Firefighters' Hearing: A Comparison With Population Databases From the International Standards Organization

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We investigated firefighters' hearing relative to general population data to adjust for age-expected hearing loss. For five groups of male firefighters with increasing mean ages, we compared their hearing thresholds at the 50th and 90th percentiles with normative and age- and sex-matched hearing data from the International Standards Organization (databases A and B). At the 50th percentile, from a mean age of 28 to a mean age of 53 years, relative to databases A and B, the firefighters lost an excess of 19 to 23 dB, 20 to 23 dB, and 16 to 19 dB at 3000, 4000, and 6000 Hz, respectively. At the 90th percentile, from a mean age of 28 to a mean age of 53 years, relative to databases A and B, the firefighters lost an excess of 12 to 20 dB, 38 to 44 dB, 41 to 45 dB, and 22 to 28 dB at 2000, 3000, 4000, and 6000 Hz, respectively. The results are consistent with accelerated hearing loss in excess of age-expected loss among the firefighters, especially at or above the 90th percentile. (J Occup Environ Med. *2001;43:650–656*)

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Hearing loss is commonly reported in firefighters.[1–8] In particular, firefighters tend to exhibit hearing loss in the higher frequencies most susceptible to excessive noise exposure: 3 kHz, 4 kHz, and 6 kHz[1–6,8]. The severity of this pattern of hearing loss is strongly associated with age and the duration of firefighting service.[1,4–6,8] When the effect of presbycusis (age-related hearing loss) is adjusted for, an association between the magnitude of hearing loss and number of years of service as a firefighter remains.[2,3]

Because hearing loss is also common in the general population,[9] the question remains whether firefighters suffer from excess hearing loss relative to the general population. When normative age-matched audiometric data are compared with those of groups of firefighters, an interesting pattern seems to emerge. The youngest firefighters tend to have better hearing compared with the general population, whereas older firefighters seem to have greater hearing loss than that of the general population.[4,8] These data suggest that firefighters tend to lose hearing at an accelerated rate, especially in the frequency ranges characteristically affected by excessive noise exposure.[4,8]

Researchers have suggested that excess hearing loss among firefighters is due to occupational noise exposure.[2–6,8] Noise-induced hearing loss has long been associated with working environments that expose the person to a relatively continuous

TABLE 1
Mean Hearing Thresholds in Decibels Measured at Each Hospital

Hospital	Age Tested		500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
	Mean	*n*						
1	39.6	113	25	16	7	11	14	21
2	39.7	112	10	8	10	16	22	20
3	39.2	94	6	6	7	13	19	25

level of excessive noise.[10] However, research has more recently begun to address the risk of noise-induced hearing loss because of intermittent exposure to unusually high decibel levels, such as those experienced by firefighters during emergency response situations.[1,2,4–6,11] During these emergency responses, the major sources of noise are vehicular, including horns, sirens, and engine noise.

Given the high prevalence of clinically abnormal audiometry among our cohort of firefighters, especially those over 40 years old,[7] we proposed to compare our cohort's hearing with that of the general population. Furthermore, we wanted to adjust for the effect of presbycusis by subtracting normative expected hearing losses. Therefore, we compared the hearing of our cohort of hazardous materials firefighters to the hearing of screened and unscreened populations from the International Standards Organization.[12–14]

Methods

Subjects

The study base included 340 firefighter-members of six regional hazardous materials response teams of the Commonwealth of Massachusetts who underwent state mandated medical surveillance/fitness for duty examinations. All of the firefighters also belong to municipal fire departments in addition to their hazardous materials duty with the state teams. This cohort was 99% male (336 of 340) and predominantly white. All firefighters were examined on a confidential basis. The Institutional Review Boards of the Harvard School of Public Health and The Cambridge Hospital approved review of the firefighters' medical records for research purposes.

Medical Examinations

Medical surveillance examinations for the firefighters were performed at one of three hospitals in 1996 or 1997 in the first year of a statewide surveillance program. All examinations were conducted in a similar fashion. Examinations included a medical, smoking, and environmental/occupational history tailored to emergency responders; physical examination; visual and audiometric testing; routine laboratory tests; and spirometry. Audiograms were available for 95% (319) of the 336 male subjects examined in 1996/97. Audiometry was assessed at hospital 1 in an isolated examination room using a screening audiometer (MA 19; Maico Diagnostics, Eden Prairie, MN). At hospital 2, audiometry was performed in an isolated booth using an audiometer (RA 500; Tremetrics, Austin, TX) . Audiometry at hospital 3 was assessed with a two-channel audiometer (TA 200 model 260; Teledyne Avionics, Charlottesville, VA) in a soundproof room. Table 1 shows the mean hearing thresholds over frequencies of 500 to 6000 Hz at each hospital. Right and left ear data have been averaged.

Analysis of Audiograms

Background noise can adversely affect hearing thresholds. The data in Table 1 strongly suggested that such an effect was present at 500 and 1000 Hz at hospital 1 because of a failure to sufficiently isolate the testing room. Therefore, we excluded data from hospital 1 from the calculations of firefighter thresholds at 500 and 1000 Hz. Because hospital 1 results were not dissimilar from the other two hospitals over the range 2000 to 6000 Hz, we included them in these threshold calculations. For all threshold calculations, we averaged right and left ear data.

Comparison of Firefighters' Threshold Data With Those of a Highly Screened Otologically Normal Population

Database A (American National Standards Institute 1996 and International Organization for Standardization 7029)[13,14] was developed from the hearing thresholds of a large, otologically normal population derived from several survey studies.[13] The subjects were screened specifically to study the effect of age (presbycusis) on hearing without confounding caused by otological disease, environmental noise, etc.[15] An otologically normal person is defined as a person "in a normal state of health who at the time of testing is free from excess wax in the ear canals, is without known ear pathology and who has no history of undue exposure to noise."[13] Therefore, comparisons with database A allow for the estimation of excess hearing loss caused by factors not related to age. The American National Standards Institute standard includes formulas to predict the distribution of database A hearing thresholds for any age from 18 to 70 years over frequencies between 125 and 8000 Hz, assuming that the median (50th percentile) hearing threshold for an 18-year-old person is 0 dB hearing loss.[13]

For each of the 319 firefighters, we created age-matched, male control subjects, one each at the 50th and 90th percentiles of database A. We then determined the predicted hearing thresholds of the control subjects at each frequency. Thus, at each percentile studied, the age distribution of database A control subjects matched that of the entire cohort of firefighters.

Relative Risk for High- and Broad-Frequency Hearing Loss in Firefighters Versus Otologically Normal Persons

High-frequency hearing loss was defined as an average threshold greater than 30 dB at 3000, 4000, and 6000 Hz. Broad frequency hearing loss was defined as an average threshold exceeding 20 dB across 500, 1000, 2000, and 4000 Hz. The number of firefighters exceeding these criteria for the average of the two ears was calculated.

To estimate the number of age-matched subjects from database A exceeding the high and broad frequency criterion, we stratified the firefighters by deciles of age. A mean age was calculated for each of the 10 groups. Then for each of these 10 ages, the percentiles at which database A subjects exceed the 20 dB hearing loss fence for 500, 1000, 2000, and 4000 Hz and the 30 dB hearing loss fence for 3000, 4000, and 6000 Hz were calculated. The percentage of control subjects exceeding the two criteria for each of the 10 age groups was determined and then multiplied by the total number of subjects in each age category. This yielded the number of failures in each decile. Finally, we summed the number of failures in each of the 10 age groups.

Comparison of Firefighters' Threshold Data With Those of Screened and Unscreened US Populations: Subtraction of Age-Expected Hearing Loss

For these comparisons, five subgroups of firefighters were examined. The groups were: 20 to 30 years old (mean age, 28 ± 3; n = 33); 31 to 40 years old (mean age, 36 ± 3 years old; n = 143); 41 to 45 years old (mean age, 43 ± 1 years old; n = 76); 46 to 50 years old (mean age, 48 ± 1 years old; n = 53); and greater than 50 years old (mean age, 53 ± 2 years old; n = 14).

For each of the 319 firefighters, we had two age-matched, male control subjects, one at the 50th percentile and one at the 90th percentile of database A. We then determined the predicted hearing thresholds of the control subjects at each frequency. Thus, at both percentiles, the age distribution of database A control subjects matched that of each subgroup of firefighters. The mean thresholds of hearing loss for the age-matched database A control subjects at each frequency were calculated for these percentiles. For each age group, frequency, and percentile (50th or 90th), we subtracted the database A hearing thresholds from those of the firefighters.

Subtraction of age-matched database A hearing thresholds from those of the firefighters allowed us to estimate excess hearing loss in the firefighters. With normative hearing losses eliminated, increasing age among the firefighters becomes a surrogate measure of increasing years of fire service with the presbycusis effect removed.

Database B examples 1 and 2[12–14] are derived from unscreened United States populations. The first example comes from a US Public Health Service Survey (1965).[16] Some of these subjects were assumed to have had unreported occupational or other exposure to noise. The second example comes from a survey in urban and rural North Carolina. The subjects were stratified by age, race, and sex,[17,18] and excluded only if they reported 2 or more weeks of industrial noise exposure. North Carolina subjects were not excluded for military service and nonindustrial noise exposure, including farming, hunting, and shop work. For database B example 2, we compared the male firefighters hearing with that of white, male North Carolinians[17] because the firefighter cohort was predominately white.

For examples 1 and 2 of database B, data are provided for the 10th, 50th, and 90th percentiles by age and sex for persons 30, 40, 50, and 60 years of age. Formulas are not given to interpolate between ages. To match the mean ages of the firefighter subgroups, database B data were averaged with appropriate weighting between male values for 30 and 40 years old or 40 and 50 years old, and so on. Because thresholds are quite similar for both examples of database B, these data were averaged before comparison with the firefighters. Because 20-year-old data are not provided for database B, we estimated database B values for a mean age of 28 years. We subtracted the change in thresholds in dB at the corresponding percentile from age 28 to age 30 for database A from database B values for 30-year-old persons. This method is justified because at both the 50th and 90th percentiles, the relative changes in thresholds with increasing age are quite similar for both databases A and B. Again, for each age group and frequency, the average database B hearing loss at the 50th and 90th percentile at each frequency was subtracted from that of the firefighters at the same percentiles.

Results

The average age of the 319 firefighters and the control subjects from database A was 39.5 ± 6.9 years. When results for both ears were averaged, 46 of 319 (14%) firefighters had high-frequency hearing loss (3000, 4000, and 6000 Hz) compared with 5% for a database A population with a similar age distribution. This yielded a relative risk for the firefighters of 2.9 (95% confidence interval, 1.7 to 5.1; $P < 0.001$; χ^2 =

TABLE 2
Mean Hearing Thresholds in Decibels for Firefighters by Age at the 50th and 90th Percentiles

	Age								
Age Group	Mean ± SD	*n*	Percentile	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
20–30	28 ± 3	33	50th	5	5	5	5	5	10
31–40	36 ± 3	143	50th	5	5	5	5	10	15
41–45	43 ± 1	76	50th	10	5	5	10	15	20
46–50	48 ± 1	53	50th	10	5	10	15	21	25
>50	53 ± 2	14	50th	5	10	10	40	45	48
20–30	28 ± 3	33	90th	18	10	15	10	15	25
31–40	36 ± 3	143	90th	15	15	15	25	32	40
41–45	43 ± 1	76	90th	15	15	20	40	50	45
46–50	48 ± 1	53	90th	22	15	20	45	50	50
>50	53 ± 2	14	90th	16	16	46	72	82	76

TABLE 3
Firefighters' Hearing Loss in Decibels HL Minus Hearing Loss for Age-Matched Database A Subjects

	Age								
Age Group	Mean ± SD	*n*	Percentile	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
20–30	28 ± 3	33	50th	5	5	4	4	3	8
31–40	36 ± 3	143	50th	4	4	3	1	5	9
41–45	43 ± 1	76	50th	8	3	1	3	5	9
46–50	48 ± 1	53	50th	7	1	4	4	7	9
>50	53 ± 2	14	50th	1	5	2	27	27	27
20–30	28 ± 3	33	90th	10	1	4	−2	1	10
31–40	36 ± 3	143	90th	5	5	2	9	13	18
41–45	43 ± 1	76	90th	4	3	4	19	23	15
46–50	48 ± 1	53	90th	9	2	1	19	16	12
>50	53 ± 2	14	90th	1	1	25	42	42	32

16.7). When both ears were averaged, 24 of 206 firefighters (12%) had broad-frequency hearing loss (500, 1000, 2000, and 4000 Hz; figures exclude hospital 1) compared with 4.0% of a database A population of similar age distribution. This yielded a relative risk for the firefighters of 2.9 (95% confidence interval, 1.5 to 5.6; $P = 0.001$, $\chi^2 = 11.4$).

Table 2 shows age-stratified hearing thresholds for the firefighters at the 50th and 90th percentiles. At the 90th percentile after age 40, there is the suggestion of a notch at 4000 Hz typical of noise-induced hearing loss.

Tables 3 and 4 show the differences between the firefighters' hearing thresholds and those predicted for persons of the same average ages from database A (Table 3) and database B (Table 4). At the 50th percentile, the oldest firefighters (>50 years old) had worse hearing relative to both comparison groups over the 3000- to 6000-Hz range. The effect was more pronounced at the 90th percentile and began earlier. Over the 3000- to 6000-Hz range, hearing generally became progressively worse with increasing age relative to the comparison groups. The group >50 years old also had worse hearing at 2000 Hz at the 90th percentile.

Table 5 shows the excess threshold shifts for the firefighters at each frequency from 28 to 53 years old at the 50th and 90th percentiles compared with databases A and B. At each of the frequencies tested, similar results were found using both databases A and B. Again, the results suggest a notch with similar or greater excess losses at 3000 and 4000 Hz than at 6000 Hz.

Discussion

In agreement with other studies of firefighters,[1–6] we found that hearing loss was common in our cohort. Whether hearing loss at high frequencies (3000, 4000, and 6000 Hz) or hearing loss over a broader frequency range (500, 1000, 2000, and 4000 Hz) was considered, 12 to 14% of the firefighters met our definitions of hearing loss for the average of both ears. This compares with a much smaller number than would be expected from an age-matched otologically normal population (database A). Because formulas for interpolation between ages or percentiles are not provided, it is unclear exactly what proportion of an age-matched, unscreened general population (database B) would be found to have hearing loss by the definitions em-

TABLE 4

Firefighters' Hearing Loss in Decibels Minus Hearing Loss for the Mean of Databases B1 and B2

Age Group	Age: Mean ± SD	Age: *n*	Percentile	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
20–30	28 ± 3	33	50th	−2	3	3	−2	−6	−6
31–40	36 ± 3	143	50th	−4	1	1	−6	−6	−7
41–45	43 ± 1	76	50th	1	0	−1	−5	−7	−8
46–50	48 ± 1	53	50th	0	−1	2	−3	−5	−7
>50	53 ± 2	14	50th	−6	3	0	17	14	10
20–30	28 ± 3	33	90th	2	−1	2	−18	−22	−20
31–40	36 ± 3	143	90th	−3	1	−2	−10	−12	−14
41–45	43 ± 1	76	90th	−5	−2	−2	−2	−2	−16
46–50	48 ± 1	53	90th	2	−3	−7	−2	−5	−14
>50	53 ± 2	14	90th	−6	−3	14	20	23	8

TABLE 5

Excess Threshold Shift for Firefighters in Decibels HL From Ages 28 to 53 Years Versus General Population Databases

Database	Percentile	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
A	50th	−4	0	−2	23	23	19
B	50th	−4	0	−3	19	20	16
A	90th	−9	−1	20	44	41	22
B	90th	−8	−2	12	38	45	28

ployed in our study. Based on the thresholds of the 90th percentile for 30- and 40-year-olds in both examples of database B, the proportions would exceed 10% and be somewhat higher for the high frequency criterion than the broad frequency criterion. Pepe et al[2] found that 18% of similarly aged firefighters (range, 21 to 59 years) failed the 30-dB high-frequency fence in both ears.

When the firefighters' data were broken down by age, the younger age groups tended to have similar or better hearing than database B, at the frequencies of 3000, 4000, and 6000 Hz at both the 50th and 90th percentiles. Again, better hearing in younger firefighters versus the general population has been observed in other samples of firefighters.[4,8] Relative to both comparison groups, as the mean age of the firefighters increased, the firefighters' hearing became worse in the high-frequency range. This effect was more pronounced at the 90th percentile and began earlier than at the 50th percentile. The excess threshold shifts from a mean age of 28 years to a mean age of 53 years were similar at each frequency whether the firefighters were compared with database A (highly screened, otologically normal subjects) or database B (unscreened general population data). At the 50th percentile, from a mean age of 28 to a mean age of 53 years old, relative to databases A and B, the firefighters lost an excess of 19 to 23 dB, 20 to 23 dB, and 16 to 19 dB at 3000, 4000, and 6000 Hz, respectively. At the 90th percentile, from a mean age of 28 years to a mean age of 53 years, relative to databases A and B, the firefighters lost an excess of 12 to 20 dB, 38 to 44 dB, 41 to 45 dB, and 22 to 28 dB at 2000, 3000, 4000, and 6000 Hz, respectively.

Therefore, the results suggest that the rate of age-related hearing loss is quite similar for databases A and B but is accelerated in the 3000- to 6000-Hz range for the firefighters, and in the 2000- to 6000-Hz range at or above the 90th percentile. Because these analyses removed the age-expected hearing losses, the threshold shift with increasing age cannot be explained by the effects of normal aging (presbycusis). In this case, age becomes a surrogate of years of service as a firefighter. Other researchers[2,3] have also found the association between the magnitude of hearing loss and number of years of service as a firefighter to remain even after the effect of presbycusis (age-related hearing loss) has been controlled for. Because the effect is much more pronounced at the 90th percentile, it suggests that a subgroup of more sensitive or susceptible individuals may exist.

Researchers have suggested that excess hearing loss among firefighters is caused by occupational noise exposure[2–6,8] Exposure assessments have consistently documented that during emergency responses, firefighters are often subject to brief periods of intense noise exceeding Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) short-term exposure limits.[2–6] The findings of high short-term exposures combined with apparent accelerated hearing loss in firefighters strongly suggest a noise-related health hazard, even though time-weighted exposures for periods of 8 to 24 hours rarely exceed OSHA and NIOSH limits.

Although an association between intermittent noise exposure and hearing loss has been found in firefighters, a causal relationship has not been established. Research has more recently begun to address the risk of noise-induced hearing loss due to intermittent exposure to high decibel levels, such as those experienced by firefighters during emergency response situations.[1,2,4–6,11] In addition, a synergistic effect between ototoxic air contaminants routinely encountered by firefighters and occupational noise has been postulated.[3] Cigarette smoking could play a similar role.[9] We could not address the role of smoking or other medical factors in this study because of the lack of smoking information or formulas for adjusting thresholds for smoking in the International Organization for Standardization comparison databases. These databases are based on studies done from the 1960s to 1980. Therefore, the prevalence of smoking in the United States would have been higher in the general population at that time than the 12% of current smokers in the firefighter cohort. We plan to study the role of smoking and other medical problems on hearing within our cohort in the near future.

The major limitation of our study was the lack of information on nonoccupational noise exposure and other historical factors that might affect hearing in the firefighters. There is also insufficient information as to the complete comparability of the reference groups to the firefighters. Although we could not completely control for these nonoccupational factors, we did use two different and independently derived sets of control hearing thresholds from a highly screened, otologically normal comparison group (database A) and an unscreened comparison group (database B examples one and two). Both examples of database B are assumed to have included subjects with exposure to noise.[16,17] In the second example, North Carolina subjects were not excluded for military service and nonindustrial noise exposure, including farming, hunting, and shop work. Nonetheless, our results for excess hearing loss in the firefighters associated with increasing age were quite similar whether we compared the firefighters with database A or B. The fact that both screened and unscreened comparison groups yielded similar results and similar rates of hearing loss with increasing age means that this finding was independent of the comparison group. The reproducibility of the results with an unscreened control group suggests that factors other than nonoccupational noise exposure are responsible for the apparent accelerated hearing loss exhibited by the firefighters.

The most important strength of our study was the ability to strictly age-match our database A control subjects. Differences in testing methods or other nonoccupational factors between the firefighters and the comparison groups would not explain the similar or better hearing of the younger firefighters compared with the control subjects, whereas older firefighters had greater than expected age-related hearing loss compared with the comparison groups. Although we could not perform exact age matching for database B, interpolation from the database A tables for age by decade for the 50th and 90th percentiles gave results almost identical to the exact age-matched ones we presented. Based on this exercise and because the rates of hearing loss with age are similar for databases A and B, we believe that the interpolated averages for database B are good estimates of what subject by subject age-matched data would have shown.

Our study and other investigations of firefighters hearing have been cross-sectional. Longitudinal investigations will be necessary to confirm that firefighters hearing loss is accelerated compared with the general population. In addition, because of numerous variables and potential confounders, none of the studies can conclusively demonstrate that firefighters' hearing loss is caused by occupational noise. Nonetheless, researchers have shown that firefighters are subject to brief intermittent periods of high levels of noise exceeding OSHA and NIOSH short-term exposure limits.[2–6] Furthermore, noise-induced hearing loss is an irreversible condition for which there is no effective medical treatment.[19] The irreversible nature of noise-induced hearing loss, the consistency of findings documenting exaggerated hearing loss in older firefighters,[1–6,8] and documented noise hazards[2–6,17] argue strongly for the widespread implementation of preventive measures. Engineering controls and personal protective equipment have been reviewed elsewhere.[3] In addition, educational interventions designed to increase the awareness of noise-induced hearing loss and promote the use of hearing protection devices have yielded positive results.[1] Therefore, although further research is still needed, sufficient information exists to confirm this hazard and to advocate prevention programs.

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Awareness of Noise-Induced Hearing Loss in the 1800s

Stephen Blackpool bent his attentive face—his face, which, like the faces of many of his order, by dint of long working with eyes and hands in the midst of a prodigious noise, had acquired the concentrated look with which we are familiar in the countenances of the deaf—the better to hear what she asked him.

Dickens C. *Hard Times.* Chapter 12 (first published in 1854)

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