uncontrolled diabetes (dB HL)	*3.10*	*1.33*	*0.022*
Clinical PTA†	Intercept	5.07	2.38	0.035
	Age (yr)	0.15	0.05	0.003
	No diabetes	0.00		
	Prediabetes (dB HL)	0.62	1.55	0.691
	Controlled diabetes (dB HL)	1.10	1.47	0.456
	Uncontrolled diabetes (dB HL)	*3.46*	*1.37*	*0.013*
High-frequency PTA	Intercept	—16.48	4.86	0.001
	Age (yr)	0.82	0.10	<0.001
	No diabetes	0.00		
	Prediabetes (dB HL)	0.03	3.19	0.993
	Controlled diabetes (dB HL)	—1.93	3.02	0.524
	Uncontrolled diabetes (dB HL)	0.75	2.81	0.789
Extended high-frequency PTA	Intercept	—43.37	7.27	<0.001
	Age (yr)	1.81	0.15	<0.001
	No diabetes	0.00		
	Prediabetes (dB HL)	—0.90	4.85	0.852
	Controlled diabetes (dB HL)	5.55	4.50	0.220
	Uncontrolled diabetes (dB HL)	—0.61	4.19	0.885

Results are for both ears of each subject averaged together. Estimates shown are age-adjusted effect sizes from the average hearing of both ears in decibels of hearing level (dB HL) for the contrast between the no diabetes group and each of the other groups. Also included is standard error of the estimates and significance (p value).

*Two subjects (nos. 12 and 138) were overly influential and removed from the model.

†One subject (no. 23) was overly influential and removed from the model.

HL, hearing level; PTA, pure-tone average.

TABLE 4

Prevalence of hearing loss impacts on quality of life by diabetes severity group

	Diabetes Status					
	No Diabetes (n = 46)	**Prediabetes (n = 22)**	**Controlled Diabetes (n = 24)**	**Uncontrolled Diabetes (n = 29)**	**All**	***p***
Competence subscale	25/46 (54.4)	8/22 (36.4)	16/24 (66.7)	18/29 (62.1)	67/121 (55.4)	0.208
Adaptability subscale	14/46 (30.4)	3/22 (13.6)	11/24 (45.8)	16/29 (55.2)	44/121 (36.4)	*0.019*
Esteem subscale	26/46 (56.5)	9/22 (40.9)	15/24 (62.5)	19/29 (65.5)	69/121 (57.0)	0.325

Values given as N (%). Age-adjusted p values reported for the overall test of association resulting from logistic regression analyses.

TABLE 5

Prevalence of hearing loss in better and poorer hearing ears, and diabetes complications by diabetes severity group

	Diabetes Status					
	No Diabetes (n = 50)	**Prediabetes (n = 23)**	**Controlled Diabetes (n = 25)**	**Uncontrolled Diabetes (n = 32)**	**All**	***p***
Prevalence of hearing loss in better ear						
250 Hz	1/50 (2.0)	1/23 (4.3)	0/25 (0.0)	4/32 (12.5)	6/130 (4.6)	0.367
Clinical PTA	2/50 (4.0)	1/23 (4.3)	1/25 (4.0)	6/32 (18.8)	10/130 (7.7)	0.110
High-frequency PTA	15/50 (30.0)	12/23 (52.2)	9/25 (36.0)	13/32 (40.6)	49/130 (37.7)	0.953
Extended high-frequency PTA*	32/50 (64.0)	16/22 (72.7)	19/25 (76.0)	25/32 (78.1)	92/129 (71.3)	0.298
Prevalence of hearing loss in poorer ear						
250 Hz	4/50 (8.0)	2/23 (8.7)	2/25 (8.0)	7/32 (15.6)	15/130 (11.5)	0.279
Clinical PTA	7/50 (14.0)	4/23 (17.4)	4/25 (16.0)	14/32 (43.8)	29/130 (22.3)	*0.021*
High-frequency PTA	21/50 (42.0)	13/23 (56.5)	17/25 (68.0)	19/32 (59.4)	70/130 (53.8)	0.336
Extended high-frequency PTA*	38/50 (76.0)	17/22 (77.3)	21/25 (84.0)	29/32 (90.6)	105/129 (81.4)	0.226
Prevalence of diabetes complications						
Peripheral (foot) neuropathy index	4/50 (8.0)	5/23 (21.7)	3/25 (12.0)	9/32 (28.1)	21/130 (16.2)	0.160
Foot sensation loss	—	—	4/25 (16.0)	13/32 (40.6)	17/57 (29.8)	0.057
Nonproliferative diabetic retinopathy**	—	—	1/23 (4.4)	11/29 (37.9)	12/52 (23.1)	*0.020*
Clinically significant macular edema**	—	—	0/23 (0.0)	3/29 (10.3)	3/52 (5.8)	0.955

Values given as N (%). Age-adjusted p values reported for the overall test of association resulting from logistic regression analysis.

Missing data:

* Missing extended high-frequency PTA and all speech understanding measures in one subject (prediabetes) due to equipment failure.

** Unable to extract vision data from five patients' electronic medical records (two subjects with controlled diabetes and three subjects with uncontrolled diabetes).

PTA, pure-tone average.