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Distribution of risk factors for hearing loss: Implications for evaluating risk of occupational noise-induced hearing loss

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This paper presents an analysis of hearing threshold levels among 2066 white male workers employed in various U.S. industries studied in the 1968–72 NIOSH Occupational Noise and Hearing Survey (ONHS). The distribution of hearing threshold levels (HTL) is examined in relation to various risk factors (age, prior occupational noise, medical conditions) for hearing loss among a population of noise exposed and control (low noise-exposed) industrial workers. Previous analyses of a subset of these data from the ONHS focused on 1172 highly ''screened'' workers. An additional 894 male workers (609 noise-exposed and 285 controls), who were excluded for various reasons (i.e., nonoccupational noise exposure, otologic or medical conditions affecting hearing, prior occupational noise exposure) have been added to examine hearing loss in an unscreened population. Data are analyzed by age, duration of exposure, and sound level (8-h TWA) by individual test frequency. Results indicate that hearing threshold levels are higher among unscreened noise-exposed and control workers relative to screened workers. Analysis of risk factors such as nonoccupational noise exposure, medical conditions, and type of industry among unscreened controls indicated that these factors were not significantly associated with increased mean HTLs or risk of material impairment over and above what is expected due to age. Age-specific mean hearing threshold levels (and percentiles of the distribution) among the unscreened ONHS control population may be used as a comparison population of low-noise exposed white male industrial workers for evaluating the effectiveness of hearing conservation programs for workers less than 55 years of age. To make valid inferences regarding occupational noise-induced hearing loss, it is important to use hearing data from reference (control) populations that are similar with respect to the degree of subject screening, type of work force (blue vs white collar), and the distribution of other risk factors for hearing loss. [DOI: 10.1121/1.1494993]

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I. INTRODUCTION

Current U.S. noise regulations require that employers in the manufacturing and mining industries of the U.S. enroll employees exposed to daily average exposures of 85 dBA or more in a hearing conservation program and to occasionally monitor their noise levels (OSHA, 1983; MSHA, 1999). These noise regulations do not cover noise-exposed workers in small businesses (less than 100 workers) or in industries such as construction, agriculture, transportation, and public utilities, where excessive noise exposure and hearing loss is likely to be prevalent (NIOSH, 1988a, b, 1990).

The burden of hearing loss due to occupational noise, and perhaps other risk factors, is likely to be greatly underestimated, due to the lack of a systematic national health surveillance system to collect statistics on hearing loss and occupational noise exposure. Hence, relatively imprecise estimates exist of the number of noise-exposed workers and the prevalence of occupational noise-induced hearing loss (NIHL) in the U.S. workforce. It has been estimated that about 9 million U.S. workers are occupationally exposed to noise levels exceeding or equal to 85 dBA on a daily basis (Simpson and Bruce, 1981), with more than half of these workers engaged in manufacturing and utility. Approximately 1 million workers are estimated to suffer from work-related hearing loss, primarily from manufacturing industries (Weeks *et al.*, 1991). The high prevalence of occupational noise exposure and the fact that long-term NIHL is a preventable condition provides researchers and public health officials a unique opportunity to develop and test interventions that may prevent NIHL for millions of individuals.

Carefully designed epidemiological studies examining the relationship of contemporary workplace noise exposure and the distribution of noise-induced hearing loss among adult U.S. worker populations have not been conducted recently. Moreover, representative U.S. national data on the burden of hearing loss from occupational noise relative to other risk factors for hearing loss are either not available (Ries, 1994) or are limited to particular states or sectors of industry (Reilly *et al.*, 1998). Such large-scale data collection efforts tend to be expensive, and when conducted, often omit important occupational information (such as job title, noise exposure level, number of years employed in noisy jobs) that can be linked to audiometric testing data. Another limiting factor in evaluating occupational hearing loss in relation to noise and other risk factors is the greater availability of hearing protection devices (HPD) in most manufacturing settings in the U.S. (Davis and Sieber, 1998; Royster and Royster, 1984). Therefore, utilizing existing data is an economical way to gather information needed for planning future studies and evaluating the impact of changes in expo-

TABLE I. Distribution of study subjects by industry group.

Industry type	Total population ($N=2066$) No.	Total population ($N=2066$) %	Exposed ($N=1401$) No.	Exposed ($N=1401$) %	Controls ($N=665$) No.	Controls ($N=665$) %
Printing	906	43.9	603	43.0	303	45.6
Steel fabrication	355	17.2	160	11.4	195	29.3
Woodworking	270	13.1	211	15.1	59	8.9
Tunnel patrol	171	8.3	146	10.4	25	3.8
Paper bag mfg.	103	5.0	82	5.9	21	3.2
Aluminum fabrication and processing	123	6.0	105	7.5	18	2.7
Quarry	69	3.3	63	4.5	6	0.9
Hydroelectric	38	1.8	0	0.0	38	5.7
Trucking	31	1.5	31	2.2	0	0.0

sure, hearing protection use, and other hearing loss risk factors in the population.

This paper analyzes one of the key studies of U.S. workers from several industries conducted by the National Institute for Occupational Safety and Health (NIOSH; formerly Bureau of Occupational Safety and Health) during 1968–1972. This study remains historically and scientifically relevant because (1) a subset of the data (1172 ''screened'' white male population) were analyzed to form the basis of the current Occupational Safety and Health Administration (OSHA) noise standard (NIOSH, 1972; Lempert and Henderson, 1973; Prince *et al.*, 1997) and (2) it is one of the few existing data sets with raw data on hearing threshold levels, TWA noise levels, risk factor, demographic, and industry type.

Data from the larger NIOSH ONHS study, which includes workers excluded from the original analyses, have never been extensively evaluated or published elsewhere. Generalizing results from the prior risk analysis to an unscreened population may allow inferences to be drawn for working populations that are more representative of workers enrolled in industrial hearing conservation programs. The main objectives of the analysis are to examine risk profiles of the unscreened population to the highly subgroup screened group and to describe the characteristics of low noise-exposed populations for use as comparative data in analysis of contemporary hearing data from noise-exposed industrial workers. In this paper, the ''screened'' population will refer to the original 1172 workers analyzed previously (NIOSH, 1972; Prince *et al.*, 1997), while those excluded from analysis are referred to as the ''excluded'' population ($N=894$). The total population of workers examined in this analysis, formed by pooling the screened and excluded ONHS subpopulations, is referred to as the ''unscreened'' population.

II. METHODS

A comprehensive description of this study was previously published in an NIOSH technical report (Lempert and Henderson, 1973). Pertinent study methods provided from that report are summarized below.

A. Study population

The study population was drawn from volunteer companies responding to publicized announcements of the study from industrial hygiene conferences and Public Health Service distributions of the procedures and goals of the Occupational Noise and Hearing Survey (ONHS). All plants requesting noise and hearing evaluations were considered for the study if the following criteria were met: (1) factory or occupational noise conditions were relevant to development of a noise standard for general industry; (2) the work force represented a wide range of years of exposure to noise (based on walk-through noise surveys). Among the 13 plants subsequently selected for this study, 9 different industrial groups are represented in the survey. For plants having less than 500 employees, the entire work force was tested. In larger plants, a random sample of employees were selected. Employees from each plant who worked in offices or other quiet areas were also included in the survey as a comparison or control group. Among the 2066 workers selected for noise monitoring, 61% of the study subjects worked in printing and steel fabrication (Table I).

B. Data collection procedures

1. Noise characterization

Preliminary surveys of each plant provided information needed to develop a sampling strategy. Noise level surveys were conducted to assess daily noise exposures of workers. The following items were obtained for each plant: location and type of operation or work performed, general noise characteristics (e.g., impulsive, steady state, low frequency), temporal characteristics (e.g., continuous, fluctuating, intermittent), and overall noise levels using the ''A,'' ''C,'' and ''linear'' scales of the sound-level meter. Tape-recorded noise samples were played through octave band and third-octave band real-time analyzers for the band with center frequencies of 31.5, 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. Recorded tapes were played through an octave band filter set through a third-octave band, real-time analyzer.

Sequential sampling of field measurements of dBA levels at intervals of 15 seconds throughout the sample period of 10 min were developed for areas where sound levels showed evidence of random variations with time. The Bruel and Kjaer (B&K) type 4420 distribution analyzer, in conjunction with the type 2305 level recorder, was used to obtain the probability distribution of sound levels over selected time intervals. Tape recordings were taken in the field to permit analysis in the laboratory. If impact sounds were present, measurements of peak-pressure levels were made using the B&K 2204S impact meter. If the impacts occurred so rapidly as to blend together, then the noise was regarded as being essentially continuous.

To determine daily noise exposure patterns for a worker or worker group, workmen and supervisors were interviewed. In many cases, time-study charts were prepared, segmenting the workday into a succession of exposures at specific noise levels and for specified durations. Discussions with both management and workers were necessary to determine changes in workers' noise exposures over the course of many years. Consideration was given to variations in occupational noise conditions due to machinery replacement or relocation and also to changes in work routine and location of workers. No mass use of hearing protection devices was observed in the companies surveyed (Prince *et al.*, 1997).

2. Audiometric and risk factor evaluation

All audiometric tests were done in a Rudmose Audiometric Travel Lab model RA-113. This audiometric van housed an acoustically isolated, sound-deadened chamber in which six persons could be tested simultaneously. Audiometric equipment consisted of a Rudmose RA-108 pure-tone six-person air-conduction audiometer that produced test tones at frequencies 0.5, 1, 2, 3, 4, and 6 kHz, presented first to the left ear and then to the right ear of each subject. Standard procedures for audiometer calibration and hearing tests were implemented as described by Lempert and Henderson (1973). Ambient noise levels in the testing booths were within the limits specified in the ANSI S3.1-1960 (R1971) standard (ANSI, 1960).

Each noise-exposed worker was tested before the beginning of this work shift to minimize temporary hearing threshold shifts from exposure to noise at the worksite immediately before the test. Test scheduling usually required subjects to arrive 30–75 min early; otoscopic examinations and administration of an questionnaire were also done at the time of testing. Non-noise-exposed workers were tested at any time during the work shift, since their pretest noise exposures were not considered significant enough to produce a temporary threshold shift. A questionnaire administered at the time of the hearing test collected information on other factors that might affect hearing loss risk, noise exposure, and interpretation of audiometric test results such as

(1) Previous job history of noise exposure—number of years worked in noisy environments.
(2) Military history, including amount of time spent using a weapon, in actual combat experience, and in routine daily exposure to nonweapon-type noise (e.g., aircraft engines, armored vehicles).
(3) Nonoccupational noise exposure, including civilian firearm use (number of rounds/year, with and without hearing protection), motorbike riding, mechanized farming, piloting an airplane, machine workshop activity, sport or drag car racing, and noisy hobbies (e.g., rock music).
(4) Medical history that included whether they ever had experienced severe head trauma, chronic ear infection, hereditary deafness, Meniere's disease, use of ototoxic drugs, ear surgery, concurrent severe head colds, or tinnitus at the time of audiometric testing.

3. Exclusion criteria

Given the study's primary aim to establish a valid statistical relationship between occupational noise exposure and hearing loss that would be applicable to general industry, NIOSH investigators excluded data from the analysis sample if (1) workers' noise exposure histories or validity of audiometric data were uncertain, and (2) observed hearing loss may have been caused by factors other than occupational noise.

Based on an evaluation of questionnaire data, audiometric test results, and otoscopic examinations, ''screened sample'' was constructed using the following exclusion criteria:

(1) Previous job history involving 2 or more years occupational noise exposure;
(2) Military history showing: (a) 100 days or more of weapons-type noise; (b) 1 or more years of actual combat experience; and/or (c) 2 or more years of routine daily exposure to nonweapon-type noise (e.g., aircraft engines, armored vehicles).
(3) Nonoccupational noise exposure, including civilian firearm use (1000 rounds/year for 1 or more years or 500 rounds/year for 5 or more years with no hearing protection use), and any noisy hobbies previously listed above if participation was at least 3 times per week for 1 or more years.
(4) History of any of the medical conditions or ototoxic drugs that could affect hearing.
(5) Otoscopic examination indicating congenital or acquired ear malformations, almost total occlusion of ear canal by cerum, perforated or severely scarred tympanic membrane or otitis media.
(6) Audiometric irregularities such as (a) suspected conductive loss in one or both ears; (b) large unilateral hearing losses (e.g., loss in one ear is 40 dB greater than the other ear at two or more test frequencies); and (c) suspected subject response to tinnitus rather than tone presentation.
(7) Significant pretest noise (significant noise exposure within 14 h prior to testing).

Approximately 1287 (35%) of the total 3699 workers were excluded because they met one or more of the above criteria. No more than three exclusions per worker were assigned. These exclusion procedures produced a sample of 2412 used to estimate the impact of industrial noise exposures on the occupational groups included in the individual

TABLE II. Exclusion criteria by exposure group.

Exclusion criteria categories	Total population ($N=894$)		Exposed ($N=609$)		Controls ($N=285$)	
	Number	Percent	Number	Percent	Number	Percent
Noise exposure history	**574**	**64.2**	**395**	**64.9**	**179**	**62.8**
Previous job noise	358	40.0	252	41.4	106	37.2
Pre-test noise[a]	21	2.4	19	3.1	2	0.7
Military Noise	134	15.0	85	14.0	49	17.2
- *weapons*	*112*	*12.5*	*72*	*11.8*	*40*	*14.0*
- *non-weapon*	*22*	*2.5*	*13*	*2.1*	*9*	*3.2*
Leisure activity noise	61	6.8	39	6.4	22	7.7
- *weapons*	*30*	*3.4*	*17*	*2.8*	*13*	*4.5*
- nonweapon	*31*	*3.5*	*22*	*3.6*	*9*	*3.2*
Medical history	**91**	**10.2**	**58**	**9.5**	**33**	**11.6**
Otologic abnormality	**67**	**7.5**	**39**	**6.4**	**28**	**9.8**
Multiple causes	**162**	**18.1**	**117**	**19.2**	**45**	**15.8**

[a]Statistically significant difference between exposed and control groups for pretest noise exposure ($X_1^2=4.95$, $p=0.03$).

plant surveys. Additional exclusion criteria were applied to the remaining workers ($N=2412$) to produce a "composite ONHS population" that could "accurately determine the risk to hearing as a function of noise level" (Lempert and Henderson, 1973). In particular, data were excluded for workers with insufficient noise exposure data or noise consisting of discrete impact sounds or noise with highly variable and unpredictable levels. All maintenance workers were excluded because of exposure uncertainty. Women were excluded due to inadequate sample size for drawing conclusions concerning the relationship between noise level and hearing loss (Lempert and Henderson, 1973). This remaining population was comprised of 1172 predominately white male workers, whose data have been previously analyzed (NIOSH, 1972; Prince *et al.*, 1997).

Based on a reconstruction of these exclusion criteria, the 2066 workers analyzed for this paper represent predominately white male workers with well-defined noise exposure data but whom have not been screened for conditions related to hearing loss commonly found in the general population of workers.

C. Analysis of the unscreened ONHS data

Demographic (age, industry type, duration employed or exposed), noise exposure (8-h TWA sound levels), and hearing health characteristics (mean and median HTLs, percent impairment) of the unscreened ONHS population are presented, as well as a breakdown of the population by exposure (control versus noise-exposed) and screening status (i.e., whether the subset of the unscreened population represents the 1172 screened or the 894 excluded workers). Analysis of the distribution of mean and median HTLs by age among the low noise-exposed "control" group for this population was conducted for purposes of comparison to the ANSI S3.44 (ANSI S3.44, 1996) and ISO 1999 (ISO, 1990) standards as well as other published reports of hearing levels among industrial workers (Berger *et al.*, 1977; Driscoll and Royster, 1984; Royster and Thomas, 1979; Royster *et al.*, 1980) and nonindustrial populations (Morrell *et al.*, 1996). Predicted mean HTL by age and frequency among the screened and unscreened ONHS control populations were examined using a least-squares regression approach (Draper and Smith, 1966), where linear and quadratic (second-order effects) of age were tested.

The effects of age and other risk factors (nonoccupational exposure, previous job noise exposure, medical conditions, military service) on risk of material hearing impairment [binaural pure tone averages (PTA) of >25 dB for frequency averages of 1–4 kHz, 0.5–2 kHz, and 3, 4, and 6 kHz; denoted as PTA-1234, PTA-512, PTA-346] among controls are examined using logistic regression methods (Breslow and Day, 1980). Statistical analyses were conducted using SAS (SAS Institute, Inc., 1989) and graphical displays of the data were produced using S-PLUS (MathSoft, 1997).

III. RESULTS

A. General population characteristics

Table II shows the number of workers who failed the criteria for each category (expressed as percentage of total) or who failed at least one of the criteria. No statistically significant differences between exposed and controls were observed for most criteria except pretest noise exposure. The proportion of noise-exposed workers with pretest noise exposure was higher than the proportion in controls [3.1% vs 0.7%, ($X_1^2=4.95$, $p=0.03$)]. However, examination of the mean and distribution of HTLs by frequency and ear do not show large differences (<5 dB HL) between the exposed and controls workers initially excluded due to previous noise exposure.

General population characteristics are presented for the screened ($N=1172$), excluded ($N=894$), and unscreened ONHS population ($N=2088$) in Table III. The mean age of the ONHS population is about 40 years. The mean age in screened controls was significantly lower than the mean age in the excluded control group. Among the screened population, the control group had a higher proportion of workers under age 29 than the exposed group. Given the selection criteria described for the study, the population represents a

TABLE III. Population characteristics by exposure status.

Variable	Total unscreened exposed population (N=1401)		Total unscreened control population (N=665)		Screened				Excluded			
					Controls (N=380)		Exposed (N=792)		Controls (N=285)		Exposed (N=609)	
Age	#	%	#	%	#	%	#	%	#	%	#	%
<29	254	18.1	165	24.8	114	30.0	150	18.9	51	17.9	104	17.1
29–35	256	18.3	128	19.3	86	22.6	170	21.5	42	14.7	86	14.1
35–43	315	22.5	131	9.7	68	17.9	171	21.6	63	22.1	144	23.7
44–50	262	18.7	111	16.7	49	12.9	124	15.7	62	21.8	138	22.7
50+	314	22.4	130	19.6	63	16.6	177	22.3	67	23.5	137	22.5
Mean±s.d.	40.5±11.6		38.8±11.9		37.0±11.9		39.9±11.8		41.2±11.6		41.3±11.2	
- Range	13–71		17–69		17–65		18–71		18–67		13–67	
- 10th, 90th percentiles	(25, 56)		(24, 56)		(23, 55.5)		(25, 57)		(25, 57)		(24, 55)	
Duration exposed[a]	#	%	#	%	#	%	#	%	#	%	#	%
<1	56	4.0	41	6.2	25	6.6	17	2.1	16	5.6	39	6.4
1–2	86	6.1	61	9.2	34	8.9	46	5.8	27	9.5	40	6.6
2–4	210	15.0	168	25.3	99	26.1	109	13.8	69	24.2	101	16.6
5–10	390	27.8	140	21.0	76	20.0	215	27.1	64	22.5	175	28.7
11–20	373	26.6	153	23.0	91	23.9	209	26.4	62	21.7	164	26.9
21+	286	20.4	102	15.3	55	14.5	196	24.8	47	16.5	90	14.8
Mean±s.d.	12.3±9.7		9.9±9.3		9.9±9.3		13.6±10.4		9.9±9.4		10.6±8.6	
- Range	0.25–46		0–41		0–40		0–46		0–41		0–42	
- 10th, 90th percentiles	(1, 27)		(1, 25)		(1, 25)		(2, 29)		(1, 25)		(1, 24)	
Daily noise level (dBA)	#	%					#	%			#	%
80–87	683	48.8	<80 dBA		<80 dBA		336	42.4			347	57.0
88–92	350	25.0					222	28.0			128	21.0
⩾92	368	26.3					234	29.6	<80 dBA		124	22.0
Mean±s.d.	89.0±4.2						89.5±4.2				88.5±4.1	
- Range	80–102						80–102				80–102	
- 10th, 90th percentiles	(86, 94)						(86, 94)				(86, 94)	

[a]For controls, ''duration exposed'' is duration of employment.

relatively stable workforce. The mean duration of noise exposure is about 12 years, with the screened population having slightly higher duration of exposure. For controls, the mean duration employed was about 10 years. With regard to noise exposure levels, a larger proportion of workers in the excluded group were exposed to 8-h time weighted average (TWA) sound levels of 80–87 dB as compared to the screened group ($X_2^2=29.2$, $p=0.001$).

As shown in Fig. 1, binaural hearing levels among low noise-exposed controls was higher at all frequencies in the unscreened control group than screened controls. However, differences in control HTL for these populations are relatively small among workers younger than 36 years. These differences were most pronounced between older workers at the highest audiometric frequencies. Figure 2 shows the median hearing threshold levels (HTL) and 10th and 90th percentiles by age and dBA level for the unscreened and unscreened ONHS populations. Similar patterns with noise exposure and age are observed in both groups, namely an increase in median HTL with increasing age and noise exposure. Comparable graphs for the screened population can be found in Fig. 1 of Prince *et al.* (1997).

The distribution of hearing threshold levels by exposure status and industry type for the unscreened ONHS population was examined and generally showed typical patterns of loss by frequency, age, and exposure status. Mean ages between controls and exposed groups were not significantly different across all industries. As expected, mean HTLs and rates of impairment were higher among the exposed versus the controls. Mean ages of workers were highest for printing (40.8 years in controls and 43.8 years in exposed) and quarry (44.8 years in controls and 42.3 years in exposed), and lowest among wood-working and paper bag manufacturing (mean ages 32 and 36 years, respectively). As to patterns of hearing loss across industry, all but the printing industry jobs showed significant noise notches among exposed workers (relative to controls) at 3 and 4 kHz. The distribution of overall HTLs by industry types suggest that some of the variability is due to differences in age, exposure years, and noise levels across these groups. Adjustment for age, exposure years, and noise levels is likely to produce mean HTLs that are fairly consistent across industry categories. The effects of industry type and other factors on age-related hearing loss are explored further in the logistic regression analysis using the low noise-exposed (''control'') population.

B. Effects of age: Analysis of control populations

Predicted hearing threshold levels by age were generated for binaural averages for each test frequency and selected frequency averages (Fig. 3). Quadratic effects of age in the unscreened ONHS population were significant for the low to mid-frequencies (0.5, 1, 2, and 3 kHz), but not for the higher

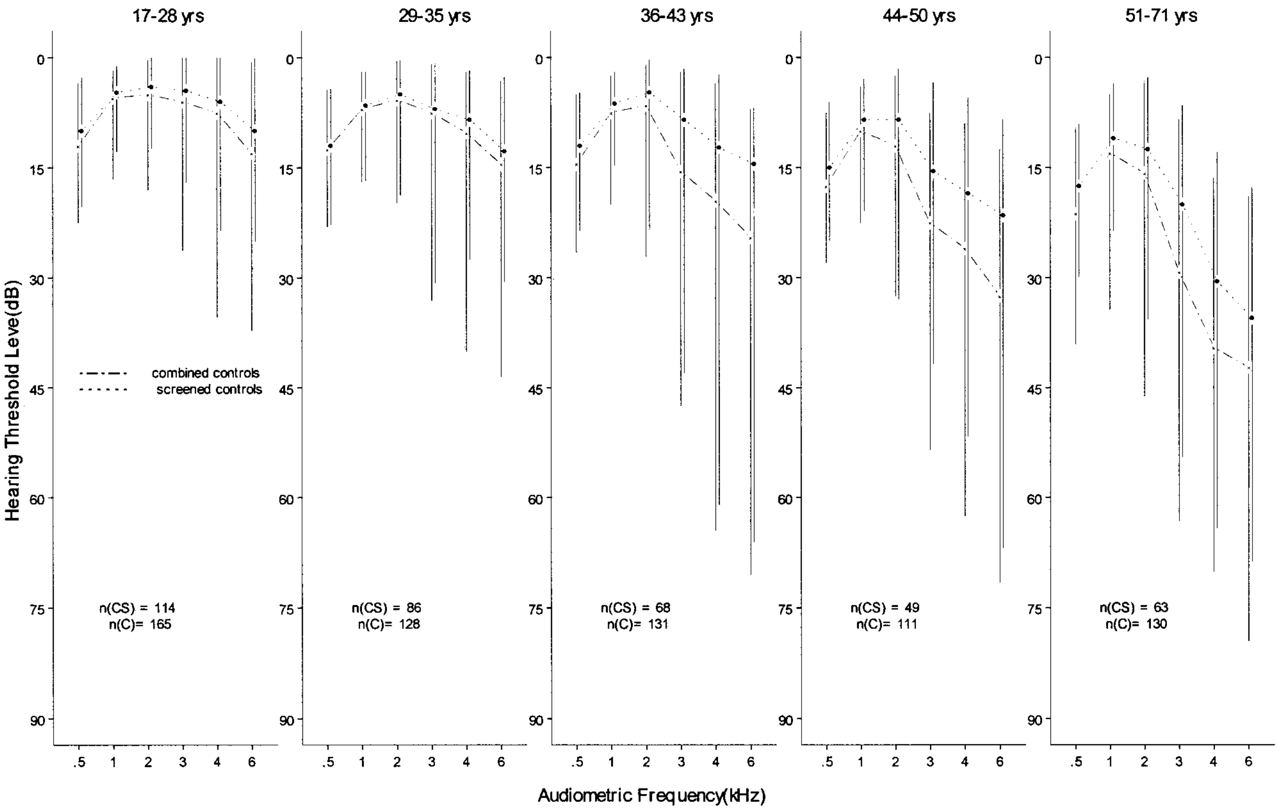

FIG. 1. Comparison of median, 10th, and 90th percentile binaural HTL among the screened and unscreened (combined) controls.

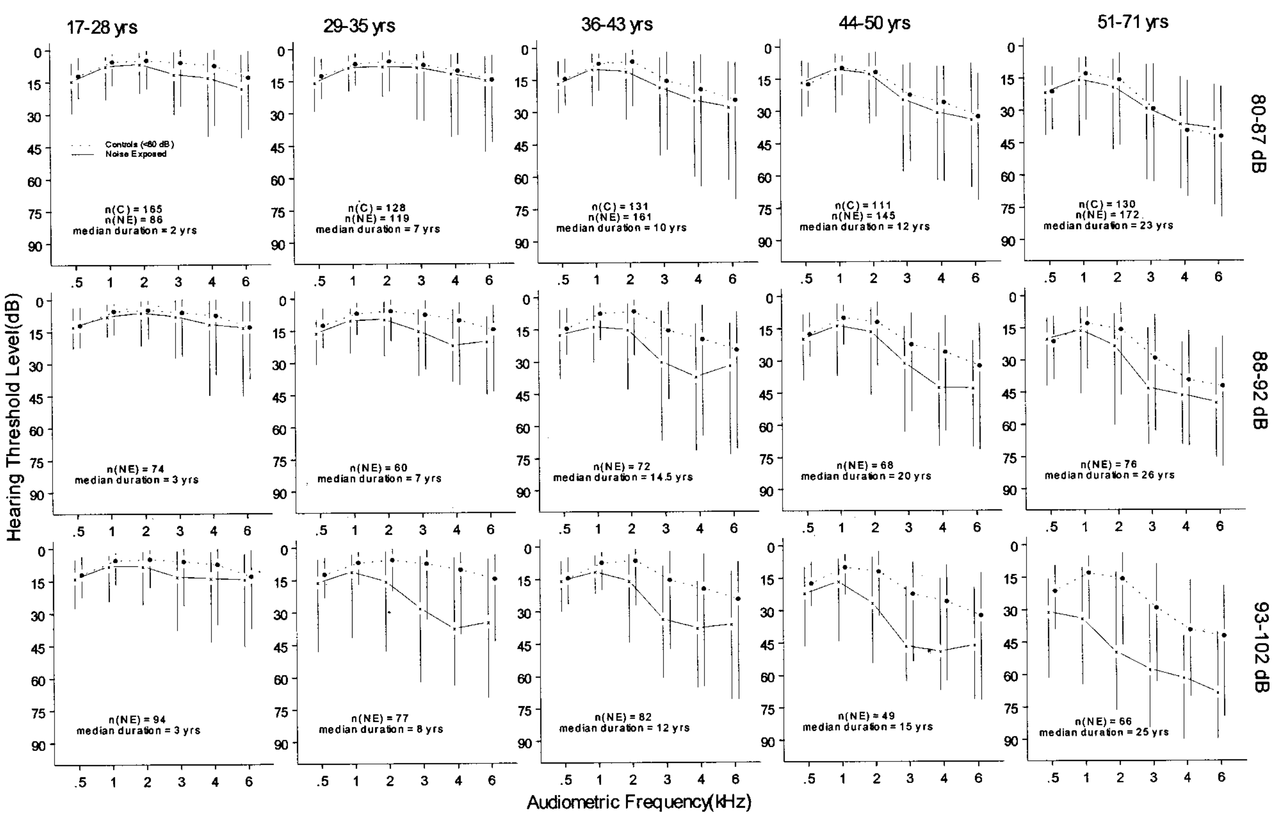

FIG. 2. Comparison of median, 10th, and 90th percentiles binaural HTL by age and dB sound level for the unscreened ONHS population by exposure status.

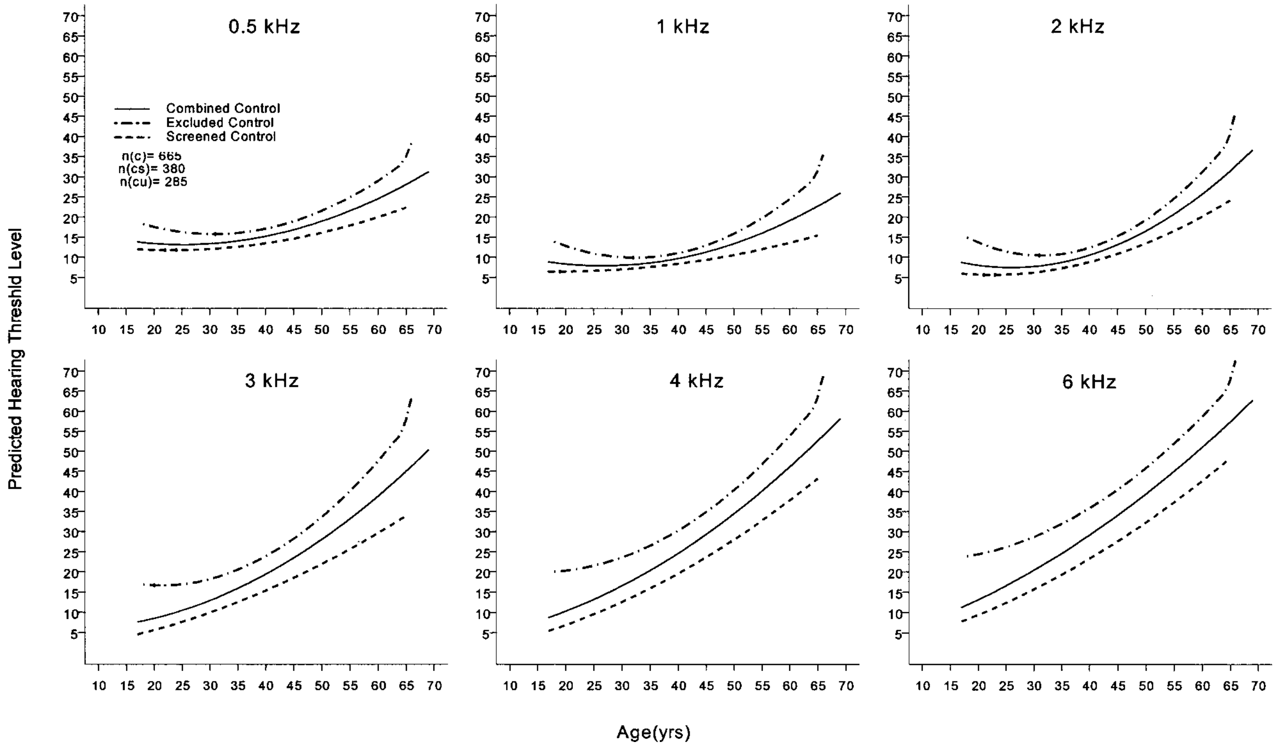

FIG. 3. Predicted hearing threshold levels by age and test frequency.

frequencies (4 and 6 kHz). The excluded control group always had higher HTLs than the screened control group for each frequency.

The means for the age categories (17–29, 30–39, 40–49, 50–59, and 60–69) were used to represent age for comparison to ANSI S3.44, 1996 and ISO 1999 (1990). Except for 500-Hz HTLs, values for this population are similar to those in annex C for white males. HTLs at 500 Hz. are higher than those observed in other populations (Driscoll and Royster, 1984; Robinson, 1970; Robinson and Sutton, 1975; Passchier-Vermeer, 1968; Morrell *et al.*, 1996), most likely due to high noise levels in the audiometric test booths. The unscreened control group had higher median HTLs and 10th and 90th percentiles than the screened control group. A comparison of median HTL among controls in the unscreened ONHS population to those based on annex B (ANSI S3.44, 1996) indicate that except for age 60, median HTLs (binaural average for each test frequency) are similar (Fig. 4).

For the screened control group, comparisons to annex A and to the Baltimore Longitudinal Study on Aging [BLSA] (Morrell *et al.*, 1996) showed higher median HTLs for 500 Hz at all ages (30, 40, 50, and 60 years) examined but relatively similar median HTL for test frequencies 1, 2, and 3 kHz. The differences between the BLSA and NIOSH screened controls decrease with increasing age for frequencies 1, 2, and 3 kHz, but generally increase with increasing age for 0.5 and 4 kHz. The observed differences of 3–9 dB (higher HTLs in the NIOSH screened controls vs BLSA) across age groups for 1, 2, and 3 kHz may be due to differences in ANSI audiometric test standards, audiometric test equipment (manual versus automatic), and procedures. Larger differences (11–20 dB across age categories) in median HTL at 4 kHz was observed between the BLSA screened population (Morrell *et al.*, 1996) and NIOSH screened controls.

C. Effect of other risk factors: Analysis of control populations

In this analysis, we examined age-adjusted odds ratios for material hearing impairment among low noise-exposed (control) workers in the ONHS unscreened population relative to various risk factors collected as part of the study. The results of the logistic regression analysis indicate that after adjustment for age, factors such as previous job exposure, nonoccupational sources of noise (leisure and military), and medical history or otologic abnormalities were not significant contributors of increased hearing impairment in the low noise-exposed unscreened ONHS population (Table IV). Although elevated rates of impairment were not statistically significant for any of the factors examined, slight elevations were noted for military weapon exposure and nonleisure weapon exposure for the frequencies most sensitive to noise-induced hearing loss (3, 4, and 6 kHz). For impairment associated with the speech frequencies (1–4 kHz and 0.5–2 kHz), elevated risk was observed for otologic abnormalities and military and leisure weapon noise exposure (0.5–2 kHz only). After adjustment for age and other factors, the type of industry was not associated with increased impairment rates among low-noise-exposed workers.

IV. DISCUSSION

The analysis focused on examining the distribution of hearing levels by various risk factors and evaluated age ef-

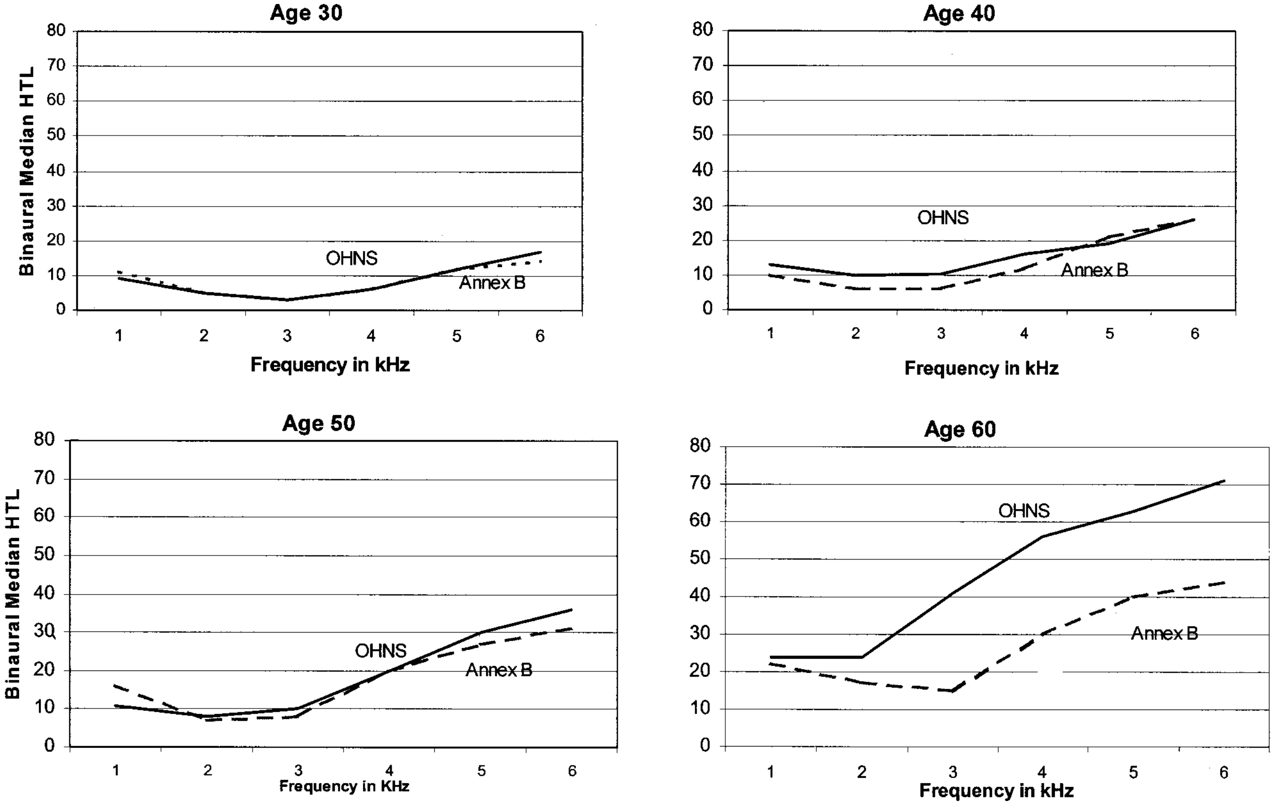

FIG. 4. Binaural average median HTL by test frequency: ONHS versus ANSI S3.44, Annex B.

fects among unscreened low-noise-exposed industrial workers for future use in evaluation of hearing levels among noise-exposed workers enrolled in hearing conservation programs. Results indicate that screened populations have lower (better) average hearing threshold levels than unscreened populations. The usual variability in hearing threshold levels was observed by age, duration exposed, noise level, and test frequency for both the screened and unscreened populations. As had been observed in other studies, variability was greatest for older age groups, higher test frequencies, and increasing noise level. Examination of age-adjusted odds ratios for various definitions of material impairment indicated that factors such as nonoccupational noise, previous noisy job exposure, and medical conditions were not associated with significant increases in material impairment. Moreover, the analyses of mean hearing threshold levels among the low-noise-exposed unscreened workers indicated that most of the increase is due to age rather than the identified risk factors for hearing loss. The type of industry from which low-noise-exposed workers are drawn was not significantly associated with increased mean hearing threshold levels or rates of impairment after adjusting for age.

TABLE IV. Age-adjusted odds ratios for hearing impairment associated with various factors among unscreened controls.

	Definition of material impairment (>25 dB)					
	PTA-1234		PTA-346		PTA-0.5,2,1	
Risk factor	Odds ratio	95% CI[a]	Odds ratio	95% CI[a]	Odds ratio	95% CI[a]
Previous job noise exposure	0.7	0.3, 1.6	0.7	0.3, 1.5	0.8	0.2, 2.6
Military noise	1.4	0.6, 3.1	1.1	0.5, 2.4	1.5	0.5, 4.0
- weapon	1.6	0.7, 3.7	1.2	0.5, 2.9	1.8	0.7, 5.0
- non-weapon	0.7	0.1, 4.1	0.7	0.1, 3.1	—	—
Leisure noise	0.9	0.3, 2.7	1.7	0.5, 2.4	1.0	0.2, 4.2
- weapon	0.6	0.1, 3.0	0.9	0.2, 4.5	1.4	0.2, 8.4
- non-weapon	1.2	0.3, 5.0	2.5	0.7, 9.6	0.6	0.1, 5.7
Medical history	1.1	0.4, 2.9	0.7	0.3, 1.9	1.1	0.3, 4.5
Otologic abnormalities	1.4	0.5, 3.9	0.6	0.2, 1.9	3.0	0.8, 10.9

[a]95% confidence limits: Lower, Upper. *P*-values associated with each factor were not statistically significant at the $p=0.05$ level. Interpretation of odd ratio is as follows: for the example of military noise, the odds or risk of material impairment (for PTA-1234 definition) among workers with military noise exposure is 1.4-fold (or 40%) higher than for workers with no military noise exposure after adjustment for all other factors in the model.

A. Implications for planning public health interventions and epidemiologic studies

Better data on the distribution of NIHL and its risk factors in the population are necessary to plan effective research protocols for testing and evaluating public health interventions. A review of the scientific literature indicates that there is generally weak and inclusive evidence that occupational hearing conservation programs prevent noise-induced hearing loss (Dobie, 1995). A key component often missing for an adequate evaluation of hearing conservation program (HCP) effectiveness is an appropriate reference population. Such populations are useful in separating the effects due to aging and other nonoccupational causes of hearing loss from occupational factors. However, there is a lack of contemporary longitudinal data for working populations not exposed to occupational noise. Currently, comparisons can be made against available populations such as the Baltimore Longitudinal Study on Aging [BLSA] (Brant and Fozard, 1990; Pearson *et al.*, 1995; Morrell and Brant, 1991; Morrell *et al.*, 1996) or statistical models (ISO 1999, 1990; ANSI S3.44, 1996).

The BLSA, a key longitudinal study on aging, is a highly selective white collar population (e.g., predominately white males, high socioeconomic status, primarily older study subjects). A comparison of the median and percentiles of HTL to the BLSA data (Morrell *et al.*, 1996) indicated that the overall spread of the distribution was similar but that there were significant differences in median HTL (11–20 dB across age categories) at 0.5 and 4 kHz. The reason for the disparity between these populations may be due to differences in ANSI audiometric standards, (ANSI, 1989 for BLSA vs ANSI, 1969 for ONHS), audiometer type (manual versus automated), audiometric test procedures (high background booth levels), or increased variability due to differences in unknown risk factors between industrial (blue collar) and nonindustrial (white collar) populations. Therefore, comparisons to actively working, noise-exposed blue collar workers may not be valid. It is likely that comparisons to a highly screened, white collar population would produce higher predicted hearing threshold levels attributable to occupational noise exposure.

The ideal comparison, a low-noise-exposed population from the same facility, is usually not available and, if it can be identified from the HCP database, the workers with less than 80 dBA exposure have intermittent exposure to hazardous noise levels. A comparison of hearing threshold data among workers with high noise exposure (85 dBA or greater) vs this internal ''low-noise'' (under 80 dBA) group would underestimate the effects of noise damage. Therefore, one goal of this analysis was to evaluate whether the unscreened ONHS control data may be used as a comparison database for purposes of evaluating hearing health outcomes and impact of noise-reduction strategies among contemporary workers enrolled in industrial hearing conservation programs. The utility of the ONHS data in this regard is important because widespread use of HPDs is not a confounding factor in this population.

Based on the current analysis, there are some caveats regarding use of these data for this purpose. First, the representativeness of the data relative to contemporary working populations is limited to white males working in certain industries. The U.S. workforce today is much more diverse with regard to gender, nationality, and race than the workforce of the 1970's. It is therefore likely that the distribution of risk factors for hearing loss (medical, social, health care, recreational noise sources, etc.) could be quite different, resulting in more variability in the underlying distribution of hearing threshold levels in the general population. For example, studies examining the impact of various risk factors (e.g., age, blood pressure, and alcohol and cigarette consumption) among noise-exposed workers (McBride, 1993; Tomei *et al.*, 1996) and non-noise-exposed workers (Brant *et al.*, 1996; Gates *et al.*, 1993; Noriyuki *et al.*, 2000) found that after adjusting for age, only a few medical factors such as abnormal ear conditions and hypertension were associated with the development of hearing loss. Gender and racial differences in the prevalence of such risk factors may also affect the burden of hearing loss in the population due to factors other than occupational noise exposure.

Second, the control population from ONHS may not be representative of white male workers in the general U.S. population (which would draw from a wider variety of industries). In the population analyzed for this paper, 61% of the sample was derived primarily from two industries (printing, 43% and steel fabrication, 17%). The sample from the printing industry had the smallest difference between controls and exposed for mean HTLs by frequency, while the largest differences by exposure status occurred in the steel fabrication group. Despite the limited range of industries represented, there appears to be a sufficiently wide range of variability for key variables such as age, noise exposure, length of employment, and level of noise exposures to provide valid inferences of the effect of noise on hearing loss without the confounding effect of HPD use. This is evidenced by the remarkable consistency of the median HTLs for most age groups among the ONHS control population compared to annex B of the ANSI and ISO standards (ANSI S3.44, 1996; ISO 1999, 1990). Annex B represents unscreened low-noise-exposed workers derived from a more representative U.S. population-based sample (i.e., a nonindustrial low-noise-exposed comparison population) over the period of 1960–62. As shown in Fig. 4, the main divergence in median HTLs between the ONHS industrial control population and annex B occurs at age 60 (55–65), where median HTLs for the ONHS unscreened control group are consistently higher (20–35 dB) for binaural averages over 3, 4, and 6 kHz than annex B. This difference for the older age group may be attributable to (a) increased statistical variability in the distribution of HTLs due to small sample size among older workers ($n=130$, aged 50+ years) in the ONHS control population relative to annex B, and (b) differential selection bias of older workers due to the cross-sectional nature of the ONHS survey, resulting in older workers having worse hearing than the general population.

Data comparisons of the distribution of HTLs for older workers (aged 55 years and older) from the ONHS population should be avoided. It is suggested that annex B or C of ANSI S3.44 (ANSI S3.44, 1996) be used as a comparison group for unscreened, noise-exposed occupational cohorts. For screened occupational groups, the screened ONHS population can be used or annex A from the ISO 1999 (ISO 1999, 1990) and ANSI S3.44 (ANSI S3.44, 1996) standards. Both standards draw their data from hearing and noise levels from populations during the 1960's and 1970's. The BLSA data (Morrell *et al.*, 1996) may be used as an additional data source, particularly if the industrial population includes white collar workers, or to estimate lower limits of expected hearing loss (best-case scenario) among medically screened workers exposed to noise on an intermittent basis. The impact of the observed differences in the distribution of HTL on estimating risk of hearing loss in unscreened populations will be evaluated in an upcoming paper examining the same set of ONHS data.

The data analyzed for this paper demonstrates the need for careful planning of future studies whose aim is to estimate the burden of noise-induced hearing loss among occupational cohorts or the general population. These studies should avoid ''convenience samples'' of volunteer industries and implement study designs so that the distribution of age and other important demographic factors is balanced between exposed and control populations to avoid spurious inferences regarding associations between hearing health outcomes and various risk factors.

The collection of more precise hearing and noise data using state-of-the-art instrumentation in epidemiological studies is a crucial foundation for planning public health and intervention campaigns aimed at reducing noise-induced hearing loss in the population, such as that highlighted in *Healthy People 2010*, which identifies and tracks important public health objectives for the nation (U.S. DHHS, 2000).

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