The Laryngoscope

ORIGINAL REPORT

Associations Between Hearing Loss and Dementia in a Large Electronic Health Record System

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Received: 24 July 2024 | **Revised:** 7 March 2025 | **Accepted:** 21 March 2025

Funding: This work was supported by NIH grant K23AG057832 (J.S.G.), Triological Society/American College of Surgeons Clinician—Scientist Career Development Award (J.S.G.), and the Columbia University Vagelos College of Physicians and Surgeon's Dean's Research Fellowship (L.H.T., M.R.G., M.W.D.).

Keywords: cognition | dementia | electronic health record III | hearing loss

ABSTRACT

Objectives: Epidemiologic analyses of hearing loss utilize national volunteer-based datasets that are restricted by limited variables and few individuals with severe disease. We overcome these limitations using two large electronic health records to study whether audiometric hearing loss is associated with dementia.

Methods: This was a cross-sectional, multicentered retrospective study using the electronic health records at the academic medical centers of Columbia University and Cornell University ($n = 31{,}997$ total) for participants ≥ 18 years old with clinical audiometry from February 1, 2020 through May 5, 2023. Hearing measures were from the better ear and included pure tone average, word recognition score, and speech reception threshold. Dementia was defined as ICD-10 diagnosis code only, dementia medications only, the presence of both conditions, and the presence of either condition. Odds ratios were computed from univariable and multivariable logistic regressions between hearing loss and dementia with 95% confidence intervals, using the covariates of age, sex, cardiovascular risk score, and site.

Results: The mean age (SD) in the combined dataset was 60.5 (18.3) years and 18,992 (59.4%) were women. All univariable regressions showed increased odds of dementia with worsening hearing, regardless of how hearing or dementia was defined. Controlling for covariates, for every 10-dB worsening in hearing by pure tone audiometry, the odds of dementia (as defined by ICD-code or medication list) increased by 1.11 times (95% CI = 1.07–1.16); for every 10% worsening in word recognition score, the odds of dementia increased by 1.06 times (95% CI = 1.01–1.11); for every 10-dB worsening of the speech reception threshold, the odds of dementia increased by 1.10 times (95% CI = 1.05–1.15).

Conclusions: Using a large electronic health record system, audiometric hearing loss defined in three separate ways was associated with increased odds of dementia. Electronic health records can corroborate and expand previously studied relationships between hearing loss and its comorbidities, including dementia.

Level of Evidence: 3.

1 | Introduction

Hearing loss (HL) is one of the most prevalent yet undertreated medical conditions affecting adults today. About one in three people in the United States over the age of 65 has HL [1–3], compared to other chronic health conditions such as diabetes (21%) [4] and major heart disease (18%) [5]. Hearing aids, a widely available, non-invasive intervention [6–8], are the primary management for the most common forms of HL, including age-related [6]. But due to multifactorial barriers including expense [9, 10], disparities in access, sociodemographic influence, and perceived stigma, the majority of those eligible for hearing aids do not acquire them. For example, among adults aged 70 years and older with age-related HL, less than 30% have ever tried using a device. Even for those who may acquire hearing aids or cochlear implants, similar factors can lead to decreased or eventual nonuse of the devices [11, 12]. Whether hearing aid usage has improved since the October 2022 availability of over-the-counter hearing aids in the United States remains to be seen. The prevalence of hearing testing in adults remains similarly poor [13, 14].

The lack of widespread testing and treatment of HL, especially age-related HL, is particularly concerning considering the growing body of research showing associations with other morbid conditions of aging. Several independent research groups [15–24] have found associations between HL and cognitive impairment, dementia, depression, and falls [25–29], and HL is the top modifiable risk factor for dementia [30]. While a small number of randomized controlled trials on the effectiveness of hearing aids are underway [31], and one recently completed [32], the best evidence base primarily consists of national epidemiologic studies of healthy volunteers that include pure tone audiometry.

Few studies have examined the relationship between HL and cognition/dementia using electronic health record (EHR) systems, primarily because until relatively recently, audiometric data have not been stored in a digitally accessible way. Historically, "digital" audiograms would be scanned as pictures, precluding automated data analysis. But studies relying on institutional EHR data possess multiple advantages over national epidemiologic studies, such as hearing data derived from gold standard audiometry performed by doctoral-level audiologists. These evaluations include high quality, objective measures beyond pure tone thresholds, such as word recognition. They also better sample older individuals with more severe HL, the population typically most of interest to practicing otolaryngologists and audiologists.

In this study, we perform one of the largest analyses to date examining the association between audiometric HL and dementia by combining the EHR systems of two large academic health centers. To our knowledge, this is the single largest study of HL and dementia using EHR systems. We uniquely use three separate high-quality objective measures of hearing: pure tone audiometry, word recognition score, and speech reception threshold. We hypothesize that HL is associated with dementia, controlling for confounders. This study illustrates that the modern EHR can serve as a platform for high-quality epidemiologic inquiry and adds to the growing literature base describing HL as a major medical and public health problem.

2 | Methods

2.1 | Participants

This study was a cross-sectional epidemiologic analysis of retrospectively collected data. Data were collected from the large EHR systems of two academic institutions, Columbia University Irving Medical Center and Weill Cornell Medicine following the implementation of new instances of Hyperspace (Epic Systems, Verona, Wisconsin). Each institution serves different geographic, socioeconomic, and cultural areas of New York City. Audiogram data were numerically stored. Scans of paper-based audiograms acquired from outside facilities were not included in the analyses. Project design and analysis were performed retrospectively, after data collection.

Participants aged ≥18 years who underwent audiometry from February 1, 2020 through May 5, 2023 were included in the initial sample. Originally, Columbia included 32,748 records and Cornell included 25,022 records. The combined dataset contained 57,770 records. For subjects with multiple audiograms, only the earliest was included (13,356 excluded). Those with incomplete audiometric data and age <18 years old were excluded (12,405 excluded). Those with illogical audiometric data, such as a word recognition score >100 or <0, were considered inappropriate outliers and excluded (10 excluded). Finally, those with missing covariates were excluded (two excluded). This left 31,997 participants total for the analytic cohort, including 16,129 from Columbia and 15,868 from Cornell. The process of participant inclusion and exclusion is shown in Figure 1.

Each center obtained its own Institutional Review Board and data request approval. This study adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist criteria [33].

2.2 | Hearing (Primary Exposure)

Hearing was assessed by an audiologist in a soundproof booth. HL was the exposure of interest for this study and measured in three ways: pure tone average (PTA), word recognition score, and speech reception threshold.

Unaided (no hearing aids or assistive devices) and sided (right vs. left) air conduction pure tone thresholds were recorded from 500 to 8000 Hz and measured in decibels (dB). Higher decibel thresholds indicated worse hearing. The PTA was calculated from 4 frequencies: 500, 1000, 2000, and 4000 Hz. Use of the four-frequency PTA is supported in prior epidemiologic studies of HL [15, 18] and public health campaigns [34]. The PTA in the better ear, which defines bilateral HL, was used for analysis. HL was defined binarily as PTA >25 dB or in categories as follows: mild (26–40 dB), moderate (41–55 dB), moderately severe (56–70 dB), severe (71–90 dB), and profound (>90 dB) [35]. When assessing odds of dementia for a specific HL category, the midpoint value was used (e.g., 32.5 dB for mild HL).

Word recognition score (speech discrimination score) was scored from 0% to 100% [36]. Lower numbers represented worse hearing. A score of 100% meant accurately repeating

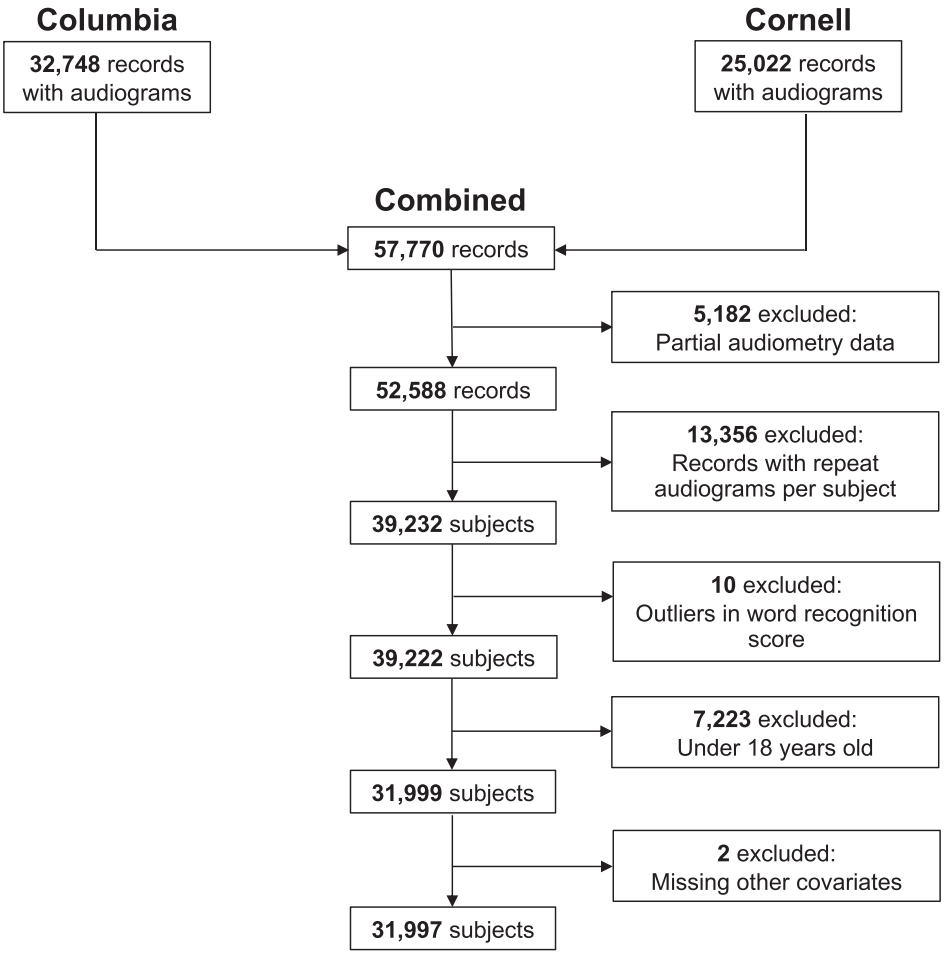

FIGURE 1 | Flowchart of participant inclusion for analysis.

100% of presented words. A normal score is generally considered to be ≥80%. Monosyllabic words were presented to the listener at 25–40 dB above their recorded speech reception threshold (described below) and the listener repeated the words. Word recognition scores were evaluated in the listener's native language or not recorded if one's native language was unavailable. Each participant had one to four word recognition scores recorded (right ear 1, right ear 2, left ear 1, left ear 2). The best of all possible word recognition scores was used for analyses.

Finally, speech reception thresholds were the level in dB at which subjects could perceive words 50% of the time. Higher numbers represented worse hearing. Listeners were presented with two-syllable words that have the same level of stress on both syllables (such as "mailbox"). The better (lower) speech reception threshold from either ear was used for analyses.

2.3 | Dementia Measures (Outcome)

Dementia is a neurocognitive condition that describes a decline in one or more of the following domains: learning and memory, language, executive function, complex attention, perceptual-motor, and social [37]. In this study, dementia was defined by either the International Classification of Diseases, 10th revision (ICD-10) coding or by medication lists.

Subjects with an ICD-10 diagnosis code of G30.X–G32.X were coded as having ICD-10-defined dementia. These codes encompass "Alzheimer's disease," "other degenerative diseases of nervous system, not elsewhere classified," and "other degenerative diseases of nervous system in diseases classified elsewhere".

Subjects with any of the following medications on their medication lists were coded as having medication list-defined dementia: donepezil, galantamine, memantine, and rivastigmine. At the time of this study, anti-amyloid disease-modifying drugs were either not approved or not widely in use for the treatment of Alzheimer's while under the Centers for Medicare and Medicaid Services coverage period [38]. Thus, they were not included as dementia indicators. This study follows previous health record-based epidemiological studies in the literature that also rely on ICD-10 codes and/or medication lists to study their populations of interest [39–41].

2.4 | Covariates

Variables that might confound the relationship between HL and dementia were included in the multivariable regression analyses. These covariates include age, sex, cardiovascular risk, and site (Columbia or Cornell). Of these factors, age is the most established potential confounder, given that age is the most

common risk factor for HL [42] and that all forms of dementia strongly relate to age.

Sex was coded as male or female. Cardiovascular risk may cause HL due to microvascular changes in the cochlea or contribute to dementia [43]. A composite cardiovascular risk variable was created by assigning one point each for the presence of hypertension and/or diabetes mellitus based on ICD-10 codes in the EHR. Scores ranged from 0 to 2, with higher scores indicating higher cardiovascular risk.

To account for any potential differences between the participant pools, site was controlled for in the analysis.

2.5 | Statistical Analysis

For descriptive statistics, means and standard deviations (SDs) were used for continuous variables. Numbers and percentages were used for categorical variables.

To analyze the association between HL and dementia, odds ratios were calculated from logistic regressions and reported with 95% confidence intervals. Separate logistic regression analyses were conducted with the three hearing measures and with the four dementia measures. Multivariable logistic regression analyses controlled for confounders. Multivariable regression model 1 controlled for age and sex. Model 2 controlled for age, sex, cardiovascular risk, and site. The model 2 multivariable regressions were termed the "fully adjusted working models" and were used for calculations of odds of dementia based on levels of HL. This was computed in the form of $e^{(coefficient \times difference)}$, where *coefficient* is the coefficient from the regression model and *difference* is the difference between the value of interest and the reference value.

All hypothesis tests were two-sided, and significance was defined as $p < 0.05$. Analyses were performed from April 2023 to March 2024 using R, version 4.2.3 (R Foundation for Statistical Computing) with RStudio, version 2023.03.0+386 (RStudio Inc.).

3 | Results

3.1 | Baseline Demographic Characteristics

Out of 31,997 total participants, 18,992 (59.4%) were women. The mean (SD) age was 60.5 (18.3) years. The age range was 18 to 105 years. In the Columbia cohort, the mean (SD) age was 59.9 (18.4) years. In the Cornell cohort, the mean (SD) age was 61.2 (18.2) years. The baseline characteristics of the study participants are outlined in Table 1.

TABLE 1 | Participant characteristics stratified by study cohort in the Columbia University Irving Medical Center and Weill Cornell Medicine Populations.

	Columbia ($n = 16,129$)	Cornell ($n = 15,868$)	Combined ($n = 31,997$)
Age, mean (SD), [range]	59.9 (18.4), [18–104]	61.2 (18.2), [18–105]	60.5 (18.3), [18–105]
Women, No. (%)	9741 (60.4%)	9251 (58.3%)	18,992 (59.4%)
Cardiovascular risk score, mean (SD)[a]	0.32 (0.60)	0.40 (0.63)	0.36 (0.62)
Pure-tone average (dB), mean (SD)	28.6 (18.6)	25.1 (16.9)	26.9 (17.8)
HL, > 25 dB, No. (%)	7498 (46.5%)	6515 (41.1%)	14,013 (43.8%)
Mild HL, > 25 to 40 dB	3681 (22.8%)	3601 (22.7%)	7282 (22.8%)
Moderate HL, > 40 to 55 dB	2283 (14.2%)	2049 (12.9%)	4332 (13.5%)
Moderately-severe HL, > 55 to 70 dB	1093 (6.8%)	664 (4.2%)	1757 (5.5%)
Severe HL, > 70 to 90 dB	324 (2.0%)	154 (1.0%)	478 (1.5%)
Profound HL, > 90 dB	117 (0.7%)	47 (0.3%)	164 (0.5%)
Word recognition score (%), mean (SD)	94.5 (11.6)	95.6 (9.3)	95.1 (10.5)
Speech reception threshold (dB), mean (SD)	23.9 (15.4)	20.5 (15.2)	22.2 (15.4)
Dementia			
By ICD-10 code only	324 (2.0%)	529 (3.3%)	853 (2.7%)
By medication list only	289 (1.8%)	157 (1.0%)	446 (1.4%)
By both ICD-10 code and medication list	129 (0.8%)	91 (0.6%)	220 (0.7%)
By either ICD-10 code or medication list	484 (3.0%)	595 (3.7%)	1079 (3.4%)

Abbreviation: HL = hearing loss.
[a]The cardiovascular risk score was created by assigning one point to each of the following risk factors in the participant's chart: hypertension and diabetes mellitus. Scores ranged from 0 to 2, with higher scores indicating higher cardiovascular risk.

3.2 | Baseline Hearing Characteristics

The average PTA in the better ear in the combined study population was 26.9 dB. About 56% of participants had normal hearing, 23% had mild HL (26–40 dB), 14% had moderate HL (41–55 dB), 5.5% had moderately severe HL (56–70 dB), 1.5% had severe HL (71–90 dB), and 0.5% had profound HL (> 90 dB). Further details for word recognition score and speech reception threshold appear in Table 1.

3.3 | Baseline Dementia Characteristics

Out of 31,997 total participants, 853 (2.7%) had ICD-10 code-defined dementia, 446 (1.4%) had medication list-defined dementia, 220 (0.7%) had both ICD-10 code and medication list-defined dementia, and 1079 (3.4%) had either ICD-10 code or medication list-defined dementia. Further details, including breakdown by site, appear in Table 1.

3.4 | Regression Analysis

A set of logistic regression models was run for each of the three definitions of HL: PTA (Table 2), word recognition score (Table 3), and speech reception threshold (Table 4). For each set of regressions, dementia was defined by ICD-10 code only, medication list only, ICD-10 code *and* medication list, and ICD-10 code *or* medication list. Across all three definitions of HL, the fully adjusted model 2 was significant when defining dementia (1) by ICD-10 code only and (2) by ICD-10 code *or* medication list.

In the fully adjusted model 2, for every 10 dB worsening in HL by PTA, the odds of dementia, defined by either ICD-10 code or medication list, increased by 1.11 times (95% CI = 1.07–1.16). Similar relationships were seen for the other definitions of dementia, except for dementia defined as having both ICD-10 and medication list, which was non-significant. Full results are shown in Table 2.

Only the model 2's for dementia by ICD-10 code and dementia by either ICD-10 code or medication list were significant. For model 2 of dementia by ICD-10 code, for every 10% worsening in HL by word recognition score, the odds of dementia increased by 1.06 times (95% CI = 1.00–1.11). For model 2 by either ICD-10 code or medication list, for every 10% worsening in HL by word recognition score, the odds of dementia increased by 1.06 times (95% CI = 1.01–1.11). Full results are shown in Table 3.

In model 2, for every 10 dB worsening in speech reception threshold, the odds of dementia, defined by ICD-10 code, increased by 1.10 times (95% CI = 1.05–1.15). Similar results were seen for the other definitions of dementia (Table 4), except for dementia defined as having both ICD-10 code and medication list, which was non-significant.

Table 5 reports odds of dementia for the fully adjusted working model 2's, and which defined dementia by either ICD-10 code or medication list. For example, the odds of dementia for someone with moderate HL was 1.46 (1.26–1.68) times higher than the odds of someone with normal hearing, adjusting for covariates. Similar effect sizes were seen for analogous word recognition scores and speech reception thresholds. See Table S1 for the breakdown of dementia vs. non-dementia participants across HL categories, Table S2 for dementia odds looking at standardized differences between the different HL variables, and Table S3 for the inclusion of a depression diagnosis covariate.

4 | Discussion

In this EHR-based study of two large academic health systems, worse hearing—as defined by either higher PTA, lower word recognition score, or higher speech reception thresholds—was associated with significantly increased odds of dementia. Those associations remained significant despite controlling for potential confounders, such as age, sex, cardiovascular risk, and study site. The increased odds of dementia were clinically meaningful.

TABLE 2 | Logistic regression models for dementia based on pure tone average hearing ($n = 31,997$).

For each 10 dB worsening in HL...	Dementia by ICD-10 Code[a]	Dementia by medication list[b]	Dementia by ICD-10 Code[a] and medication list[b]	Dementia by ICD-10 Code[a] or medication list[b]
	$n = 853$ with dementia	$n = 446$ with dementia	$n = 220$ with dementia	$n = 1079$ with dementia
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Model 1[d]	1.07 (1.02–1.12)*	1.16 (1.09–1.23)*	1.11 (1.01–1.21)*	1.10 (1.06–1.15)*
Model 2[e]	1.09 (1.04–1.15)*	1.13 (1.06–1.20)*	1.09 (0.99–1.19)	1.11 (1.07–1.16)*[c]

Abbreviations: CI = confidence interval, OR = odds ratio.
[a]G30.X–G32.X.
[b]Donepezil, galantamine, memantine, or rivastigmine.
[c]Fully adjusted working model.
[d]Controlled for age and sex.
[e]Controlled for age, sex, cardiovascular risk, and site.
*$p < 0.05$.

TABLE 3 | Logistic regression models for dementia based on word recognition score hearing ($n = 30{,}465$).

For each 10% worsening in word recognition score…	Dementia by ICD-10 Code[a]	Dementia by medication list[b]	Dementia by ICD-10 Code[a] and medication list[b]	Dementia by ICD-10 Code[a] or medication list[b]
	$n = 853$ with dementia	$n = 446$ with dementia	$n = 220$ with dementia	$n = 1079$ with dementia
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Model 1[d]	1.03 (0.98–1.09)	1.05 (0.99–1.12)	1.01 (0.92–1.11)	1.05 (1.00–1.10)*
Model 2[e]	1.06 (1.00–1.11)*	1.03 (0.97–1.10)	1.00 (0.91–1.09)	1.06 (1.01–1.11)*[c]

Abbreviations: CI = confidence interval, OR = odds ratio.
[a]G30.X–G32.X.
[b]Donepezil, galantamine, memantine, or rivastigmine.
[c]Fully adjusted working model.
[d]Controlled for age and sex.
[e]Controlled for age, sex, cardiovascular risk, and site.
*$p < 0.05$.

TABLE 4 | Logistic regression models for dementia based on speech reception threshold hearing ($n = 30{,}713$).

For each 10 dB worsening in speech reception threshold…	Dementia by ICD-10 Code[a]	Dementia by medication list[b]	Dementia by ICD-10 Code[a] and medication list[b]	Dementia by ICD-10 Code[a] or medication list[b]
	$n = 853$ with dementia	$n = 446$ with dementia	$n = 220$ with dementia	$n = 1079$ with dementia
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Model 1[d]	1.05 (1.00–1.11)*	1.13 (1.06–1.21)*	1.04 (0.95–1.15)	1.09 (1.04–1.14)*
Model 2[e]	1.07 (1.02–1.13)*	1.10 (1.03–1.18)*	1.03 (0.93–1.13)	1.10 (1.05–1.15)*[c]

Abbreviations: CI = confidence interval, OR = odds ratio.
[a]G30.X–G32.X.
[b]Donepezil, galantamine, memantine, or rivastigmine.
[c]Fully adjusted working model.
[d]Controlled for age and sex.
[e]Controlled for age, sex, cardiovascular risk, and site.
*$p < 0.05$.

TABLE 5 | Odds of dementia based on levels of hearing loss ($n = 30{,}713$ to 31,997).

	Odds of dementia (95% CI)
Pure tone hearing category[a] ($n = 31{,}997$)	
Normal	Reference
Mild HL	1.24 (1.14, 1.35)
Moderate HL	1.46 (1.26, 1.68)
Moderately-Severe HL	1.71 (1.39, 2.10)
Severe HL	2.07 (1.56, 2.73)
Profound HL	2.56 (1.77, 3.67)
Word recognition score[b] ($n = 30{,}465$)	
100%	Reference
80%	1.12 (1.03, 1.23)
60%	1.26 (1.05, 1.51)
40%	1.42 (1.08, 1.85)
20%	1.60 (1.11, 2.27)
0%	1.80 (1.14, 2.79)
Speech reception threshold[c] ($n = 30{,}713$)	
0 dB	Reference
20 dB	1.20 (1.10–1.31)
40 dB	1.44 (1.20–1.73)
60 dB	1.74 (1.32–2.27)
80 dB	2.09 (1.45–2.99)
100 dB	2.51 (1.59–3.93)

Note: Predictions are based on the fully adjusted working models, which controlled for age, sex, cardiovascular risk, and site (if applicable), and which defined dementia by either ICD-10 code or mediation list.
Abbreviations: CI = confidence interval, HL = hearing loss.
[a]All $p < 0.001$. For calculating odds, the midpoint dB value for each pure tone hearing category (except profound which has no upper limit) was used as follows: 12.5 dB for normal, 32.5 dB for mild, 47.5 dB for moderate, 62.5 dB for moderately-severe, 80 dB for severe, 100 dB for profound. For word recognition and speech reception threshold, the percentage values (for word recognition score) or dB values (for speech reception threshold) listed in the Table were used to calculate odds.
[b]All $p = 0.01$.
[c]All $p < 0.001$.

For example, an individual with a moderate HL (PTA of about 50 dB) would have nearly 1.5 times the odds of dementia compared to someone with normal hearing. An individual with severe HL would have over double the odds. Similar findings were seen for speech reception thresholds. Although these were observational data, taken together, they raise the question of whether using hearing aids as an intervention to shift patients from a high level of HL to a lower level may impact the odds of dementia. Randomized controlled trials would be needed to answer this.

These results support previous associations between HL and dementia found in national epidemiologic studies using healthy volunteers [12–20]. Previous work by our group has found associations between HL and decreased cognition as measured on neurocognitive assessments [21, 22], or between HL and incident dementia [44–46].

With nearly 32,000 participants, this is the single largest study of its kind using raw EHR data to our knowledge. Uniquely, we found associations using three high-quality, objective methods to define HL. In particular, word recognition scores and speech reception thresholds have rarely been reported in epidemiological studies as they are largely absent from national epidemiologic datasets. Our primary findings of increased dementia odds demonstrate the value of using an EHR system to identify associations with important public health problems, in this case dementia. This is enabled by numerically stored audiometric data and a massive scale of records. The presence of these additional audiometric variables in the EHR also enables supplementary analyses that allow us to compare the effect of hearing measures that might be better suited to evaluate more central versus peripheral hearing mechanisms on dementia odds. Our analyses show lower odds of dementia for WRS compared to PTA across HL categories (Table 5), which may suggest opposition to the "reverse causation" that dementia causes HL on audiogram. Though further research, particularly in the form of clinical trials, is needed to better understand the causal mechanisms and directionality of HL on dementia, our work supports the hypothesis that not only is HL a modifiable risk factor for dementia, but perhaps it may mitigate or prevent cognitive decline. As the ACHIEVE trial demonstrates, HL treatment may reduce cognitive change for those at higher risk for dementia (older, lower baseline cognitive scores, and factors such as increased cardiovascular risk) [32].

Most high-quality epidemiologic studies examining the association between HL and negative health states have used large, national epidemiologic datasets with audiometric data (e.g., the National Health and Nutrition Examination Survey; NHANES). These datasets are often representative of the US population and relatively easy to access. However, EHR data from large medical systems have several advantages. First, a larger sample size improves statistical power and can enable finding associations within subgroups of interest. Our study contains data from only the first 3.5 years since the record system was implemented and already has nearly 32,000 adult subjects with audiometric data. This is substantially larger than studies using national epidemiologic datasets with audiometric information, including NHANES [47] and others [21, 48, 49]. Though insurance claims datasets can contain millions of subjects, HL is defined binarily with diagnostic codes [32, 45, 50–52]. Second, EHRs are longitudinal, whereas many prominent national epidemiologic datasets, such as NHANES, are cross-sectional. Our Epic EHR system is relatively new, having been in existence for under 4 years as of the time of this analysis. We plan to perform longitudinal analyses in the future. Third, EHR data will tend to contain subjects with more severe disease since they are based at locations of care. Our 3.5-year-old sample contained 642 (2%) individuals with severe-to-profound HL, as opposed to 21 individuals in NHANES after merging 18 years of data [50]. This study provides more power to create predictive models of those with

more extreme disease, which would be of particular interest to otolaryngologists who tend to focus on severe disease as opposed to public health researchers who tend to focus more on common disease. Along similar lines, our data included 874 participants who were at least 90 years old, an age group that would typically be excluded in community-based national epidemiologic studies that rely on relatively healthy volunteers. Fourth, richer data measures are potentially available. We were able to analyze the word recognition score and speech reception threshold in addition to pure tones, which may better represent real-world hearing abilities and enhance the study's ecological validity. Other otolaryngologic variables of interest (i.e., dysphonia, hyposmia) that are not routinely captured in national epidemiologic studies can be studied as well using EHRs.

We defined dementia separately by ICD-10 diagnostic code, the presence of 4 medications that are commonly used for treating dementia, the presence of both, and the presence of either of the aforementioned two definitions. This was an attempt to raise the sensitivity and specificity of the dementia definition, since diagnostic code-based or medication-based analyses in EHRs are proxies for accurate dementia diagnosis. We found qualitatively similar associations between HL and dementia in the fully adjusted multivariable models across all definitions except for the "both" condition. This exception of the "both" condition suggests we may have been underpowered to identify an association as it contained only 220 participants (0.7% of the cohort). It is possible significance would have been reached with more subjects. In the future, we plan to incorporate sub-analyses by specific dementia diagnoses, such as those with only Alzheimer's dementia. Also, new anti-amyloid medications, such as lecanemab, should be included in future studies now that they have widespread approval.

This study has limitations. As a cross-sectional analysis of observational data, we cannot infer causation, that is, we are unable to state HL causes dementia. Longitudinal observational studies as well as randomized controlled trials have the advantage of exploring incident cognitive impairment (new cases over time). However, the long latency in developing dementia creates a methodologic challenge. We controlled for factors that could confound the relationship between hearing and dementia, such as age or cardiovascular risk. However, we cannot control for unmeasured or unknown confounders of interest (e.g., education and genetic factors). In particular, sociodemographic variables like education are not consistently recorded in the EHR. It is recognized that residual confounding is common in cognitive aging studies, particularly with regard to social determinants of health. As a result, the possibility of confounding as an explanation for our results is still possible. Only a properly designed randomized controlled trial can eliminate the possibility of confounding. Lastly, we chose to only use the first (baseline) audiogram and ignore follow-up audiograms, even if they were worse. In the future, we plan to perform longitudinal analyses that capture the progression of HL.

This study pooled data from two academic institutions that together capture considerable socioeconomic, racial, and cultural diversity, which helps make the results of this study more generalizable. However, both institutions are located in New York City and may not capture geographic diversity [53]. This may limit the generalizability of findings to populations in different regions or countries, as well as to smaller, community healthcare settings. Another limitation is that we could not assess for HL treatment with hearing aids as the data is not coded or even consistently reported (whether structured or unstructured) in the EHR system. However, given the overall low percentage of adults who wear hearing aids in the United States (about 7% of the population 45 years and older with HL [54]) we presume that most individuals with HL in this study were untreated. While limited treatment data may be available for cochlear implant candidates, only about 2% of this study population of all adults would possibly be candidates [12]. Furthermore, the lack of controlling for HL treatment would tend to underestimate our findings by biasing our results towards the null hypothesis (i.e., no association between HL and dementia). Finally, in some cases the word recognition score was coded non-numerically such as "could not test." This can occur when the participant refuses the test, could not cooperate, or is profoundly deaf and could not detect that words were being presented. Because of the ambiguity, these cases could not be analyzed. We suspect that a non-trivial number of those who actually had 0% word recognition were coded as "could not test" and thus were not included in the analysis.

This study represents an important step in leveraging large EHR systems for continued inquiry into the associations between HL and dementia, as well as other potential outcomes such as depression, falls, or mortality. This study also comes at an important time as randomized controlled trials, such as ACHIEVE [32] and EARHLI [31], examine the effect of hearing interventions on improving pre-specified outcomes such as cognitive change. By leveraging the size and broad array of subspecialty-specific variables available in EHRs, researchers may generate more specific epidemiologic inquiry in the quest to improve hearing healthcare.

5 | Conclusion

Using a novel, large EHR, HL, as defined by PTA, word recognition score, and speech reception threshold, was associated with clinically significant increased odds of dementia. This paper highlights the utility of EHRs to corroborate and expand previously studied relationships between HL and other age-related conditions, including dementia, with massive power. Future research should continue leveraging EHR systems to explore HL's associations with lesser studied variables, perform longitudinal analyses, and examine unique at-risk subpopulations.

Acknowledgments

The authors would like to acknowledge the support of Jori P. Grossman and Steven Yen, both of whom were instrumental in accessing and organizing the data used in this project.

Disclosure

This paper was submitted as a Triological Thesis for society membership at the 2024 Triological Society Combined Sections Meeting from January 25–27, 2024 in West Palm Beach, Florida.

Conflicts of Interest

The authors declare no conflicts of interest.

References

1. NIH, "Quick Statistics About Hearing, Balance, & Dizziness," accessed May 5, 2023, https://www.nidcd.nih.gov/health/statistics/quick-statistics-hearing#:~:text=One%20in%20eight%20people%20in,based%20on%20standard%20hearing%20examinations.&text=About%202%20percent%20of%20adults,adults%20aged%2055%20to%2064.

2. F. R. Lin, "Hearing Loss Prevalence in the United States," *Archives of Internal Medicine* 171, no. 20 (2011): 1851, https://doi.org/10.1001/archinternmed.2011.506.

3. NIDCD Information Clearinghouse, "Age-Related Hearing Loss (Presbycusis)," accessed August 7, 2023, https://www.nidcd.nih.gov/health/age-related-hearing-loss.

4. "National Diabetes Statistics Report 2020," 2020, https://www.cdc.gov/diabetes/pdfs/data/statistics/national-diabetes-statistics-report.pdf.

5. Statistics NCfH, "Respondent-Reported Prevalence of Heart Disease in Adults Aged 18 and Over, by Selected Characteristics: United States, Selected Years 1997–2019," accessed August 7, 2023, https://www.cdc.gov/nchs/data/hus/2020-2021/HDPrv.pdf.

6. B. Yueh, N. Shapiro, C. H. Maclean, and P. G. Shekelle, "Screening and Management of Adult Hearing Loss in Primary Care," *Journal of the American Medical Association* 289, no. 15 (2003): 1976, https://doi.org/10.1001/jama.289.15.1976.

7. B. Yueh, P. E. Souza, J. A. McDowell, et al., "Randomized Trial of Amplification Strategies," *Archives of Otolaryngology—Head & Neck Surgery* 127, no. 10 (2001): 1197–1204, https://doi.org/10.1001/archotol.127.10.1197.

8. P. T. Kitterick and M. A. Ferguson, "Hearing Aids and Health-Related Quality of Life in Adults With Hearing Loss," *Journal of the American Medical Association* 319, no. 21 (2018): 2225, https://doi.org/10.1001/jama.2018.5567.

9. L. E. Cortina, A. Amini, J. Benson, V. W. Huang, and J. G. Naples, "Hearing Loss and Sociodemographic Barriers to Health Care Access Using the All of Us Research Program," *Otolaryngology–Head and Neck Surgery* 170, no. 1 (2024): 76–83, https://doi.org/10.1002/ohn.431.

10. F. R. Lin and S. Chadha, "Over-The-Counter Hearing Aids—Using Regulatory Policy to Improve Public Health," *New England Journal of Medicine* 388, no. 23 (2023): 2117–2119, https://doi.org/10.1056/nejmp2302355.

11. C. L. Nieman, N. Marrone, S. L. Szanton, R. J. Thorpe, and F. R. Lin, "Racial/Ethnic and Socioeconomic Disparities in Hearing Health Care Among Older Americans," *Journal of Aging and Health* 28, no. 1 (2016): 68–94, https://doi.org/10.1177/0898264315585505.

12. A. M. Nassiri, D. L. Sorkin, and M. L. Carlson, "Current Estimates of Cochlear Implant Utilization in the United States," *Otology & Neurotology* 43, no. 5 (2022): e558–e562, https://doi.org/10.1097/mao.0000000000003513.

13. M. Grewal, J. Dragon, and J. S. Golub, "Age-Related Disparities in the Treatment of Borderline/Mild Hearing Loss in the United States," *OTO Open* 6, no. 1 (2022): 2473974X221083092, https://doi.org/10.1177/2473974x221083092.

14. U. S. P. S. T. Force, A. H. Krist, K. W. Davidson, et al., "Screening for Hearing Loss in Older Adults: US Preventive Services Task Force Recommendation Statement," *JAMA* 325, no. 12 (2021): 1196–1201, https://doi.org/10.1001/jama.2021.2566.

15. J. A. Deal, J. Betz, K. Yaffe, et al., "Hearing Impairment and Incident Dementia and Cognitive Decline in Older Adults: The Health ABC Study," *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* 72, no. 5 (2017): 703–709, https://doi.org/10.1093/gerona/glw069.

16. R. K. Gurgel, P. D. Ward, S. Schwartz, M. C. Norton, N. L. Foster, and J. T. Tschanz, "Relationship of Hearing Loss and Dementia," *Otology & Neurotology* 35, no. 5 (2014): 775–781, https://doi.org/10.1097/mao.0000000000000313.

17. J. Gallacher, V. Ilubaera, Y. Ben-Shlomo, et al., "Auditory Threshold, Phonologic Demand, and Incident Dementia," *Neurology* 79, no. 15 (2012): 1583–1590, https://doi.org/10.1212/WNL.0b013e31826e263d.

18. F. R. Lin, E. J. Metter, R. J. O'Brien, S. M. Resnick, A. B. Zonderman, and L. Ferrucci, "Hearing Loss and Incident Dementia," *Archives of Neurology* 68, no. 2 (2011): 214–220, https://doi.org/10.1001/archneurol.2010.362.

19. R. F. Uhlmann, "Relationship of Hearing Impairment to Dementia and Cognitive Dysfunction in Older Adults," *JAMA: The Journal of the American Medical Association* 261, no. 13 (1989): 1916, https://doi.org/10.1001/jama.1989.03420130084028.

20. J. S. Golub, K. K. Brewster, A. M. Brickman, et al., "Subclinical Hearing Loss Is Associated With Depressive Symptoms," *American Journal of Geriatric Psychiatry* 28, no. 5 (2020): 545–556, https://doi.org/10.1016/j.jagp.2019.12.008.

21. J. S. Golub, A. M. Brickman, A. J. Ciarleglio, N. Schupf, and J. A. Luchsinger, "Audiometric Age-Related Hearing Loss and Cognition in the Hispanic Community Health Study," *Journal of Gerontology: Biological Sciences and Medical Sciences* 75, no. 3 (2020): 552–560, https://doi.org/10.1093/gerona/glz119.

22. J. S. Golub, A. M. Brickman, A. J. Ciarleglio, N. Schupf, and J. A. Luchsinger, "Association of Subclinical Hearing Loss With Cognitive Performance," *JAMA Otolaryngology. Head & Neck Surgery* 146, no. 1 (2020): 57, https://doi.org/10.1001/jamaoto.2019.3375.

23. J. S. Golub, J. A. Luchsinger, J. J. Manly, Y. Stern, R. Mayeux, and N. Schupf, "Observed Hearing Loss and Incident Dementia in a Multiethnic Cohort," *Journal of the American Geriatrics Society* 65, no. 8 (2017): 1691–1697, https://doi.org/10.1111/jgs.14848.

24. S. Möller, J. Lykkegaard, R. S. Hansen, L. Stokholm, N. K. Kjær, and L. J. Ahrenfeldt, "Sensory Impairments and the Risk of Cognitive Decline and Dementia Across Sex, Age, and Regions: Longitudinal Insights From Europe," *Archives of Gerontology and Geriatrics* 127 (2024): 105584, https://doi.org/10.1016/j.archger.2024.105584.

25. F. R. Lin, "Hearing Loss and Falls Among Older Adults in the United States," *Archives of Internal Medicine* 172, no. 4 (2012): 369, https://doi.org/10.1001/archinternmed.2011.728.

26. K. J. Contrera, J. Betz, D. J. Genther, and F. R. Lin, "Association of Hearing Impairment and Mortality in the National Health and Nutrition Examination Survey," *JAMA Otolaryngology. Head & Neck Surgery* 141, no. 10 (2015): 944–946, https://doi.org/10.1001/jamaoto.2015.1762.

27. B. R. Rutherford, K. Brewster, J. S. Golub, A. H. Kim, and S. P. Roose, "Sensation and Psychiatry: Linking Age-Related Hearing Loss to Late-Life Depression and Cognitive Decline," *American Journal of Psychiatry* 175, no. 3 (2018): 215–224, https://doi.org/10.1176/appi.ajp.2017.17040423.

28. L. J. Ahrenfeldt, S. Möller, D. L. Nielsen, N. K. Kjær, J. Søndergaard, and J. Lykkegaard, "Sensory Impairments and Depressive Symptoms in Europe: A Cross-National Cohort Study," *Aging & Mental Health* 28, no. 12 (2024): 1591–1599, https://doi.org/10.1080/13607863.2024.2345790.

29. G. Ogliari, J. Ryg, N. Qureshi, K. Andersen-Ranberg, L. L. Scheel-Hincke, and T. Masud, "Subjective Vision and Hearing Impairment and Falls Among Community-Dwelling Adults: A Prospective Study in the Survey of Health, Ageing and Retirement in Europe (SHARE)," *European Geriatric Medicine* 12, no. 5 (2021): 1031–1043, https://doi.org/10.1007/s41999-021-00505-4.

30. G. Livingston, J. Huntley, K. Y. Liu, et al., "Dementia Prevention, Intervention, and Care: 2024 Report of the Lancet Standing Commission," *Lancet* 404, no. 10452 (2024): 572–628, https://doi.org/10.1016/s0140-6736(24)01296-0.

31. J. S. M. Golub, "Early Age-Related Hearing Loss Investigation (EARHLI): A Randomized Controlled Trial to Assess Mechanisms Linking Early Age-Related Hearing Loss and Alzheimer's Disease and Related Dementias, NIH," accessed July 31, 2023, https://reporter.nih.gov/search/EaC3BhVN6USBfOMuTswDVQ/project-details/10521559.

32. F. R. Lin, J. R. Pike, M. S. Albert, et al., "Hearing Intervention Versus Health Education Control to Reduce Cognitive Decline in Older Adults With Hearing Loss in the USA (ACHIEVE): A Multicentre, Randomised Controlled Trial," *Lancet* 402 (2023): 786–797, https://doi.org/10.1016/s0140-6736(23)01406-x.

33. "STROBE—Strengthening the Reporting of Observational Studies in Epidemiology," accessed August 10, 2023, https://www.strobe-statement.org/.

34. "Hearing Number. Johns Hopkins Bloomberg School of Public Health," accessed August 1, 2023, https://hearingnumber.org/.

35. A. C. Carl, M. H. Hohman, and J. Cornejo, *Audiology Pure Tone Evaluation* (StatPearls Publishing, 2023).

36. M. K. Salmon, J. Brant, M. H. Hohman, and D. Leibowitz, *Audiogram Interpretation* (StatPearls Publishing, 2023).

37. Association AP, *Diagnostic and Statistical Manual of Mental Disorders (DSM-5)*, 5th ed. (American Psychiatric Association, 2013).

38. J. R. Sims, J. A. Zimmer, C. D. Evans, et al., "Donanemab in Early Symptomatic Alzheimer Disease," *Journal of the American Medical Association* 330 (2023): 512–527, https://doi.org/10.1001/jama.2023.13239.

39. A. A. Harb, R. Chen, H. S. Chase, K. Natarajan, and J. M. Noble, "Clinical Features and Outcomes of Patients With Dementia Compared to an Aging Cohort Hospitalized During the Initial New York City COVID-19 Wave," *Journal of Alzheimer's Disease* 81, no. 2 (2021): 679–690, https://doi.org/10.3233/jad-210050.

40. M. Ryvicker, Y. Barrón, S. Shah, et al., "Clinical and Demographic Profiles of Home Care Patients With Alzheimer's Disease and Related Dementias: Implications for Information Transfer Across Care Settings," *Journal of Applied Gerontology* 41, no. 2 (2022): 534–544, https://doi.org/10.1177/0733464821999225.

41. A. Ponjoan, J. Garre-Olmo, J. Blanch, et al., "Epidemiology of Dementia: Prevalence and Incidence Estimates Using Validated Electronic Health Records From Primary Care," *Clinical Epidemiology* 11 (2019): 217–228, https://doi.org/10.2147/clep.S186590.

42. M. Cheslock and O. De Jesus, *Presbycusis* (StatPearls Publishing, 2023).

43. K. Wattamwar, Z. J. Qian, J. Otter, et al., "Association of Cardiovascular Comorbidities With Hearing Loss in the Older Old," *JAMA Otolaryngology. Head & Neck Surgery* 144, no. 7 (2018): 623–629, https://doi.org/10.1001/jamaoto.2018.0643.

44. K. K. Brewster, M.-C. Hu, S. Zilcha-Mano, et al., "Age-Related Hearing Loss, Late-Life Depression, and Risk for Incident Dementia in Older Adults," *Journals of Gerontology: Series A* 76, no. 5 (2021): 827–834, https://doi.org/10.1093/gerona/glaa242.

45. A. Chern, R. K. Sharma, and J. S. Golub, "Hearing Loss and Incident Dementia: Claims Data From the New York SPARCS Database," *Otology & Neurotology* 43, no. 1 (2022): 36–41, https://doi.org/10.1097/mao.0000000000003338.

46. Z. Liang, A. Li, Y. Xu, X. Qian, and X. Gao, "Hearing Loss and Dementia: A Meta-Analysis of Prospective Cohort Studies," *Frontiers in Aging Neuroscience* 13 (2021): 695117, https://doi.org/10.3389/fnagi.2021.695117.

47. H. C. Wu, T. Thallmayer, J. A. Deal, J. F. Betz, N. S. Reed, and F. R. Lin, "Prevalence Trends in Hearing Aid Use Among US Adults Aged 50 to 69 Years With Hearing Loss—2011 to 2016 vs 1999 to 2004," *JAMA Otolaryngology. Head & Neck Surgery* 147, no. 9 (2021): 831, https://doi.org/10.1001/jamaoto.2021.1572.

48. A. R. Huang, K. Jiang, F. R. Lin, J. A. Deal, and N. S. Reed, "Hearing Loss and Dementia Prevalence in Older Adults in the US," *Journal of the American Medical Association* 329, no. 2 (2023): 171–173, https://doi.org/10.1001/jama.2022.20954.

49. F. R. Lin, K. Yaffe, J. Xia, et al., "Hearing Loss and Cognitive Decline in Older Adults," *JAMA Internal Medicine* 173, no. 4 (2013): 293–299, https://doi.org/10.1001/jamainternmed.2013.1868.

50. A. M. Goman and F. R. Lin, "Prevalence of Hearing Loss by Severity in the United States," *American Journal of Public Health* 106, no. 10 (2016): 1820–1822, https://doi.org/10.2105/ajph.2016.303299.

51. D. Tsimpida, E. Kontopantelis, D. Ashcroft, and M. Panagioti, "Comparison of Self-Reported Measures of Hearing With an Objective Audiometric Measure in Adults in the English Longitudinal Study of Ageing," *JAMA Network Open* 3, no. 8 (2020): e2015009, https://doi.org/10.1001/jamanetworkopen.2020.15009.

52. F. Mahomed, W. de Swanepoel, R. H. Eikelboom, and M. Soer, "Validity of Automated Threshold Audiometry: A Systematic Review and Meta-Analysis," *Ear and Hearing* 34, no. 6 (2013): 745–752, https://doi.org/10.1097/01.aud.0000436255.53747.a4.

53. M. Arce Rentería, T. M. Mobley, N. D. Evangelista, et al., "Representativeness of Samples Enrolled in Alzheimer's Disease Research Centers," *Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring* 15, no. 2 (2023): e12450, https://doi.org/10.1002/dad2.12450.

54. J. H. Madans, J. D. Weeks, and N. Elgaddal, "Hearing Difficulties Among Adults: United States, 2019. NCHS Data Brief," 2021, https://stacks.cdc.gov/view/cdc/107540.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.