

Changes in Hearing Thresholds over 10 Years in Older Adults

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Abstract

Changes in hearing thresholds over a 10-year period in a large population of older adults (2130) ranging in age from 48 to 92 years were documented. Pure-tone thresholds at frequencies from 0.5 to 8 kHz were evaluated at a baseline examination and 2.5, 5, and 10 years later. For younger age groups (50–69 years of age), threshold changes were generally greatest for higher frequencies; in older age groups (70–89 years of age), threshold changes were generally greatest for lower frequencies due to a ceiling effect at higher frequencies. At frequencies of 0.5, 1, 2, and 8 kHz, the pattern of 10-year changes in thresholds across audiometric frequencies was generally similar for men and women. Threshold changes at 4 and 6 kHz were relatively constant for all ages in men across the 10-year examination period; threshold changes at the same frequencies in women increased for the 48–59 and 60–69 years age groups and then tended to level off. Other than age and gender, the best baseline examination predictors of 10-year thresholds at a specific audiometric frequency were the baseline threshold at that frequency followed by the baseline threshold for the next higher test frequency.

Key Words: Aging, hearing loss, hearing sensitivity, presbycusis

Abbreviations: BLSA = Baltimore Longitudinal Study of Aging; EHLS = Epidemiology of Hearing Loss Study

Sumario

Se documentó el cambio en los umbrales auditivos durante un período de 10 años en una gran población de adultos mayores (2130), con edades entre 48 y 92 años. Se evaluaron los umbrales para tonos puros desde 0.5 a 8 kHz en una medición basal y después de 2.5, 5 y 10 años. Para grupos de edad más jóvenes (50-69 años de edad), los cambios de umbrales fueron generalmente mayores para las frecuencias más agudas; in grupos de edad mayor (70-89 años de edad), los cambios de umbral fueron

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generalmente mayores para las frecuencias graves, debido a una efecto tope en las frecuencias más agudas. En las frecuencias de 0.5, 1, 2 y 8 kHz, el patrón de cambio en los umbrales después de 10 años en todas las frecuencias audiométricas fue similar para hombres y mujeres. Los cambios de umbrales en 4 y 6 kHz fueron relativamente constantes para todas las edades en los hombres, a lo largo del período de evaluación de 10 años; los cambios de umbrales en las mismas frecuencias en mujeres aumentaron en los grupos de edad de 48–59 y 60–69 años, y luego tendieron a nivelarse. Además de la edad y el género, los mejores elementos basales de predicción de los umbrales a 10 años en una frecuencia audiométrica específica fueron el umbral basal en esa frecuencia, seguido del umbral basal en la siguiente frecuencia de prueba más aguda.

Palabras Clave: Envejecimiento, pérdida auditiva, sensibilidad auditiva, presbiacusia

Abreviaturas: BLSA = Estudio Longitudinal de Baltimore sobre Envejecimiento; EHLS = Estudio de Epidemiología sobre Pérdida Auditiva

Presbycusis (age-related hearing loss) is probably the most prevalent basis for sensorineural hearing loss in older adults (Sajjadi et al, 2000) and ranks among the top three or four chronic conditions affecting adults over 65 years of age (National Center for Health Statistics, 1990). Although there are a number of studies documenting the prevalence and degree of hearing loss with advancing age (Moscicki et al, 1985; Gates et al, 1990; Cruickshanks et al, 1998), there are considerably fewer studies that have documented the progression of age-related hearing loss. Further, many of the earlier studies on the progression of hearing loss with advancing age were restricted to selected age groups (e.g., Eisdorfer and Wilkie, 1972; Moller, 1981; Rahko et al, 1985; Ostri et al, 1986; Pedersen et al, 1989; Ostri and Parving, 1991) and typically were based on relatively small samples, particularly for older age groups (e.g., Eisdorfer and Wilkie, 1972; Milne, 1977; Keay and Murray, 1988; Davis et al, 1991).

The three largest contemporary studies of hearing loss progression in older adults were conducted within the Epidemiology of Hearing Loss Study (Cruickshanks et al, 2003), the Framingham Heart Study (Gates et al, 1990; Gates and Cooper, 1991), and the Baltimore Longitudinal Study of

Aging (BLSA [Brant and Fozard, 1990; Pearson et al, 1995; Morrell et al, 1996]). Cruickshanks and colleagues (2003) documented the incidence and progression of hearing loss in a large population of older adults. Progression of hearing loss was defined as a change greater than 5 dB in the pure-tone average (0.5, 1, 2, and 4 kHz). Specific thresholds and changes in hearing thresholds across age groups at specific audiometric frequencies were not addressed in the Cruickshanks and colleagues article and are the subject of this report.

Gates and Cooper (1991) examined changes in hearing thresholds over a six-year period in 1475 participants within the Framingham cohort. Participants ranged in age from 58 to 88 years at the initial test and from 64 to 94 at the time of the six-year follow-up examination. Gates and Cooper reported that the six-year rate of hearing loss progression increased with age in a similar manner for men and women at frequencies ≤ 2 kHz. Although the rate of change was greater at lower frequencies, the largest absolute changes in hearing thresholds with age were observed at higher test frequencies. Across age groups, women generally demonstrated larger six-year changes in thresholds than men for all frequencies, but the difference across

gender was significant only at 0.5 kHz. At 4 and 6 kHz, the rate of change in hearing level with age decreased with age for men but increased with age for women. At 8 kHz, the rate of increase (worsening) in hearing levels slowed with older age groups for both men and women. Overall, most of the increases in hearing thresholds over the six-year span were at frequencies of 6 and 8 kHz, and the changes were similar for men and women (Gates and Cooper, 1991).

In the initial study of hearing loss progression from the BLSA, Brant and Fozard (1990) evaluated changes in hearing sensitivity for 813 men between 20 and 95 years of age over a 15-year interval. Of interest for the present study were findings for adults aged 50 years and older. In these older adults, Brant and Fozard documented mean changes in tone thresholds from 0.125 to 8 kHz over the 15-year test interval. In terms of changes in hearing levels with age, the authors noted that differences in thresholds across individual participants accounted for as much of the variance in thresholds as that represented by age. Further, variations in thresholds were greatest for the older age groups. Specific to the progression of hearing loss with age, Brant and Fozard reported that the rate of hearing loss across the 15-year interval in the older age groups was more rapid at the speech frequencies (0.5–3 kHz) than at 8 kHz. The rate of change in hearing loss was relatively constant at 8 kHz; the progression of hearing loss at speech frequencies increased markedly after 40–50 years of age. These findings are in contrast to those from the Framingham cohort; Gates and Cooper (1991) reported that among older participants in the Framingham Heart Study, hearing loss progression was generally greater at 6 and 8 kHz for both men and women.

Expanding on the report of Brant and Fozard (1990), Pearson and colleagues (1995) evaluated hearing loss progression in a group of BLSA men and women more rigorously screened for noise exposure, otologic disorders, and other selected risk factors. The Pearson and colleagues report was based on tone thresholds for 681 men and 416 women aged 20–90 years. The audiometric threshold data covered a period of up to 23 years for portions of the participant pool. A primary emphasis of this report was a comparison of hearing loss progression with age for men

and women. In a comparison of progression effects for men and women, Pearson and colleagues noted that changes in hearing level for earlier age decades were more than two times faster in men than in women. After age 60 years, however, the rates of increased hearing loss became similar across men and women. Also after age 60, hearing levels tended to plateau in the higher frequencies for men but continued to increase (worsen) for women. After age 80 years, the rate of increased hearing loss did not differ for men and women. Across older age groups, hearing sensitivity at 0.5 kHz was better for men than for women. The opposite was the case at higher test frequencies (>1 kHz); at higher test frequencies, hearing loss was greater for men than for women. Specific to men, the rate of increased hearing loss was greater for older men than for younger men, and the differences with age were greatest for higher test frequencies. These last two findings are in contrast to the Gates and Cooper (1991) report from the Framingham study.

In an extension of the Pearson and colleagues (1995) report, Morrell and colleagues (1996) provided cross-sectional and longitudinal data for a group of BLSA men and women rigorously screened for risk factors similar to the screening criteria used by Pearson and colleagues. The Morrell and colleagues report provides reference ranges and percentiles of hearing levels across age groups (30–80 years of age) over an approximate 15-year span for 456 men and 234 women from the BLSA. These data sets provide additional detail of the longitudinal effects reported earlier in the Pearson and colleagues (1995) article.

Unrelated to the three study groups mentioned above, Lee and colleagues (2005) reported changes in pure-tone thresholds for 188 older adults, 60–81 years of age, over a time span ranging from three to 11 years. Lee and colleagues reported faster rates of threshold change at higher frequencies for older women relative to those for older men. They also noted that the rate of threshold change at lower frequencies (0.25–2 kHz) was positively correlated with initial thresholds at higher frequencies.

Although the earlier studies reviewed provide useful preliminary data on the progression of age-related hearing loss, the populations studied were somewhat demographically restrictive and the number of

participants in older age groups (particularly 70 years and higher) was relatively small. Participants in the Framingham study, for example, were required to have no evidence of coronary heart disease (Moscicki et al, 1985; Gates et al, 1990); BLSA participants were generally more highly educated and from a higher socioeconomic status, and 93 percent reported their general health as good or excellent (Shock et al, 1984). The sample sizes for the Framingham, BLSA, and Lee and colleagues (2005) study groups were relatively small for older age categories of 70 years and higher (Shock et al, 1984; Brant and Fozard, 1990; Gates and Cooper, 1991). These and other characteristics of the earlier cohorts may, in part, be fundamental to the differences observed across studies in terms of hearing loss progression with age in both men and women. Further, there are no contemporary epidemiological studies that have reported findings on the changes in hearing sensitivity at specific audiometric frequencies in a large unscreened sample of older adults. This was the purpose of the present study. Specifically, we examined changes in hearing thresholds over a 10-year period in a population of older adults ranging in age from 48 to 92 years.

METHOD

Participants

Participants tested for the present study were individuals who had been tested previously in the Epidemiology of Hearing Loss Study (EHLS). Details regarding the original cohort and data on the prevalence and five-year incidence and progression of hearing loss have been published in earlier publications (Cruickshanks et al, 1998; Cruickshanks et al, 2003). In addition, the Cruickshanks and colleagues (1998) report provides detailed threshold-specific mean and variance data from the baseline examination. During 1987–1988, a private census was conducted to identify residents of the city or township of Beaver Dam, Wisconsin, aged 43–84 years, who were invited to participate in the Beaver Dam Eye Study, a study of age-related ocular disorders. Out of 5924 eligible people, 4926 participated in associated eye examinations from 1988 to 1990. Beaver Dam Eye Study participants (Linton et al, 1991; Klein et al, 1996) alive as of March 1, 1993, were eligible for the baseline examination for the EHLS

($n = 4541$), which occurred at the time of the five-year follow-up visit for the eye study. Of those eligible, 3753 (82.6%) participated (1993–1995), and 42.3 percent of the participants were men. The mean age of participants was 65.8 years (range 48–92 years).

A 2.5-year follow-up examination was conducted from 1995 to 1997 among those baseline participants who were aged 75 years or older as of June 1, 1995. Among the 898 who were eligible, 801 participated (89.2%), and 32.6 percent of the participants were men. The mean age of these participants was 82.0 years (range 75–94 years). A five-year follow-up examination among participants of all ages was conducted from 1998 to 2000 (Cruickshanks et al, 2003). Of the 3407 who were eligible, 2800 participated (82.2%), and 41.4 percent of the participants were men. The mean age at the five-year follow-up was 69.3 years (range 53–97 years). A 10-year follow-up examination was conducted from 2003 to 2005. Of the 2902 who were eligible, 2395 participated (82.5%), and 41.0 percent of the participants were men. The mean age at the 10-year follow-up was 72.7 years (range 58–100 years). The EHLS was approved by the applicable Human Subjects Committee of the University of Wisconsin–Madison. Informed consent was obtained from each participant at the beginning of the examinations.

Procedures

Behavioral air-conduction thresholds for tones were obtained in both ears of participants at audiometric frequencies of 0.25 through 8 kHz using a diagnostic audiometer (Virtual 320 or Grason-Stadler GSI 61). The same air-conduction thresholds were obtained at baseline, 2.5-year, 5-year, and 10-year examinations. Bone-conduction thresholds were obtained at 0.5 and 4 kHz during the baseline and 2.5-year examinations and at 0.5, 2, and 4 kHz for subsequent examinations. A conventional bracketing procedure (American Speech-Language-Hearing Association, 1978) was used for all threshold measures. The audiometers were calibrated every six months in accordance with appropriate American National Standards Institute (ANSI) standards (ANSI, 1989, 1996, 2004). Testing was completed in sound-treated test rooms that met standard requirements for the exclusion

of ambient noise from 0.5 through 8 kHz (ANSI, 1991, 1999). Because the test rooms did not always comply with ambient noise requirements at 0.25 kHz, data presented in this report are limited to 0.5–8 kHz test frequencies.

Statistical Analyses

Data analyses were completed on air-conduction thresholds at the baseline examination and at 2.5-, 5-, and 10-year examinations. Statistical analyses were completed with S-PLUS software (Insightful Corporation, Seattle; see Venables and Ripley, 2002). Smoothed curves summarizing relationships between thresholds (or changes in thresholds) and age were generated using the locally weighted least-squares curve-fitting technique (Chambers et al, 1983, pp. 180–188). When a participant was unable to hear a tone, the highest audiometer output level was recorded as the threshold. The impact of this assignment was likely minimal because the number of cases was small across test frequencies. Less than 1 percent of thresholds for 0.5–4 kHz, less than 2 percent for 6 kHz, and less than 4.5 percent for 8 kHz were affected. Further, this method obviated the need to exclude findings for participants with greater hearing loss. The relationship between baseline and 10-year thresholds was examined with generalized estimating equations (GEE) that account for the correlation between ears within subject (Hardin and Hilbe, 2002). The significance of the resulting estimated coefficients was tested with Z-tests, with a Bonferroni adjustment based arbitrarily on the number of frequencies examined (seven), yielding a significance level of $.05/7 = .0071$. In order to assess the effect of missing data, additional analyses estimated missing thresholds at 10 years based on the change in thresholds observed by five years (multiplied by two) or, if five-year thresholds were not available, based on the change in thresholds observed at 2.5 years (multiplied by four). These produced results that were similar to the analyses below and so are not given here. For the GEE models, to reduce the ceiling effect resulting from decibel levels that were close to the maximum output

of the audiometer, threshold data were excluded from the analyses for individuals whose thresholds were at or above 100 dB at baseline for 0.5, 1, 2, 3, or 4 kHz; whose thresholds were at or above 95 dB at baseline for 6 kHz; or whose thresholds were at or above 85 dB at baseline for 8 kHz.

RESULTS

Hearing Thresholds by Age Intervals

Figure 1 includes thresholds for all participants (and ears), men, and women. The smoothed curves represent both right and left ears for all four examinations (baseline, 2.5 years, 5 years, and 10 years). These data are based on a participant pool of 3625 unique participants and 7242 unique ears. To our knowledge this is the largest published longitudinal collection of audiometric thresholds for the same population of older adults. The plots demonstrate increases in thresholds with age, with the slope of the curves generally being steeper with higher frequencies and advancing age. After approximately 80 years of age, the rate of change in thresholds begins to slow for the higher frequencies (6 and 8 kHz). The general finding of greater absolute hearing loss for men relative to women and for higher frequencies relative to lower frequencies at all ages from 48 years and up reported in past studies (Cruickshanks et al, 1998; Cruickshanks et al, 2003) is evident in the cumulative thresholds across the 10-year examination period. Differences in the oldest age displayed in these and subsequent figures are due to differences in the oldest participants tested for women versus men and in the specific participants tested for different examination periods.

Changes in Thresholds over the 10-Year Examination Period

Figure 2 includes smoothed curves of 10-year threshold changes for all participants, men, and women. These plots include data for both ears but for only baseline and 10-year examinations, representing 2130 unique participants and 4201 unique ears. Threshold increases are apparent at all frequencies and ages, but less change was observed for higher frequencies in older participants than for lower frequencies. The opposite was true for younger participants. This is

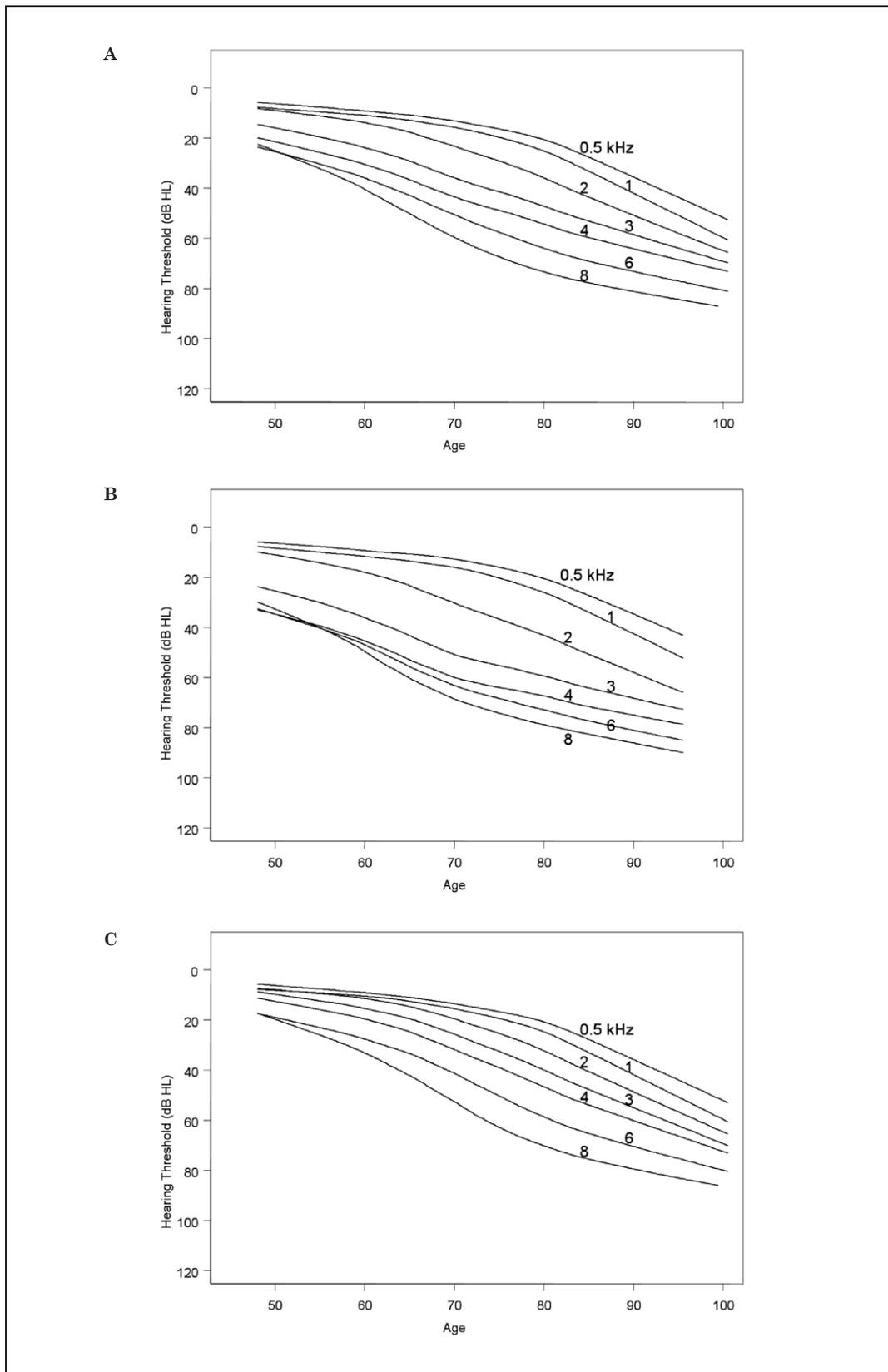


Figure 1. Hearing thresholds (smoothed curves) for baseline, 2.5-year, 5-year, and 10-year examinations. Thresholds are in dB HL and include all ears from the four examinations. The parameter is test frequency in kHz. Panel A includes thresholds for all participants, and the plot is based on data for 3625 participants and 7242 ears. Panel B includes thresholds for men, and the plot is based on data for 1559 participants and 3112 ears. Panel C includes thresholds for women, and the plot is based on data for 2066 participants and 4130 ears.

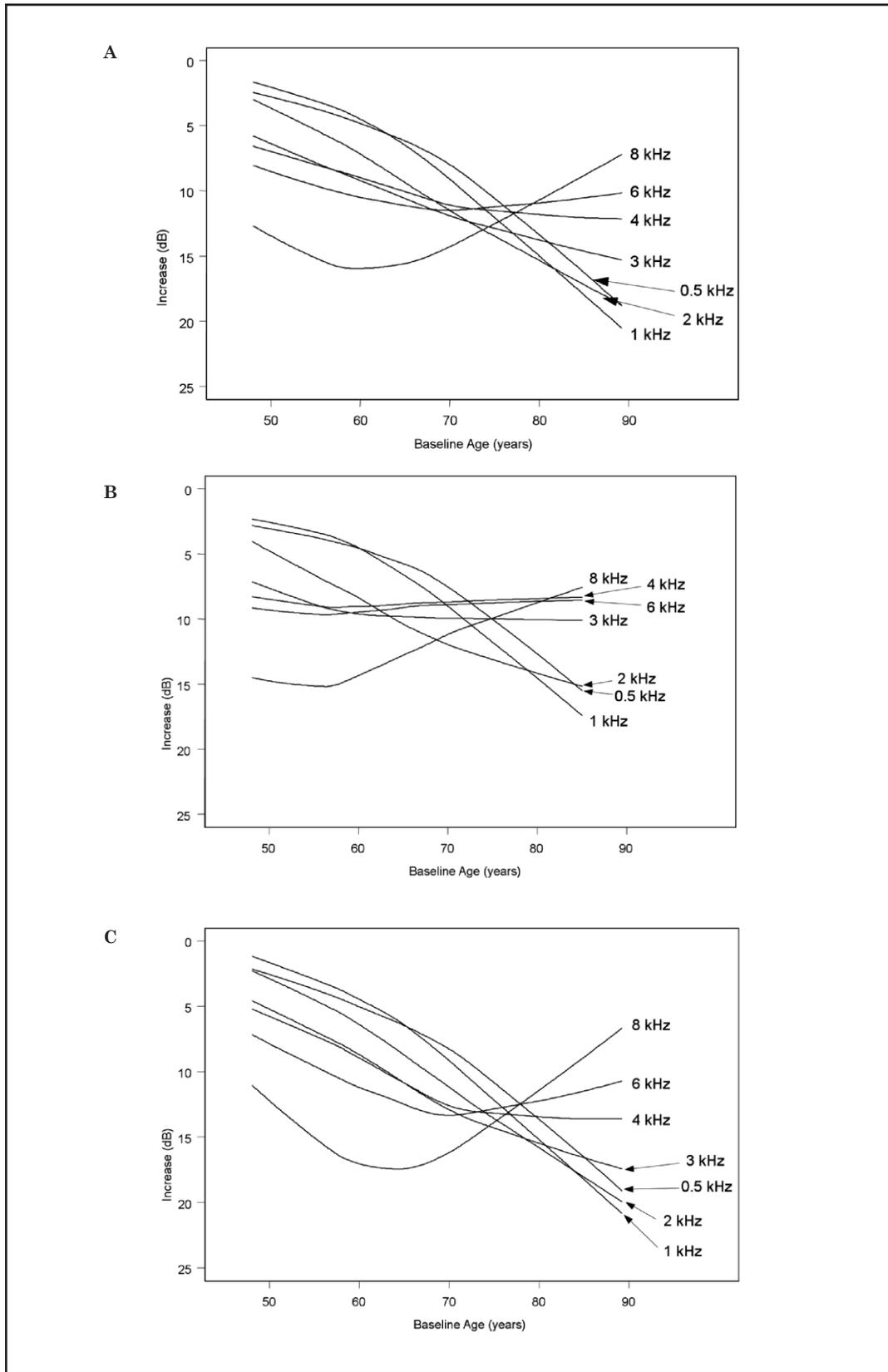


Figure 2. Increase in hearing thresholds (smoothed curves) over 10 years. Increase is the difference in threshold (in dB) between baseline and 10-year examination measures. The parameter is test frequency in kHz. Panel A includes data for all participants, and the plot is based on data for 2130 participants and 4201 ears. Panel B includes data for men, and the plot is based on data for 899 participants and 1769 ears. Panel C includes data for women, and the plot is based on data for 1231 participants and 2432 ears.

likely due to the greater hearing loss at baseline in higher frequencies for older adults. Given the higher thresholds for older adults at higher frequencies, there is a smaller range for change before the

limits of the audiometer are reached. This ceiling effect at higher frequencies is illustrated in Figure 3. This figure includes the percent of ears in specific age groups with thresholds greater than 60 dB HL at

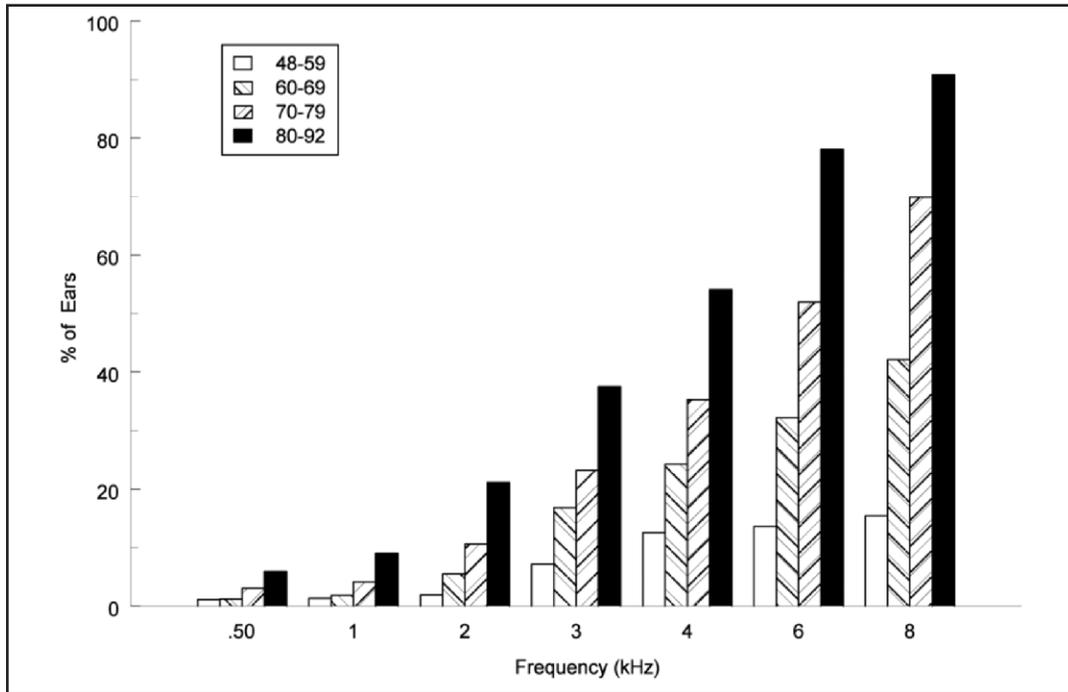


Figure 3. Percentage of baseline thresholds greater than 60 dB HL for specific age groups (48–59, 60–69, 70–79, 80–92 years of age). The plot is based on data for 3558 participants (7105 ears).

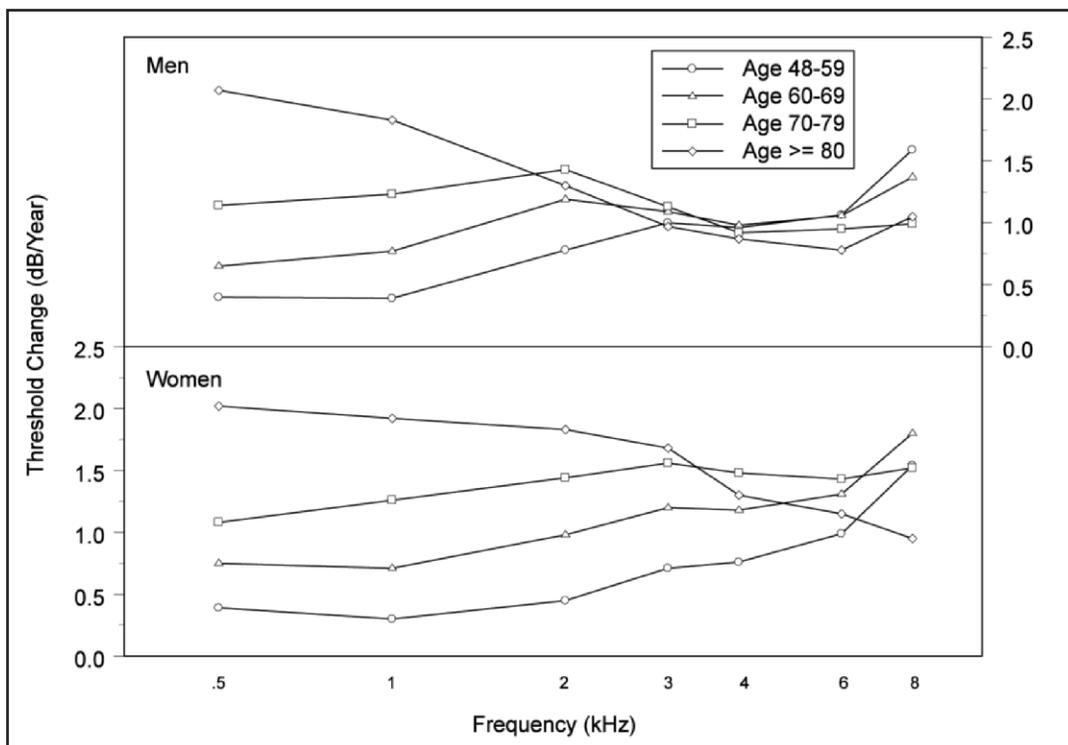


Figure 4. Mean rate of change in hearing thresholds (dB per year) over 10 years for men (upper panel) and women (lower panel). The circles, triangles, rectangles, and diamonds represent data for age groups of 48–59 years, 60–69 years, 70–79 years, and ≥80 years, respectively.

each test frequency. For the oldest participants, the percentage of such thresholds exceeded 80 percent at 6 and 8 kHz. At 8 kHz, for example, more than 90 percent of participants in the 80–92 years age group had a hearing threshold >60 dB HL at baseline. Because the maximum output of the audiometers was 100 dB HL at that frequency, the dynamic range for potential change in threshold was quite small.

At frequencies of 0.5, 1, 2, and 8 kHz, the pattern of 10-year changes in thresholds across audiometric frequencies was generally similar for men and women. The pattern of threshold change at 3 kHz differed for men and women. The change in thresholds at 3 kHz was relatively constant from 60 through 79 years of age for men. In women, the change in threshold at 3 kHz generally increased directly with age, similar to the pattern of decline observed for lower frequencies. Threshold changes at 4 and 6 kHz were relatively constant for all ages in men across the 10-year examination period. In women, changes in thresholds at 4 and 6 kHz increased for the 48–69 years age range and then tended to level off.

Rate of Change in Thresholds

The rate of change in thresholds for men and women in specific age groups is illustrated in Figure 4. For both men

and women, younger age groups evidenced greater rates of threshold change for higher frequencies. The difference in rate of change for lower and higher frequencies decreased with increasing age. For the oldest groups of men and women, the rate of change in threshold was greatest for lower frequencies. As an example, the rate of change in thresholds for 48- to 59-year-old men was approximately 0.4 dB per year at 0.5 kHz and approximately 1.6 dB per year at 8 kHz. In the case of men ≥80 years of age, the rate pattern was reversed; rate of change was approximately 2.1 dB per year at 0.5 Hz and a little over 1 dB (1.05) per year at 8 kHz. These same patterns held for the same age groups of women as well.

Baseline and 10-Year Threshold Relations

Linear regression models were used to determine predictors of 10-year thresholds. Table 1 includes estimated linear regression coefficients from GEE models associated with 10-year hearing thresholds. The total number of ears represented by each model was 4188, 4188, 2425, 1758, 4180, 4171, 4128, and 3978 for 0.5, 1, 2 (female), 2 (male) 3, 4, 6, and 8 kHz, respectively. Included in the models were baseline thresholds, baseline age, gender, age squared, and an age/gender interaction term. The model for 2 kHz is stratified by

Table 1. Estimated Linear Regression Coefficients for Predicting 10-Year Hearing Thresholds from Baseline Thresholds

10-Year Frequency	Intercept	Baseline Predictors									(Age) ²	Age: Gender
		0.50	1	2	3	4	6	8	Age	Gender		
0.50	-18.3712	0.7081	0.2560	0.0367	-0.0027	0.0308	-0.0116	0.0231	0.3408	-0.6271	0.0134	-0.0012
1	-17.9047	0.0537	0.8591	0.1507	0.0303	-0.0069	-0.0031	0.0345	0.3275	1.1965	0.0088	-0.0286
2	-18.5630	-0.0289	0.1653	0.7376	0.1390	0.0177	0.0240	0.0385	0.3815	F	0.0006	NA
	-7.5120	0.0280	0.0434	0.7273	0.2928	-0.0207	-0.0968	0.0955	0.2147	M	-0.0048	NA
3	-3.7092	-0.0313	0.1186	-0.0317	0.6613	0.2188	-0.0156	0.0845	0.2042	9.5015	-0.0038	-0.1483
4	2.7223	-0.0270	0.0785	-0.0057	0.0136	0.6798	0.1291	0.0894	0.1445	11.7057	-0.0062	-0.1647
6	8.2190	-0.0696	0.1095	-0.0160	-0.0462	0.2004	0.4257	0.3119	0.1169	6.4971	-0.0079	-0.0992
8	11.9870	-0.0637	0.1391	-0.0217	-0.0356	0.1053	-0.0402	0.7236	0.2541	7.7949	-0.0185	-0.1180

Note: The units for all thresholds are dB HL, the units for frequency are kHz, and the unit for age is years. Gender is male (M) versus female (F) except for 10-year frequency at 2 kHz, which is stratified by M and F separately. Estimated coefficients that are significant at the .0071 level (the nominal two-sided .05 significance level adjusted using the Bonferroni method for a sevenfold multiplicity of comparisons) are in boldface. The total number of ears represented by the models at 0.5, 1, 2 (F), 2 (M), 3, 4, 6, and 8 kHz is 4188, 4188, 2425, 1758, 4180, 4171, 4128, and 3978, respectively.

men and women because there was a statistically significant interaction between baseline threshold and gender for this frequency. Using the 10-year threshold at 1 kHz as an example, other than age and gender effects, we found that this threshold was predicted primarily by the 1 kHz threshold at baseline and, second, by the threshold at the next higher frequency (2 kHz) at baseline. With the exception of 2 kHz for women, this pattern was observed for the other 10-year thresholds as well. A separate analysis was conducted in which missing 10-year thresholds were estimated as described earlier. The total number of ears represented by each model in this analysis was 5726, 5723, 3328, 2387, 5712, 5689, 5626, and 5444 for 0.5, 1, 2 (female), 2 (male) 3, 4, 6, and 8 kHz, respectively. The results in terms of significant coefficients for each frequency were the same as those displayed in Table 1, suggesting that loss to follow-up is not a primary reason for the observed patterns.

DISCUSSION

Age and Gender Differences

Threshold changes over a 10-year examination period in older adults indicated increases in hearing loss across all frequencies. The frequencies at which threshold changes were greatest depended on the age of participants. For the 48–59 and 60–69 years age groups, for example, threshold changes were largest at higher frequencies (3–8 kHz). For the older age decades (≥ 80 years), the greatest changes in thresholds were noted for lower frequencies (0.5–2 kHz). As noted earlier, the smaller changes in threshold observed at higher frequencies are likely due to the greater baseline hearing loss at higher frequencies for the older adults. Accordingly, the dynamic range for potential change was reduced at higher frequencies. Similarly, the greater change in thresholds with increasing age for women relative to men at 2 and 3 kHz may be due to the greater hearing loss at baseline for men. Accordingly, there was less available to lose in terms of male thresholds. The greater degree of hearing loss for higher frequencies in men versus women is consistent with earlier reports (Moscicki et al, 1985; Gates et al, 1990; Gates and Cooper, 1991; Pearson et al, 1995; Cruickshanks

et al, 1998; Cruickshanks et al, 2003). The increased prevalence of noise exposure among male participants for the present study may account for portions of the differences in hearing loss at higher frequencies.

It is difficult to compare the findings for the present study directly with those from earlier studies due to differences in sample size, age ranges, the time span over which thresholds were compared, and characteristics of the participants included in the analyses. These differences surely contribute to observed variations in findings across studies, some of which were reviewed above. There are some similarities in the present findings and those of previous studies. The general pattern of increasing hearing loss with age, greater hearing loss in the high frequencies across older age groups, and the slowing of threshold changes in older age groups at higher frequencies (e.g., 8 kHz) was noted earlier by Gates and Cooper (1991), Brant and Fozard (1990), and Pearson and colleagues (1995). At the same time, there are clear disparities in the current findings relative to earlier reports. Using the same earlier reports as examples, Gates and Cooper (1991) report that threshold changes were greater for women than for men at all frequencies. This was not the case in the current study. Further, the changes in thresholds for men and women over the 10-year examination period varied complexly across age and frequency. Brant and Fozard (1990) report that by age 70 the greatest rate of threshold change was in the speech frequencies and 3 kHz, not for higher frequencies. This finding was consistent with findings for older participants in the current study, with the exception of changes at 3 kHz. The change in thresholds at 3 kHz for men over 70 years of age was relatively constant and in contrast to the pattern of change for women. Similarly, Pearson and colleagues (1995) report that above 30 years of age, men had better thresholds than women at 0.5 kHz; this was not the case in the current study.

Rate of Change in Thresholds over 10 Years

Younger age groups evidenced greater rates of threshold change for higher frequencies; the absolute difference in rate of change for lower and higher frequencies

decreased with increasing age. For the oldest groups of men and women, the rate of change in threshold was greatest for lower frequencies. These general patterns also are reported by Lee and colleagues (2005). It should be noted, however, that the age groupings and the specific rate values at specific audiometric frequencies differ for the Lee and colleagues report and the current study. The patterns observed for rate of change in dB per year in the current study are not particularly consistent with those of Pearson and colleagues (1995). In the case of 70-year-old men, for example, Pearson and colleagues note that the rate of change generally increased with increases in audiometric frequency from 0.5 to 8 kHz. In the current study, the rate of change in thresholds for 70- to 79-year-old men was relatively flat across the same audiometric frequencies.

Baseline Predictors of Hearing Loss Progression

Based on linear regression models, other than age and gender the best predictor of hearing threshold after 10 years of follow-up at a specific audiometric frequency in the present study was the baseline threshold at that same frequency. The next best predictor was the baseline threshold at the next highest test frequency. Lee and colleagues (2005) report that the rate of threshold change at lower frequencies (0.25–2 kHz) was positively correlated with initial thresholds at higher frequencies. This is not generally consistent with results from the present study. The best predictors of 10-year changes in threshold for lower frequencies (0.5 and 1 kHz) were the baseline threshold at the same frequency and the baseline threshold at the next highest frequency. The differences in findings may well be related to the difference in sample sizes for the two studies as well as the more limited age range sampled in the Lee and colleagues study.

SUMMARY AND CONCLUSIONS

The present study documents 10-year changes in auditory thresholds for a large unscreened population of older adults. Thresholds, changes in thresholds, rate of change in thresholds, and baseline measurement predictors of 10-year thresholds are

reported for specific age groups and for men and women. For earlier age decades (50–60 years), threshold changes over 10 years were largest at higher frequencies (3–8 kHz); for older participants (≥ 80 years), the greatest changes in thresholds occurred for lower frequencies (0.5–2 kHz). This same general pattern with age also was observed for the rate of change in thresholds over 10 years. Specifically, younger age groups (both men and women) demonstrated faster rates of threshold change for higher frequencies, and older groups demonstrated faster rates of threshold change for lower frequencies. Although the pattern of 10-year changes in thresholds from 50 to 80 years of age was similar for men and women at lower frequencies (0.5–1 kHz), patterns differed for men and women across the same age range at 3–4 kHz. Other than age and gender, the best baseline examination predictor of 10-year thresholds at a specific audiometric frequency was the baseline threshold at that frequency; the second best predictor was generally the baseline threshold for the next highest test frequency.

Our findings document the continuing decline in hearing thresholds with advancing age. For younger age groups (e.g., 50–60 years of age), the changes in thresholds are greatest at higher frequencies, with less hearing loss for lower frequencies. However, the rate of change in thresholds for the lower-frequency region, including frequencies important for hearing and understanding speech, increases for older age ranges (70–89 years of age). This has clear clinical implications in terms of the increased numbers of older people who may experience problems understanding speech in everyday situations and who require appropriate audiologic intervention. The typical progression of hearing loss with advancing age indicates a need for educational programs regarding the risk for age-related hearing loss and the importance of audiologic referral for older adults experiencing hearing difficulties. Indeed, the time may be overdue for implementation of hearing screening programs for all older adults given the growing number of persons over the age of 65 years, the number of such persons who may be expected to present with significant hearing loss, and the typical progression of hearing loss with advancing age.

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