# Hearing Screening Age Considerations for Adults: National Health and Nutrition Examination Survey

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## Abstract

**Background** The United States Preventative Service Taskforce recently determined that there was insufficient evidence to recommend hearing screening in adults.
**Purpose** To determine the age to screen adults in the U.S. for hearing loss and identify factors related to increased odds of hearing loss.
**Research Design** Epidemiological Cross-Sectional Study.
**Study Sample** Data from 3,409 individuals aged 20–69 years(y) were analyzed from the 1999–2000 and 2000–2002 cycles of the National Health and Nutrition Examination Survey (NHANES).
**Data Collection and Analysis** Hearing sensitivity from 0.5–8 kHz was assessed and hearing loss was defined as pure tone average 0.5, 1, 2, 4 kHz (PTA4) $>$ 15 dBHL for the worse ear. Thresholds were examined separately for men and women in 2-year intervals. A multivariate ordinal regression model adjusting for age, sex, race/ethnicity, and education was used to examine relationship to determinants.
**Results** Slight ($>$15 dBHL) hearing loss based on threshold at a single audiometric frequency was first evident in males aged 28–29y. For females, this occurred at age 34–35y. The age at which average PTA4 increased above 15 dBHL (slight hearing loss) was 46–47y for males and 56–57y for females. Multivariate ordinal regression revealed the following "high risk" factors: increased age, male sex, tinnitus, perceived hearing loss, and diabetes.
**Conclusions** For the function of primary prevention, these data suggest screening should initiate at $\sim$30y for males and 35y for females, the ages when average hearing thresholds at a single frequency can be classified as slight hearing loss. For secondary prevention, the recommended screening ages are higher – 45y for males and 55y for females. Hearing screening is recommended for asymptomatic adults, especially those with high risk factors. Our results also highlight the limitations of PTA4 in identifying early indices of hearing loss.

**Keywords**
- hearing loss
- epidemiology
- screening

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Hearing loss screening has become a universal standard for newborns in the United States (U.S.). A wealth of literature has been published supporting the benefits of early identification and intervention for hearing loss in pediatric populations (e.g., Yoshinaga-Itano et al, 2000; Bower and John, 2014; Young et al, 2011).[1–3] Yet the prevalence of congenital hearing loss (0.1%) and hearing loss among school-aged children (3.1%) in the U.S. (Mehra et al, 2009)[4] pales in comparison to the prevalence of hearing loss in adults, which ranges from 39.3% in 60–69 year olds, to 90.3% in persons ≥80 years old (Goman and Lin, 2016; Hoffman et al, 2017).[5,6]

Adult hearing loss has been associated with social-affective issues (e.g., social isolation), increased fall risk, numerous medical comorbidities, increased risk of all-cause mortality, and cognitive decline (Hodkinson, 1973; Lin and Ferrucci, 2012; Mick et al, 2014; Livingston et. al., 2017).[7–10] Recently, Golub et al (2020)[11] reported evidence of cognitive deficits in persons with slight hearing loss (i.e., pure tone average [0.5, 1, 2, 4 kHz] >15 dBHL in lieu of the common epidemiological cutoff of 25 dBHL).

The high prevalence of hearing loss in adults and associations with cognitive decline and medical comorbidities is a significant public health concern and raises the question, should we be screening the adult population for hearing loss? In 2014, the United States Preventative Taskforce (USPSTF) released updated recommendations and concluded that evidence was insufficient to support hearing screening for adults ≥50y (Moyer, 2012).[12] This recommendation is in stark contrast to the Healthy People 2020[13] goals of "increasing the proportion of persons who had a hearing examination on schedule" and "increasing the portion of persons with hearing impairment who have ever used a hearing aid or assistive listening device or who have cochlear implants" (Healthy People, 2020).[13] The USPSTF is also in contradiction to recommendations from professional organizations; for example, the American Speech-Language-Hearing Association (ASHA) recommends screening adults for hearing loss every decade through age 50y and at 3-year intervals thereafter (Valente et al, 2006).

A missing factor in supporting screening recommendations is identifying the age to screen adults. The age proposed may be dependent on the purpose of the screening, which can be to prevent hearing loss (primary prevention) and/or to provide strategies to mitigate progression of hearing loss and provide early intervention to improve function (secondary prevention). In this study, we aim to identify the ideal age for adult hearing screening to 1) institute preventative measures for patients with normal hearing (primary prevention) and 2) to prevent further progression or initiate appropriate treatment (secondary prevention). The analysis also considers the implications of how hearing loss is defined in identifying early evidence of pathology and enabling early intervention.

## Methods

The National Health and Nutrition Examination Survey (NHANES) is an ongoing "rolling" cross-sectional survey of the civilian non-institutionalized population of the United States. Between 1999 and 2002, NHANES collected data on 21,004 individuals of all ages (9,965 in 1999–2000 and 11,039 in 2001–2002). The NHANES data used are publicly available (Curtin et al, 2012).[14] Although newer NHANES data are available, only the surveys from 1999–2002 contain information on balance and Healthy Eating Index (HEI).

### Participants

From the total pool of 21,004 NHANES participants from the 1999–2000 and 2000–2002 cycles, there were 8,143 participants ages 20 to 69 years. Audiometric data were collected in a sub-sample of 3,853 participants from the two NHANES cycles (1999–2000: 1,807 participants; 2000–2002: 2,046 participants). The NHANES protocol excludes audiograms with inconsistent audiometry at 1000 Hz of more than 10 dB differences at re-test. Of the 3,853 participants with audiometric data, there were 3,409 participants included in the final analysis after exclusion due to inconsistent, incomplete, or missing auditory data.

### Audiometric Testing

The examination consisted of a questionnaire, otoscopic examination, tympanometry and pure-tone air-conduction threshold measures at 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, and 8.0 kHz. A pure tone average (PTA) was calculated for 0.5, 1.0, 2.0, and 4.0 kHz, referred to as PTA4. Based on PTA4, participants were categorized according to presence and severity of hearing loss. "Normal" hearing sensitivity was defined as PTA4 <= 15 dBHL, slight hearing loss was defined as > 15 to <= 25 dBHL, mild hearing loss was defined as > 25 to <= 40 dBHL, and moderate or greater hearing loss > 40 dBHL, based on ASHA clinical cutoff recommendations (Clark, 1981).[15] Hearing loss was also defined as average threshold at any audiometric frequency > 15 dBHL (slight), or 25 dBHL (mild), or 40 dBHL (moderate) for the worse ear. *Self-reported hearing difficulty* was based on a question of general condition of hearing, which read, "Which statement best describes your hearing (without a hearing aid)? Would you say your hearing is good, that you have a little trouble, a lot of trouble, or are you deaf?" *Any tinnitus in the past year* was defined as answering "yes" to the question, "In the past 12 months, have you ever had ringing, roaring, or buzzing in your ears? Finally, the articulation index (AI) was calculated using the count-the-dot method by plotting the mean thresholds for the age corresponding to the defined hearing losses above (Killion and Mueller et al, 2010).[16]

## Covariates

As part of the NHANES data collection, trained interviewers administer detailed questionnaires and examinations assessing various factors that may influence health outcomes. Covariates included in our analyses were based on the previous literature, preliminary Spearman's rho correlation analyses, and preliminary multivariate logistic regression models. Covariates considered included *demographics*:



 

age (categorized in 2-year increments for finer estimate), sex, race/ethnicity, education level; *self-reported exposures*: noise exposure, smoking status, alcohol use, ototoxic drugs, dizziness, vision difficulty; *told by physician conditions*: diabetes, hypertension, heart attack, cancer, arthritis, overweight; and *calculated outcomes*: pure tone average (PTA), body mass index (BMI; kg/m2), and dietary quality (measured by the Healthy Eating Index [HEI]).[17] Medical conditions were based on questions asking if the participant had been told by their doctor, they have the specific condition, for example "have you even been told by your doctor you have diabetes?" BMI and HEI were based on examination data.

## Statistical Analysis

Data were entered into the Complex Samples Analysis incorporating 4-year sample weights. Sample weights are assigned to each sample as a measure of the number of people in the population represented by that sample person, this allows estimates representative of the U.S. civilian non-institutionalized population. Wald statistics were performed for overall models and $\alpha \leq 0.05$ was defined as statistically significant. For univariate analysis, categorical data were analyzed with chi-square analysis and continuous data with *t*-test. Multivariate ordinal regression models adjusting for age, sex, race/ethnicity, and education were used to examine relationships to risk factors. Variance is shown by standard error of the mean (SEM). All analyses were performed in SPSS version 26 (SPSS, Inc., Chicago, IL).

## Results

The descriptive data shown in ►**Table 1** are stratified by hearing status based on PTA4 and shows p-values for chi-square (categorical variables) and *t*-test (continuous variables). The percentages represent the frequency counts corresponding to each variable based on hearing status (row percentage). The total column shows total percentage and counts for each variable or categories of the variable (column percentage). ►**Table 2** shows the cumulative odds ratios (OR) and 95% confidence intervals (CI) for the adjusted relationships for variables that met significance criteria ($p < 0.05$). Tinnitus, noise exposure, high blood pressure, arthritis, stroke, heavy drinking, use of over the counter (OTC) analgesics, diabetes, and perceived hearing loss maintained statistical significance with increased odds of hearing loss. On the other hand, every 1-point increase in HEI score was related to a 2.0% decreased odds of hearing loss (OR 0.98, 95% CI: 0.98–0.99).

The variables with adjusted statistical significance were then entered into a single multivariate ordinal regression model to identify "high-risk" factors relative to age-related hearing loss (as defined by PTA4 categories) and screening recommendations, shown in ►**Table 3**. The primary variables associated with increased odds of hearing loss were increased age, male sex, chronic tinnitus, perceived hearing loss, firearm use, and diabetes. No other health or audiological variables remained significant in the model. In contrast, compared with Caucasians, African Americans showed decreased odds of hearing loss (OR 0.64, 95% CI: 0.47–0.87), however, no other race/ethnicity demonstrated a significant relationship to PTA4.

Next, we examined the relationship between age and pure-tone audiometric thresholds. ►**Fig. 1** depicts hearing thresholds by frequency with increasing age category for the right ear. Based on the strong relationship to sex, we stratified the findings for males (1A) and females (1B). The grayscale on the graph reflects common clinical cutoffs for hearing sensitivity (Clark, 1981).[15] Average thresholds in males (►**Fig. 1A**) aged 28–29y represented the youngest age group with a threshold at a single frequency >15 dBHL (green circle); for females this occurred at age 34–35y. The orange circles depict the age that average threshold at any frequency increased >25 dBHL; this was observed in males at age 42–43y and for females at age 52–53y. The blue circles represent the age that average threshold at any frequency increased above 40 dBHL; this was observed for males at age 50–51y and for females at the age 64–65y. The age at which average PTA4 increased above 15 dBHL (slight hearing loss) was 46–47y for males and 56–57y for females, a 10-year difference (represented by yellow circles in ►**Fig. 1**). The age average PTA4 increased above 25 dBHL (mild hearing loss) was 60–61y for males (represented by red circles). Females on average did not show PTA4 >25 dBHL (no red circles in 1B).

As illustrated by ►**Fig. 1**, thresholds at higher frequencies not captured by PTA4 are elevated at younger ages. For example, when average PTA4 increased above 15 dBHL (yellow circles) in males, average threshold at 6.0 kHz was 30.68 (SEM= 3.11) dBHL and at 8.0 kHz, 29.79 (SEM = 2.99) dBHL, consistent with a mild high frequency hearing loss on average. For females, these thresholds were 27.78 (SEM = 2.52) dBHL at 6.0 kHz and 31.69 (SEM = 3.24) dBHL at 8.0 kHz, also consistent with a mild high frequency hearing loss on average. Note: We also performed a stratification by race/ethnicity; the results showed earlier onset of hearing loss in Caucasians by 2 years compared with African Americans (*data not shown*).

To further inform our recommendation we also calculated the Articulation Index (AI) for each of the pure tone thresholds and cutoffs illustrated in ►**Fig. 1**. For example, the AI for PTA4 >15 dBHL (yellow circles) was 89% for males and 90% for females (►**Table 4**). Hearing loss-based threshold at any frequency >15dBHL or any single frequency >25 dBHL was consistent with AI >90%. For threshold at any frequency >40 dBHL or PTA4 >25 dBHL the AI approached 80% and lower.

## Discussion

Our goal in this analysis was to determine age ranges that show evidence of hearing loss based on pure tone thresholds to inform hearing screening recommendations for adults. For the function of primary prevention, our data suggest screening should initiate at ~30y for males and 35y for females, the ages before average hearing thresholds at a single frequency fall into the range of slight hearing loss. Screening hearing at this age would allow baseline thresholds to be established



 

**Table 1** Descriptive demographic data for NHANES 1999–2002. Stratified by hearing-loss categories based on PTA4. Sample weights applied

| Characteristic | *n* | Hearing Status based on PTA4 (*n [%]*) | | | | p-value |
|---|---|---|---|---|---|---|
| | | Normal <= 15 dB HL | Slight >15 and <= 25 dB HL | Mild >25 and <= 40 dB HL | Moderate + > 40 dB HL | |
| **Sex** | | | | | | |
| Female | 1810(51.1%) | 1263 (71.2%) | 369 (19.3%) | 128 (6.7%) | 50 (2.7%) | <0.001 |
| Male | 1599(48.9%) | 798 (52.1%) | 417 (26.7%) | 265 (15.2%) | 119 (6.0%) | |
| **Age (y)** | | | | | | |
| 20–21 | 175(5.1%) | 156 (87.3%) | 14 (8.8%) | 4 (1.7%) | 1 (2.3%) | <0.001 |
| 22–23 | 161(4.0%) | 145 (87.7%) | 12 (9.9%) | 4 (2.4%) | 0 (0.0%) | |
| 24–25 | 159(3.9%) | 140 (87.2%) | 15 (9.7%) | 2 (0.9%) | 2 (1.6%) | |
| 26–27 | 156(4.2%) | 130 (82.3%) | 24 (16.1%) | 1 (1.3%) | 1 (0.3%) | |
| 28–29 | 149(4.3%) | 125 (83.3%) | 19 (19.7%) | 5 (4.0%) | 0 (0.0%) | |
| 30–31 | 134(4.1%) | 111 (79.3%) | 17 (15.9%) | 6 (4.8%) | 0 (0.0%) | |
| 32–33 | 148(5.2%) | 119 (84.5%) | 19 (10.5%) | 7 (3.9%) | 3 (1.1%) | |
| 34–35 | 156(5.0%) | 134 (85.6%) | 18 (12.7%) | 3 (1.6%) | 1 (0.1%) | |
| 36–37 | 137(4.5%) | 106 (75.9%) | 24 (19.3%) | 7 (4.8%) | 0 (0.0%) | |
| 38–39 | 145(5.3%) | 99 (65.2%) | 36 (26.7%) | 8 (6.2%) | 2 (1.9%) | |
| 40–41 | 140(4.5%) | 97 (69.5%) | 33 (23.4%) | 8 (6.3%) | 2 (0.9%) | |
| 42–43 | 141(4.7%) | 89 (57.9%) | 37 (30.3%) | 10 (8.62%) | 5 (3.2%) | |
| 44–45 | 159(5.7%) | 98 (61.6%) | 44 (29.2%) | 14 (8.3%) | 3 (0.8%) | |
| 46–47 | 137(5.7%) | 74 (54.1%) | 42 (25.4%) | 15 (15.0%) | 6 (5.5%) | |
| 48–49 | 116(4.2%) | 64 (53.8%) | 31 (27.3%) | 17 (15.6%) | 4 (3.3%) | |
| 50–51 | 143(4.5%) | 74 (52.6%) | 43 (28.1%) | 23 (16.7%) | 3 (2.5%) | |
| 52–53 | 133(4.2%) | 61 (46.5%) | 52 (39.1%) | 11 (7.1%) | 9 (7.3%) | |
| 54–55 | 108(3.4%) | 42 (40.4%) | 41 (37.2%) | 19 (15.2%) | 6 (7.2%) | |
| 56–57 | 93(3.1%) | 34 (35.7%) | 28 (30.4%) | 22 (26.4%) | 9 (7.5%) | |
| 58–59 | 85(2.8%) | 23 (26.6%) | 25 (28.9%) | 24 (32.2%) | 13 (12.4%) | |
| 60–61 | 160(2.7%) | 50 (32.0%) | 57 (34.0%) | 40 (22.3%) | 13 (11.8%) | |
| 62–63 | 130(2.4%) | 30 (22.0%) | 43 (35.6%) | 37 (25.7%) | 20 (16.7%) | |
| 64–65 | 117(2.1%) | 22 (18.4%) | 42 (32.9%) | 32 (26.7%) | 21 (22.0%) | |
| 66–67 | 134(2.5%) | 21 (12.9%) | 43 (31.8%) | 42 (34.8%) | 28 (20.5%) | |
| 68–69 | 93(1.8%) | 17 (15.7%) | 27 (24.3%) | 32 (41.9%) | 17 (18.1%) | |
| **Race/Ethnicity** | | | | | | |
| White | 1555(69.0%) | 906 (59.9%) | 361 (23.7%) | 203 (12.2%) | 85 (4.6%) | <0.001 |
| Black | 669(11.1%) | 421 (69.6%) | 168 (21.8%) | 49 (5.7%) | 31 (2.8%) | |
| Mexican | 851(7.7%) | 531 (70.8%) | 183 (19.1%) | 101 (7.8%) | 36 (2.3%) | |
| Hispanic | 207(7.6%) | 123 (63.6%) | 48 (21.5%) | 26 (8.8%) | 10 (6.1%) | |
| Other | 127(4.7%) | 80 (60.4%) | 26 (23.7%) | 14 (11.1%) | 7 (4.8%) | |
| **Education** | | | | | | |
| < High School | 1059(19.8%) | 532 (51.7%) | 271 (25.0%) | 171 (15.8%) | 85 (7.5%) | <0.001 |
| High School | 758(14.4%) | 448 (58.3%) | 198 (26.4%) | 80 (10.9%) | 32 (4.3%) | |
| > High School | 1590(55.5) | 1080 (67.0%) | 317 (20.7%) | 141 (9.1%) | 52 (3.2%) | |

(*Continued*)



 

**Table 1** (*Continued*)

| Characteristic | *n* | Hearing Status based on PTA4 (*n [%]*) | | | | p-value |
|---|---|---|---|---|---|---|
| | | Normal <= 15 dB HL | Slight >15 and <= 25 dB HL | Mild >25 and <= 40 dB HL | Moderate + > 40 dB HL | |
| **Noise Exposure** | | | | | | |
| Work | 1011(33.0%) | 541 (54.7%) | 256 (25.5%) | 154 (14.7%) | 60 (5.2%) | <0.001 |
| Recreational | 742(25.6%) | 452 (60.2%) | 162 (22.5%) | 91 (12.3%) | 37 (5.0%) | 0.193 |
| Firearm | 224(7.6%) | 106 (44.9%) | 56 (27.5%) | 41 (20.5%) | 21 (7.6%) | <0.001 |
| **Hearing Health** | | | | | | |
| Ototoxic Medication | 439(13.1%) | 189 (47.8%) | 128 (26.8%) | 85 (17.9%) | 37 (7.5%) | <0.001 |
| Tinnitus | 786(23.7%) | 408 (53.1%) | 183 (23.4%) | 124 (15.6%) | 71 (7.9%) | <0.001 |
| Chronic Tinnitus | 472 (14.6%) | 215 (46.2%) | 111 (24.6%) | 86 (17.9%) | 60 (11.3%) | <0.001 |
| Perceived Hearing Loss | 706 (22.4%) | 234 (36.1%) | 166 (24.4%) | 177 (24.8%) | 129 (14.7%) | <0.001 |
| Use Hearing Aid | 51(1.3%) | 0 (0.0%) | 1 (1.5%) | 13 (26.2%) | 37 (72.3%) | <0.001 |
| Hearing Tested | 2563(81.8%) | 1567 (62.2%) | 571 (22.3%) | 284 (10.8%) | 141 (4.6%) | 0.827 |
| **Health** | | | | | | |
| Diabetes | 291(6.7%) | 81 (30.2%) | 105 (31.3%) | 74 (27.4%) | 31 (11.2%) | <0.001 |
| Vision Difficulty | 643 (16.3%) | 318 (53.9%) | 168 (24.7%) | 114 (16.7%) | 43 (4.7%) | 0.002 |
| Cancer | 200(6.6%) | 82 (44.5%) | 60 (29.9%) | 40 (17.8%) | 18 (7.9%) | <0.001 |
| Stroke | 64(1.6%) | 17 (35.2%) | 16 (23.2%) | 20 (23.5%) | 11 (18.0%) | <0.001 |
| Heart Attack | 78(2.2%) | 23 (32.2%) | 25 (30.6%) | 21 (25.8%) | 9 (11.4%) | <0.001 |
| Hypertension | 838 (21.7%) | 358 (44.3%) | 251 (29.4%) | 162 (18.7%) | 67 (7.5%) | <0.001 |
| Arthritis | 607 (17.1%) | 233 (39.8%) | 184 (31.1%) | 127 (18.2%) | 63 (10.8%) | <0.001 |
| Dizziness | 403(18.8%) | 157 (42.7%) | 114 (27.0%) | 86 (19.3%) | 46 (11.0%) | 0.1 |
| Smoke | 1629(50.5%) | 855 (55.6%) | 428 (25.9%) | 232 (12.9%) | 114 (5.6%) | <0.001 |
| Alcohol 5 /day | 473(17.0%) | 205 (48.1%) | 130 (26.0%) | 91 (17.4%) | 47 (8.5%) | <0.001 |
| OTC Analgesics | 592(19.8%) | 271 (48.9%) | 167 (25.9%) | 105 (17.7%) | 49 (7.5%) | <0.001 |
| Overweight | 979 (29.8%) | 500 (54.3%) | 289 (27.0%) | 135 (13.0%) | 55 (5.6%) | <0.001 |
| Veteran | 391 (12.8%) | 143 (40.8%) | 111 (26.9%) | 87 (21.6%) | 50 (10.7%) | <0.001 |
| | | | **Mean and Standard Error of Mean (SEM)** | | | |
| Healthy Eating Index | 3315 | 63.41 (0.46) | 62.22 (0.41) | 63.06 (0.88) | 62.53 (1.03) | 0.01 |

Abbreviations: OTC, Over the Counter; PTA, Pure Tone Average; y, years.

and patient counseling on prevention strategies. For the function of secondary prevention (early identification), we recommend hearing screening in adults at the age of 45y for males and 55y for females. This recommendation corresponds to the age of average slight hearing loss (> 15 dBHL) based on PTA4, aligns with an average AI of 89–90%, and is the approximate age that any individual threshold, on average, is elevated above 25 dBHL or mild hearing loss. As observed in ►**Fig. 1**, younger age groups do show elevated thresholds at 6.0 and 8.0 kHz, but the impact on the AI is minimal. Screening at the proposed ages would allow for early identification of hearing loss, establishment of baseline hearing sensitivity for counseling on strategies for minimizing progression of hearing loss, and early intervention with aural rehabilitation or amplification.

Our data also highlight the limitations of the commonly used PTA4 in capturing early evidence of high frequency hearing loss that can affect speech understanding or that may be related to other auditory complaints such as tinnitus. For example, the World Health Organization (WHO) defines hearing loss as PTA4 >25 dBHL (WHO, 2018).[18] However, we observed that when males on average had a PTA4 >25 dBHL (60–61y) they had on average thresholds at individual high frequencies (3.0, 4.0, 6.0, and 8.0 kHz) > 40 dBHL. Examination of thresholds by age group reveals that females, on average, never reached an average PTA4 >25 dBHL despite thresholds at individual mid and high frequencies (3.0, 4.0, 6.0, and 8.0 kHz) corresponding to mild to moderate degrees of hearing loss. That is, by the time there is evidence of an average mild hearing loss on the basis of the WHO criteria,

 

**Table 2** Adjusted cumulative odds ratios (OR) and 95% confidence intervals for significant factors related to hearing loss based on PTA4

| | Cumulative OR | 95% Confidence Interval | |
|---|---|---|---|
| **Variable** | | | |
| **Noise Exposure** | | | |
| Firearm | 1.54 | 1.04 | 2.28 |
| Recreational | 1.36 | 1.06 | 1.72 |
| Job | 1.21 | 1.00 | 1.47 |
| **Hearing Health** | | | |
| Tinnitus | 1.59 | 1.31 | 1.94 |
| Chronic Tinnitus | 1.91 | 1.48 | 2.47 |
| Perceived Loss | 3.62 | 2.85 | 4.58 |
| **Health** | | | |
| Diabetes | 1.67 | 1.21 | 2.31 |
| Stroke | 2.46 | 1.18 | 5.11 |
| Hypertension | 1.32 | 1.02 | 1.71 |
| Arthritis | 1.44 | 1.12 | 1.84 |
| Alcohol 5/day | 1.43 | 1.02 | 1.99 |
| OTC Analgesics | 1.24 | 1.00 | 1.52 |
| Healthy Eating Index | 0.98 | 0.98 | 0.99 |

Abbreviations: OTC, Over the Counter; PTA, Pure Tone Average.
[a]Adjusted for age, sex, race/ethnicity, and education.

**Table 3** Cumulative odds ratios (OR) and 95% Confidence Intervals for high risk factors

| | Cumulative OR | 95% Confidence Interval | |
|---|---|---|---|
| Variable | | | |
| **Sex** | **2.77** | **2.35** | **3.27** |
| **Age** | **1.09** | **1.07** | **1.10** |
| Race | | | |
| Mexican | 0.91 | 0.62 | 1.35 |
| Hispanic | 1.31 | 0.79 | 2.15 |
| **Black** | **0.60** | **0.46** | **0.78** |
| Other | 0.96 | 0.54 | 1.70 |
| White | ref | ref | ref |
| **Education** | | | |
| **<High School** | **1.81** | **1.28** | **1.60** |
| **High School** | **1.23** | **1.01** | **1.50** |
| > High School | ref | ref | ref |
| Noise | | | |
| **Firearm Use** | **1.58** | **1.02** | **2.46** |
| Recreational Noise | 1.09 | 0.86 | 1.40 |
| Job Noise | 1.25 | 0.97 | 1.62 |
| Hearing Health | | | |
| **Chronic Tinnitus** | **1.42** | **1.05** | **1.89** |
| **Perceived hearing loss** | **3.30** | **2.5** | **4.38** |
| Health | | | |
| **Diabetes** | **1.65** | **1.16** | **2.33** |
| Stroke | 1.76 | 0.78 | 3.97 |
| Hypertension | 1.14 | 0.83 | 1.57 |
| Arthritis | 0.96 | 0.76 | 1.30 |
| Alcohol 5/day | 1.67 | 0.97 | 1.28 |
| OTC Analgesics | 0.97 | 0.76 | 1.22 |
| **Healthy Eating Index** | **0.98** | **0.97** | **0.99** |

Abbreviation: OTC, Over the Counter.
Bold text indicates statistical significance, $p < 0.05$.

thresholds at high frequencies have already reached levels consistent with a moderate hearing loss on average. The WHO has recently adopted the Global Burden of Disease Expert Group on Hearing Loss recommended cutoff for the PTA4 to be revised to > 20 dBHL (Olusanya et al, 2019).[19] The age that males on average reached a 20 dBHL PTA4 was 54–55 years of age; females was 62–63 years of age. Even with the more stringent definition of "normal" hearing, when the average audiogram reaches PTA4 > 20 dBHL, thresholds at 3.0 kHz and higher are on average at moderate degrees of hearing loss, and the articulation index for males and females with PTA4 > 20dBHL drops to 80% and 90% respectively.

The use of PTA as a measure of hearing status has a long history with the original application for predicting speech understanding and an average of 0.5, 1.0, and 2.0 kHz (Fletcher, 1929),[20] called the Speech PTA. In 1942, a procedure was proposed using thresholds for 0.25–4.0 kHz to determine percent hearing loss for medico-legal purposes (called the AMA method) with numerous variations over time (Glorig, 1961).[21] After several iterations, it was soon realized that this limited frequency range, though predictive of speech performance in quiet, was not reflective of speech understanding in more realistic settings with competing noise. In 1979, the threshold at 3.0 kHz was added to the formula to account for hearing in noise (AAO, 1979).[22] Still, research as early as the 1960s up to today support the importance of thresholds up to 8.0 kHz for speech understanding, particularly for speech sounds like /s/ and /z/ and in considering the effects of competing noise (e.g., Kryter et al, 1962; Suter, 1978; Lippman, 1996; Stelmachowicz et al, 2004).[23–26] More recently, the importance of hearing beyond conventional testing limits of 8.0 kHz have been highlighted, supporting the role of extended high frequency hearing (> 8.0 kHz) in speech understanding, localization of sound, and music appreciation (e.g., Moore et al, 2012; Zadeh et al, 2019; Hunter et al, 2020).[27–29]

We also completed a "high-risk" analysis. We observed that in addition to age and sex, Caucasians, persons reporting

 

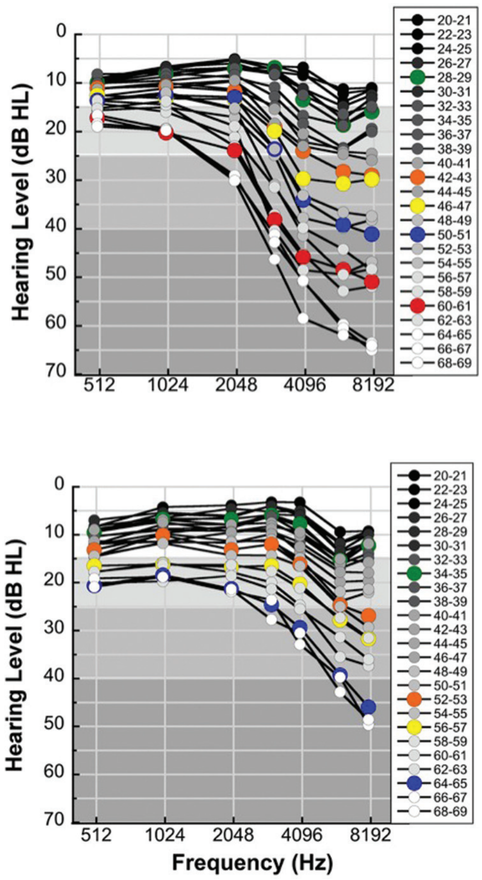


**Fig. 1 Hearing thresholds by age group in 2-year increments**. The figure shows audiograms for the right ear stratified by age and sex. The top panel shows males with increasing age and the bottom females with increasing age. The green circles reveal the earliest age threshold at any frequency was >15 dBHL. The orange circles show the earliest age threshold at any frequency was >25 dBHL. The yellow circles show the earliest age average PTA4 was >15 dBHL. The blue circles show the earliest age any average frequency was >40 dBHL. The red circles reflect the earliest age that average PTA4 was >25 dBHL (not observed for females). The background white and gray scale show cutoffs for normal (0–15 dBHL), slight (>15–25 dBHL), mild (>25 dBHL-40 dBHL), and moderate (>40 dBHL) or greater hearing loss based on ASHA criteria.

tinnitus, persons with perceived hearing difficulty, persons reporting use of firearms, and persons diagnosed with diabetes have increased odds of hearing loss in multivariate models. These relationships are not surprising and supported by previous research. Race/ethnicity differences in hearing loss prevalence have been well described in the literature with African Americans in general having lower prevalence (Hoffman et al, 2017).[6] It is also well known that persons with tinnitus and perceived hearing difficulty have increased odds of elevated audiometric thresholds (Curti et al, 2019).[30] Consistent with other reports, diabetes had an independent relationship to hearing loss (Bainbridge et al, 2011).[31] Firearms can produce high intensity impulse sounds with significant risk for hearing loss. Screening hearing of persons that use firearms can present an opportunity to discuss prevention strategies including consistent and appropriate use of hearing protection and suppressors (Lobarinas et al., 2017).[32] We recommend adults with these

**Table 4** Articulation index (%) data for males and females based on thresholds for five definitions of hearing loss. Data are shown for the age category corresponding to each hearing loss cutoff

| | Articulation Index for Average Thresholds at Age Corresponding to Hearing Loss Cutoffs | |
|---|---|---|
| Hearing Loss Cutoff | Male | Female |
| Any Frequency > 15 dB HL | 98% | 99% |
| Any Frequency > 25 dB HL | 92% | 95% |
| Any Frequency > 40 dB HL | 83% | 83% |
| PTA4 > 15 dB HL | 89% | 90% |
| PTA4 > 25 dB HL | 71% | – |

Abbreviation: PTA, Pure Tone Average.
dash: females in any age group did not reach PTA4 >25 dBHL.

“high-risk” factors adhere to the proposed age recommendations for hearing screening and be made aware of additional “risk” for hearing loss related to firearm use and diabetes.

A limitation of this study is the cross-sectional design, which prohibits inferences regarding causality. Additionally, some covariate data were obtained via self-report (e.g., smoking status), which may result in over- or underestimates. Last, our recommendations may not be generalizable beyond the age and race/ethnicity groups evaluated.

## Conclusion

In summary, this analysis suggests the screening ages of adults for hearing loss based on age-related changes in pure tone audiometry. Distinct age-based recommendations are made for males and females. It is our position that such screening may result in earlier detection of hearing loss and more timely intervention, therefore decreasing burden on the healthcare system.

Conflict of Interest
None declared.

Disclaimer
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