Hearing Sensitivity in Adults Screened for Selected Risk Factors

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Abstract
As a means of partially distinguishing age effects and other risk factors in presbyacusis, hearing thresholds for 56- to 65-year-old participants screened for exclusion of selected risk factors were compared with thresholds for 48- to 55-year-old participants without the same risk factors. Hearing thresholds for both age groups were also compared with age-appropriate International Standards Organization (ISO) norms. Even after screening participants for exclusion of selected risk factors, differences in hearing sensitivity remained across age groups. Across the male and female groups, thresholds were generally better (lower) for 48 to 55 year olds than for 56 to 65 year olds. ISO norms generally underestimated the degree of hearing loss for participants of comparable age in the present study. The underestimation was small at lower test frequencies, was greater for 56 to 65 year olds, and was largest at test frequencies above 2000 Hz.

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

Abbreviations: ANSI = American National Standards Institute, EHLS = Epidemiology of Hearing Loss Study, ISO = International Standards Organization

Presbyacusis is a most prevalent problem in older adults. According to the National Institute on Aging, “About one-third of Americans between age 65 and 74 and one-half of those age 85 and older have hearing problems” (NIA, 1999). Further, the number of individuals 65 years old and over in the United States will reach approximately 70 million by 2030, and those 85 years old and over currently constitute the fastest growing portion of the population (US Bureau of the Census, 1998). Based on these population demographics and on published prevalence studies, there will be an increasing number of older adults in the United States with significant hearing loss (e.g., Moscicki et al, 1985; Gates et al, 1990; Cruickshanks et al, 1998b).

Several investigators have documented the decrease in hearing abilities with advancing age (e.g., Bunch, 1929; Corso, 1963; Moller, 1981; Waudby, 1984; Moscicki et al, 1985; Brant and Fozard, 1990; Gates et al, 1990; Cruickshanks et al, 1998b). What is not clear, however, is whether age-related hearing loss is solely a result of aging, a consequence of environmental effects and other factors, or a combination of influences. A well-documented environmental influence on age-related hearing loss, for example, is the deleterious effect of excessive noise exposure (Rosenhall et al, 1990; Cruickshanks et al, 1998b; Mills et al, 1998). The hearing loss observed in many older adults, particularly men, represents the combined influence of age and noise exposure, and it is difficult to separate the contributions of each. As Mills et al (1998) have noted, “the allocation of a hearing loss in an older individual into a noise component and an aging component is not straightforward” (p. 121).

A complete understanding of the underlying determinants of presbyacusis is, in part, dependent on data and observational analyses that distinguish aging effects and other factors...
have been identified include cardiovascular disease, smoking, and a familial history of hearing impairment. The first two factors (cardiovascular disease, smoking) are likely linked through a generalized compromise of cardiovascular systems basic to the integrity of the human auditory system (Johnsson and Hawkins, 1972; Makishima, 1978; Cruickshanks et al., 1998a). Rosen and Olin (1965) found that 40- to 59-year-old individuals without cardiovascular disease had better hearing sensitivity than individuals of the same age with cardiovascular disease. Susmano and Rosenbush (1988) reported that after adjusting for a number of confounding variables (e.g., age, gender, hypertension, cigarette smoking), the probability of an individual with ischemic heart disease having hearing loss was eight times greater than that for individuals of the same age without heart disease. Rubinstein et al. (1977) found that 65- to 85-year-old adults with cardiovascular disease and signs of peripheral circulation impairment had significantly greater hearing loss than people of the

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same age without cardiovascular disease. Based on histologic studies of temporal bones and brain sections from older adults with hypertension, Makishima (1978) noted a positive correlation for the degree of narrowing of the internal auditory artery and the degree of spiral ganglion atrophy and hearing loss. Gates et al (1993) reported a significant association between cardiovascular disease and audiometric thresholds in the Framingham cohort of older adults. Finally, Cruickshanks et al (1998a) reported that older adults who were smokers were approximately twice as likely to have a hearing loss as nonsmokers of a similar age. A similar association between cigarette smoking and hearing loss has also been reported by others (NCHS, 1967; Siegelaub et al, 1974).

Another primary risk factor for age-related hearing loss is a significant family history of hearing impairment (Cruickshanks KJ, unpublished data, 1999; Gates et al, 1999). Results from the Framingham Heart Study (Gates et al, 1999) suggested that "a clear familial aggregation occurs for age-related hearing levels" (p. 654). The familial relation, however, was considerably stronger for sibling-sibling and mother-child comparisons than for father-child comparisons, suggesting that the relation between genetic/hereditary factors and other risk factors is not entirely clear, particularly in men. The higher prevalence of excessive noise exposure in men may have confounded father-child comparisons.

As a means of partially distinguishing age effects and other risk factors in presbyacusis, the present study was aimed at an examination of hearing sensitivity in older adults who did not present with previously identified risk factors (otologic disorder, middle ear dysfunction, noise exposure, cardiovascular disease, history of ototoxic drug ingestion, smoking, family history of hearing loss) for hearing loss in older adults. The basic assumption was that whatever residual hearing loss was observed would be attributed to the aging process and other factors (e.g., environmental or genetic components) not accounted for in the analysis model. Certainly, given our present state of knowledge regarding the potential determinants of presbyacusis, it is not possible to control for or even identify all factors that may underlie hearing loss with age. However, evaluation of auditory effects for known risk factors in presbyacusis extends our knowledge of age effects apart from other influences. This is important because the outcomes of such research may enable segregation of hearing loss attributable to risk factors that can be avoided or prevented in future generations of older adults.

The purposes of the present study, then, were to examine hearing sensitivity in a cohort of adults free of the previously identified risk factors and to compare auditory thresholds for the same cohort with age-appropriate norms. All participants who were between 48 and 65 years of age in the Epidemiology of Hearing Loss Study (EHLS) (Cruickshanks et al, 1998b) and who, based on diagnostic measures and self-report, did not present with any of the identified risk factors were included in the analyses. For the purposes of age group analyses, participants were assigned to one of two age groups: 48 to 55 years of age and 56 to 65 years of age. The selected age range of 56 to 65 years was based primarily on sample size concerns. This range included the oldest group of participants from the EHLS pool without the identified risk factors that offered a reasonable sample size for evaluation. The two age groups selected also enabled comparison of thresholds for the 48- to 55-year-old and 56- to 65-year-old EHLS groups with International Standards Organization (ISO) (ISO, 1984, 1990) age-appropriate threshold norms for persons 50 and 60 years of age, respectively. Two primary comparisons of hearing sensitivity were used as a means of determining residual effects (including age) apart from the identified risk factors: (1) comparison of auditory thresholds for the 56- to 65-year-old EHLS group with thresholds for participants from the EHLS pool who were aged 48 to 55 years and also did not present with any of the identified risk factors and (2) comparison of auditory thresholds for the 48- to 55-year-old and 56- to 65-year-old EHLS groups with thresholds for adults (50 and 60 years of age, respectively) who were "otologically normal" and "highly screened"—supposedly representative of persons having age-appropriate hearing sensitivity apart from environmental influences (noise) (ISO, 1984, 1990). The two sets of threshold comparisons were designed to evaluate the presence/absence and magnitude of residual effects, apart from the influences of the identified risk factors, based on different age and population referents.

METHOD

Participants

The analysis group for the present study was comprised of 355 participants (269 women, 86
men) aged 48 to 65 years in the baseline examination of the population-based study of hearing loss in older adults, the EHLS. For the purposes of data analyses, the participant data were assigned to two age groups: 48 to 55 years of age (118 women, 47 men) and 56 to 65 years of age (151 women, 39 men). Approximately 99 percent of the participants were non-Hispanic white. Further details regarding the study population, including the prevalence and degree of hearing loss for the entire group of study participants, have been provided in earlier reports (Klein et al, 1992; Cruickshanks et al, 1998b; Nondahl et al, 1998; Wiley et al, 1998).

The criteria for exclusion of risk factors for selected participants were based on audiologic measures or on self-report responses obtained from an interview. All participants chosen reported a negative history of otologic disorder (including any past history of otic surgery) and a negative history of the identified risk factors. A history of noise exposure was defined as having had a full-time job for which speaking in a raised voice or louder was necessary to be heard within 2 feet of a person; having driven a tractor, at least half the time without a cab enclosure; or having worked in the military in front-line warfare, in a tank or plane, in the engine room of a ship, using heavy artillery, or on weapons ranges at least seven times in a year. A history of cardiovascular disease was defined as reporting that a physician had told them that they had experienced a stroke, a myocardial infarction, or angina. Persons who reported any history of ototoxic drug (aminoglycosides, cancer-treating drugs) use were excluded from the analyses. To be classified as having a history of smoking, a person had to have smoked at least 100 cigarettes in his or her lifetime. A family history of hearing loss was defined as either parent having developed a hearing loss before the age of 60 or a sibling having a hearing loss at any age. Abnormal middle ear function was considered to be present if (1) an air–bone gap (≥ 15 dB) was detected at 500 or 4000 Hz in either ear; (2) the tympanogram showed a flat or severely reduced peak-compensated static acoustic admittance (peak \( Y_{\text{rm}} \) ≤ 0.1 acoustic mmhos), high peak \( Y_{\text{tm}} \) (≥ 3.0 acoustic mmhos), or an equivalent ear canal volume \( V_{\text{re}} \) ≥ 3.0 cm³; or (3) the examiner reported evidence on otopscopic evaluation of drainage, a bulging or retracted eardrum, a visible air–liquid line, or a perforated eardrum.

**Procedures**

Audiometric air-conduction thresholds for tones of 500 through 8000 Hz and bone-conduction thresholds at 500 and 4000 Hz were determined for each participant in one test session on the same day. Behavioral air-conduction thresholds for tones were obtained using a diagnostic audiometer (Virtual, 320). A conventional bracketing procedure (ASHA, 1978) was used for all threshold measures. The audiometer was calibrated in accordance with appropriate American National Standards Institute (ANSI) standards (ANSI, 1989, 1996). All testing was performed in sound-treated rooms meeting ANSI standards for ambient background noise (ANSI, 1991).

**RESULTS**

As noted earlier, a primary purpose of the present study was to examine hearing sensitivity in a cohort of older adults free of the identified risk factors (otologic disorder, middle ear dysfunction, ototoxic drugs, noise exposure, cardiovascular disease, smoking, family history of hearing loss). In the examination of residual effects (including age), signal frequency and gender were variables in each comparative analysis. Data comparisons for EHLS groups were based on mean thresholds for age groups and gender. Median thresholds were used in comparison of EHLS data with ISO age norms; only median norms are provided in the ISO age profiles (ISO, 1984, 1990). Statistical analyses were restricted to comparisons of EHLS data and were based on t-tests using an alpha level of .05.

**Age and Gender Comparisons (EHLS Data)**

Residual effects were examined through comparisons of auditory thresholds for the 56- to 65-year-old EHLS group and for EHLS participants who were 48 to 55 years of age and also did not present with any of the identified risk factors. Mean thresholds for both age groups are included in Table 1; Table 2 includes summary statistics for the data comparisons.

**Age**

Among women, the thresholds for 48- to 55-year-old women were significantly lower than those for 56- to 65-year-old women at all test fre-
Table 1  Threshold Data (dB HL) for Participants in the Present Study

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>6000</th>
<th>8000</th>
</tr>
</thead>
<tbody>
<tr>
<td>48 to 55 year olds Man (n = 47) Mean</td>
<td>7.3</td>
<td>9.4</td>
<td>13.9</td>
<td>26.3</td>
<td>35.0</td>
<td>39.8</td>
<td>38.6</td>
</tr>
<tr>
<td>SD</td>
<td>7.2</td>
<td>6.2</td>
<td>13.5</td>
<td>20.6</td>
<td>22.0</td>
<td>21.2</td>
<td>23.4</td>
</tr>
<tr>
<td>Median</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>35</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td>Women (n = 118) Mean</td>
<td>8.8</td>
<td>11.5</td>
<td>11.7</td>
<td>13.6</td>
<td>17.6</td>
<td>25.3</td>
<td>27.7</td>
</tr>
<tr>
<td>SD</td>
<td>9.0</td>
<td>11.2</td>
<td>12.2</td>
<td>12.7</td>
<td>14.2</td>
<td>16.2</td>
<td>18.9</td>
</tr>
<tr>
<td>Median</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>56 to 65 year olds Man (n = 39) Mean</td>
<td>12.6</td>
<td>14.7</td>
<td>19.5</td>
<td>33.2</td>
<td>43.2</td>
<td>48.6</td>
<td>49.5</td>
</tr>
<tr>
<td>SD</td>
<td>10.1</td>
<td>9.5</td>
<td>15.4</td>
<td>21.2</td>
<td>22.9</td>
<td>21.4</td>
<td>20.5</td>
</tr>
<tr>
<td>Median</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>25</td>
<td>35</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Women (n = 151) Mean</td>
<td>12.5</td>
<td>15.3</td>
<td>17.1</td>
<td>20.7</td>
<td>26.6</td>
<td>36.2</td>
<td>41.7</td>
</tr>
<tr>
<td>SD</td>
<td>15.9</td>
<td>15.8</td>
<td>16.3</td>
<td>17.5</td>
<td>19.2</td>
<td>20.7</td>
<td>21.8</td>
</tr>
<tr>
<td>Median</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td>25</td>
<td>30</td>
<td>35</td>
</tr>
</tbody>
</table>

The absolute difference in mean threshold across the female groups increased with increases in signal frequency, ranging from 3.7 to 14 dB. In the case of men, the 48 to 55 year olds had significantly lower mean thresholds than those for 56 to 65 year olds at 500, 1000, and 8000 Hz (Fig. 1B). The absolute differences in mean thresholds

Table 2  Summary Statistics (t-tests) for Age and Gender Comparisons

<table>
<thead>
<tr>
<th>Dependent Variable (Hz)</th>
<th>48 to 55 Year Olds</th>
<th>56 to 65 Year Olds</th>
</tr>
</thead>
<tbody>
<tr>
<td>df</td>
<td>t</td>
<td>p Value</td>
</tr>
<tr>
<td>500</td>
<td>245</td>
<td>-2.40*</td>
</tr>
<tr>
<td>1000</td>
<td>265</td>
<td>-2.31*</td>
</tr>
<tr>
<td>2000</td>
<td>267</td>
<td>-3.13*</td>
</tr>
<tr>
<td>3000</td>
<td>266</td>
<td>-3.85*</td>
</tr>
<tr>
<td>4000</td>
<td>266</td>
<td>-4.42*</td>
</tr>
<tr>
<td>6000</td>
<td>266</td>
<td>-4.85*</td>
</tr>
<tr>
<td>8000</td>
<td>267</td>
<td>-5.53*</td>
</tr>
</tbody>
</table>

Age groups were 48 to 55 years and 56 to 65 years. For each t-test, an F (folded) statistic was computed to test for equality of the two variances (Steel and Torrie, 1980). In cases for which the null hypothesis of equal variances was rejected, Satterthwaite's (1946) approximation was used to compute the degrees of freedom associated with the approximate t.

*Significant at .05
Figure 1  

A. Mean audiometric thresholds for the two groups of women in the present study. The filled squares (■) are data for the 48 to 55 year olds; the open circles (○) represent thresholds for the 56 to 65 year olds. B. Mean audiometric thresholds for the two groups of men in the present study. The filled squares (■) are data for the 48 to 55 year olds; the open circles (○) represent thresholds for the 56 to 65 year olds. C, Mean audiometric thresholds for the 48 to 55 year olds in the present study. The filled squares (■) are data for men and the open circles (○) represent thresholds for women. D, Mean audiometric thresholds for the 56 to 65 year olds in the present study. The filled squares (■) are data for the men and the open circles (○) represent thresholds for women.

by male age group at these test frequencies were 5.3, 5.3, and 10.9 dB, respectively.

**Gender**

Overall, mean thresholds for men were significantly higher than those for women at frequencies of 3000 through 8000 Hz. This was the case for both age groups (Figs. 1C and 1D). The differences in mean thresholds at frequencies 3000 through 8000 Hz for the male and female groups ranged from 10.9 to 17.4 dB for 48 to 55 year olds and from 7.8 to 16.6 dB for 56 to 65 year olds.
Comparisons with ISO Age Norms

These analyses involved comparisons of auditory thresholds for the 48- to 55-year-old and 56- to 65-year-old EHLS groups, with those for ISO adults (50 and 60 years of age, respectively) having age-appropriate hearing sensitivity apart from environmental influences (noise) (ISO, 1990). As noted earlier, comparisons of thresholds with ISO norms were limited to descriptive comparisons based on median thresholds for age groups. No cell sizes or appropriate variance measures are provided in the ISO standard for further statistical analyses.

Overall, ISO norms tended to underestimate the degree of hearing loss for both age groups in the present study. The degree of underestimation, however, differed for age groups and for men and women. ISO median thresholds for men were consistently better (lower) than those for men in the present study, particularly at higher test frequencies (above 2000 Hz) (Figs. 2A and 2B). This was the case for the 50- and 60-year-old men, and the differences at higher frequencies were greater for the 50 year olds (Fig. 2A). For both groups of men, differences in median thresholds relative to ISO medians were less than 5 dB at frequencies below 3000 Hz. Median thresholds for women in the present study were generally higher than those in the ISO standard, but the differences were smaller than those observed for men (Figs. 2C and 2D). The absolute difference in median thresholds relative to ISO medians ranged from 1 to 9 dB across all frequencies and both women groups.

**DISCUSSION**

**Age and Gender**

Relative to the presence and extent of age-related hearing loss, the differences in hearing sensitivity remained across age groups, even after screening participants for exclusion of selected risk factors. Some of the observed differences in thresholds, particularly at lower test frequencies, were small and, although statistically significant, are likely within expected clinical variability for threshold audiometry. This was typically not the case at higher frequencies, however, and across the male and female groups, thresholds were consistently better (lower) for 48 to 55 year olds than for 56 to 65 year olds. In evaluating residual effects, it should be noted that the thresholds for men and women in the present study were consistently lower than those for unscreened participants of similar age in the total EHLS population (Cruickshanks et al., 1998b). Also, data for common age groups in the unscreened EHLS population are in good agreement with those from the Framingham study (Gates et al., 1990). Specific to the present study, Cruickshanks et al. (1998b) provided graphic comparison of thresholds for men and women 60 to 64 years of age from the EHLS and Framingham studies. This comparison indicated "no evidence of threshold differences" in the two studies (Cruickshanks et al., 1998b, p. 881). Overall, then, findings from the present study suggest that the risk factors evaluated in the present study account for part, but not all, of the age-related changes in hearing sensitivity. This is an important outcome to the extent that the specified risk factors can be eliminated or reduced in future generations of older adults. The implication is that the prevention or reduction of such risk factors would be associated with reductions in the prevalence and degree of age-related hearing loss among older adults.

The finding of differences in thresholds across age groups after screening participants for the selected risk factors suggests that additional factors (including age) also contribute to the observed differences. The overall finding that the selected risk factors did not account for all of the differences in hearing sensitivity across age groups may be attributable to several factors, and these factors may well be complexly interrelated. On the surface, the presence of an age effect apart from other factors is at least partially supported. Differences in hearing sensitivity across age groups remained after factoring out the selected risk factors. Alternatively, it could be argued that the screening techniques used to identify risk factors were not entirely effective in ruling out the specified risk. Differences in thresholds for men and women, for example, were significant only at frequencies from 3000 to 8000 Hz. This frequency range corresponds with that most typical of hearing loss in persons exposed to excessive environmental noise. Further, it is clear that the prevalence of excessive noise exposure is greater for male than for female participants. Accordingly, the finding may indicate that the self-report interview technique used was not entirely successful in eliminating individuals (particularly men) who experienced significant noise exposure. Indeed, as noted in the introduction, this may be very difficult to accomplish in any sizable sample of adult participants. The criteria used for noise exposure were aimed primarily at occu-
pational and military noise exposure; accordingly, some participants may have experienced other forms of noise exposure that influenced auditory thresholds for higher frequencies. In other reports from the EHLS, for example, significant hearing loss has been observed for older adults who participate in recreational and leisure-time activities that involve significant noise exposure (Nondahl et al., 2000; Dalton et al., 2001). Also, participants may have under-reported their noise exposure history.

It is possible that similar, unknown effects may have been present for other risk factors as well. The screening techniques for history of
familial hearing loss, smoking, and cardiovascular disease were also based on self-report, and the screening process may not have been entirely effective in ruling out partial effects for these risk factors in selected participants.

Another factor that must be considered is the unique character of the population and, more specifically, the subsample selected for study. The exclusion of participants who did not present with the selected risk factors resulted in a final study group that was considerably smaller than the original sample in the same age groups. Further, unique characteristics of the screened group may have contributed to the observed outcomes. The number of female participants, for example, was higher than that for male participants. Further, age comparisons were limited to only two decades across the lifespan. As noted in the Method section, this was necessary to ensure a reasonable sample size for analyses of residual effects.

ISO Comparisons

In general, ISO norms underestimated the degree of hearing loss for participants of comparable age in the present study. This underestimation was small at lower test frequencies and smaller for women than for men. Similar to findings across EHLS groups, some of the observed threshold differences are likely within the precision and reliability limits of clinical audiometry. Differences in thresholds for the ISO and EHLS groups were larger at higher test frequencies, however, and were greater for men, particularly those in the 50-year-old group. Like the observed age and gender effects, differences in thresholds for the EHLS and ISO groups are likely related to a number of issues, including differences in the respective participant samples, screening techniques, and generation issues. Both the screened EHLS and ISO data pools, for example, were based on relatively small samples. In addition, there were noted differences in the specific age groupings for both 50- and 60-year-old participants. The EHLS groups of 48 to 55 and 56 to 65 years, for example, may have constituted a different specific distribution of participant ages within each group relative to the ISO groups. These and other sample differences may have contributed to the threshold differences observed for the two data sets.

Alternatively, it might be argued that the ISO norms are not accurate predictors of age-related hearing loss for contemporary older adults. Specifically, given that the screening of participants in the present study accounted for considerably more risk factors than those used in the ISO standard, the disparity in measured thresholds for participants in the present study relative to ISO norms may suggest the need to re-evaluate age-appropriate threshold norms using findings from contemporary studies in larger populations. The ISO norms are based on studies conducted 30 to 40 years ago and may no longer be accurate referents for estimating age-related hearing loss in older adults. In terms of typical noise exposure, for example, there are likely appreciable differences in the degree of noise exposure across generations. The levels of industrial and environmental noise have increased considerably over the past several decades, and it has been demonstrated that the effects of age-related hearing loss and noise-induced hearing loss are not simply related in an additive manner; rather, the two effects may be multiplicative across age cohorts (Mills, 1992). Accordingly, the independent and combined effects of age and noise exposure may differ significantly across generational cohorts.

There may also be differences across past and current generations relative to diet, lifestyle, and health that relate to the observed differences at given age decades. Indeed, some have argued that such historical changes across cohorts bring into question the applicability of standards in the classification of age-appropriate health markers in older adults (Deeg et al, 1996). Deeg et al reviewed surveys in older adults that indicated differences in the prevalence and severity of health disability in older adults. Relevant to the present study, although surveys have reported generally better health in later cohorts (Jagger et al, 1991; Manton et al, 1993), the prevalence of selected serious diseases (such as heart disease and diabetes) is higher among recent cohorts relative to earlier cohorts. Finally, self-reports of health status, noise exposure, and other risk factors may differ across generations of adults (Idler, 1993). These historical differences in health, disability, and self-perceptions of risks and disability across cohorts may underlie portions of the observed differences in hearing sensitivity for older adults in the present study and those in the ISO group.

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