

The Global Burden of Occupational Noise-Induced Hearing Loss

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Background Excessive noise is a global occupational health hazard with considerable social and physiological impacts, including noise-induced hearing loss (NIHL). This paper describes the worldwide morbidity of occupational NIHL in the year 2000.

Methods The proportion of the population exposed to occupational noise was estimated using noise exposure data from the US National Institute for Occupational Safety and Health (NIOSH), adjusted by data on the distribution of the work force by occupational category and economic sector, and economic activity rates in each WHO subregion. These values for the exposed population and risk measures for NIHL were used to develop estimates of the attributable fraction (AF) of adult-onset hearing loss resulting from occupational noise exposure. The AFs were applied to WHO estimates of total disability-adjusted life years (DALYs) from adult-onset hearing loss to estimate the DALYs due to occupational noise.

Results Worldwide, 16% of the disabling hearing loss in adults (over 4 million DALYs) is attributed to occupational noise, ranging from 7% to 21% in the various subregions. The effects of the exposure to occupational noise are larger for males than females in all subregions and higher in the developing regions.

Conclusions Occupational noise is a significant cause of adult-onset hearing loss. The majority of this NIHL burden can be minimized by the use of engineering controls to reduce the generation of noise at its source. Am. J. Ind. Med. 48:446–458, 2005.

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INTRODUCTION

Excessive noise is a pervasive occupational hazard with many adverse effects, including elevated blood pressure, reduced performance, sleeping difficulties, annoyance and stress, tinnitus, noise-induced hearing loss (NIHL), and temporary threshold shift. Of these, the most serious health effect is NIHL resulting from irreversible damage to the delicate hearing mechanisms of the inner ear. NIHL typically involves the frequency range (pitch) of human voices, and thus interferes with spoken communications.

In the United States alone, about 9 million workers are exposed to time-weighted average (TWA) sound levels of

85 dB and above [Simpson and Bruce, 1981, quoted in Suter, 2000], and about 10 million have NIHL >25 decibels (dB) [USDOL-OSHA, 2002]. In the European Union, 28% of workers surveyed reported that at least one-fourth of the time, they are occupationally exposed to noise loud enough that they would have to raise their voices to hold a conversation (corresponds to approximately 85–90 dB) [EASHW, 2000]. Summary statistics on noise exposure are not available for most industrializing and non-industrialized countries; however, high occupational noise exposure levels were reported in 17 studies conducted in 12 countries in South America, Africa, and Asia. These high noise levels occurred in a wide range of workplaces, including manufacture of foods, fabrics, printed materials, metal products, drugs, watches, and in mining (see Table I). Many of these studies reported hearing losses in exposed workers.

Adult-onset hearing loss has been described as the “fifteenth most serious health problem” in the world, with profound effects ranging from social isolation and stigmatization of individuals to serious national economic burdens [Smith, 2004]. Estimates of the number of people affected worldwide by hearing loss increased from 120 million in 1995 [WHO, 1999; WHO, 2001] to 250 million worldwide in 2004 [Smith, 2004]. Much of this impairment may be caused by exposure to noise on the job. The purpose of this study was to estimate the global burden of adult-onset hearing loss resulting from occupational exposure to noise.

MATERIALS AND METHODS

Basic Methodology

The Comparative Risk Assessment (CRA) methodology used throughout WHO in the 2000 Global Burden of Disease project required estimates of the proportion of the population exposed to a risk factor, the approximate level(s) of that exposure, and the resulting relative risk(s) of that exposure, for 14 WHO epidemiological subregions, both genders, and seven age groups [Nelson et al., 2005]. For morbidity and mortality analyses, WHO has grouped its 191 Member States into six geographical regions (Africa, Americas, Europe, Eastern Mediterranean, Southeast Asia, and Western Pacific). These regions are further subdivided into five possible mortality strata (A–E), based on child mortality and adult male mortality, resulting in the 14 epidemiological regions. The A regions have very low child and very low adult mortality; the E regions have high child and very high adult mortality. As examples, the US is classified in America A, while America B includes Jamaica, and Haiti is part of America D [WHO, 2002].

To determine the Global Burden of Occupational Disease and Injury, we determined the proportion of the population exposed to selected occupational risk factors and the levels of those exposures based on economic sector

(where people work) and occupational category (the type of work they do). Using this methodology, we estimated the proportion of workers world-wide exposed to noise at moderately high (85–90 dB) and high (>90 dB) levels, and the relative risks of hearing loss at those exposure levels. The choice of these levels was based on the recommended exposure limits (REL) for occupational noise exposure around the world: 85 dB in most developed countries, and 90 dB in the US and in many developing countries (e.g., [Hessel and Sluis-Cremer, 1987; Alidrisi et al., 1990; Shaikh, 1996; Hernandez-Gaytan et al., 2000; Osibogun et al., 2000; Sriwattanatamma and Breysse, 2000; Ahmed et al., 2001]).

The proportion of the world-wide workforce exposed to moderately high and high noise within each occupational category was based on US NIOSH data from the early 1980s on noise exposure at or above 85 dB for US production workers by industry [NIOSH, 1998]. These values were combined with data on the distribution of the work force by occupational category and economic sector and the economic activity rates (EAR) [see Nelson et al., 2005] to determine the proportion of the population with occupational exposure to noise.

Excess risks for hearing loss >25 dB resulting from moderately high and high noise exposure were taken from an article by Prince et al. [1997] based on US data, and adjusted to match the definition of hearing loss used by WHO, i.e., ≥ 41 dB. Relative risks were estimated from excess risks using data on background hearing loss at given ages taken from England [Davis, 1989]. As global data on the frequency of occurrence, duration, and intensity of noise exposure and the relative risks of that exposure do not exist, the US estimates were adapted to reflect conditions in other WHO subregions. Attributable fractions (in this case, the proportion of adult hearing loss that was caused by occupational exposure to noise) were then calculated by subregion, gender, and age-group. These attributable fractions were multiplied by the WHO estimates of the global disability-adjusted life years (DALYs) resulting from adult-onset hearing loss to obtain estimates of the DALYs attributable to occupational NIHL, stratified by age, gender, and subregion. (DALYs are a summary measure which calculates the years lost from ideal lifespan due to morbidity and premature mortality, thus representing the gap between the current situation, and an ideal situation where everyone achieves standard life expectancy (per the WHO standard, 82.5 years for women, 80 years for men) in perfect health. See Nelson et al. [2005] for further explanation.)

The theoretical minimum exposure was defined as less than 80 dB, a level found not to have an increased risk of causing hearing loss [NIOSH, 1998]. Due to data limitations, it was not possible to estimate frequency of exposure by occupational categories to occupational noise between 80 and 85 dB.

TABLE I. Studies of Noise Exposures and Hearing Impairment in Selected Developing Countries

Country	Facility/job	Sound levels	Hearing loss	Notes	Source
Brazil	Rotogravure printing workers	Continuous noise levels from 71 to 93 dB	Some 49% of 124 workers exposed to noise and organic solvents had hearing loss (>25 dB) in the high frequencies, significantly associated with age		Morata et al. [1997]
Egypt	Road traffic policemen in Cairo	Average 97 dB with horns, 85 without; 97 at railway crossings	About 20-dB loss at all frequencies compared to office policemen		Kamat et al. [1989]
Egypt	Textile factory	78–91 dB in wool sorting and combing units	Compared to nonexposed controls, workers exposed to ≤85 dB had only 1% increase in hearing impairment after 12 years. In workers exposed to >85 dB the increased risk was 9.6%	Hearing impairment was defined as average of left and right ear thresholds at 0.5, 1 and 2 kHz, > 25 dB	Mosehiet al. [1979]
Hong Kong	Five industries: weaving, bottling, metal working, spinning, airport	L_{eq} (8-h time-weighted average, dB): weaving 102; bottling 94; metal working 96; spinning 97; airport 80–90	Compared to controls, noise-exposed workers had significantly higher thresholds in most age groups and in all five industries, closely matching predicted values	No evidence was found for any ethnic differences between western groups and Cantonese Chinese, either in general hearing ability or in response to long-term noise exposure	Evans and Ming [1982]
India	Heavy engineering industry: machine shop and press divisions	Ranged from 83–116 dB. At selected work sites: press 94–110; machine shop 83–92; foundry 86-116	Mean hearing threshold: 40 controls 4–24 dB; 53 machine shop employees 14–40 dB; 60 press employees 19–70 dB	Hearing impairment was progressive with age for all groups. Use of hearing protection was recommended	Raja and Ganguly [1983]
India	Textile mill weavers	102–104 dB	120 weavers, exposed 1–15 years. In the age range 30–34 years, median threshold of audibility in the right/left ear was 55/55 compared to 15/15 for controls; for 35–39-year-olds the threshold was 60/55 compared to 15/15 for controls		Bhattacharya et al. [1981]
India	Drug and pharmaceutical company	Noise levels in dB: fermentation 100–105; air compressor 95–102; ammonia compressor 93–97; primary air filter 104–106. Night shift levels were 1–3 dBA higher	—	Authors recommended engineering controls and hearing conservation programme, including use of hearing protection	Bhattacharya et al. [1990]
India	Watch factory in Bangalore	Maximum noise levels ranged from 74 in assembly to 99 dB in the diesel generator room	—		Mukherjee et al. [1995]
Nigeria	Car assembly	94–108 dB	Hearing thresholds of 165 workers were significantly higher than nonexposed controls, and correlated significantly with employment duration		Oleru et al. [1990]

Nigeria	Textile workers in five factories in Lagos	Continuous noise levels of 95–115 dB	Hearing thresholds of 61 noise-exposed workers were significantly higher than 90 nonexposed controls. After 7 years of employment, exposed workers lost 2–12 dB per year, compared to 0.6–1.8 dB per year in controls	No hearing protection worn. Exposed workers did not display 4000-Hz notch, and the shape of the audiograms ^a was convex upwards, indicating lower losses at the middle frequencies. (Typical audiograms with NIHL display a convex downwards shape, indicating higher losses at the middle frequencies)	Oleru [1980]
Pakistan	Polyester fibre plant	Average noise levels: filament take-up unit 93.2 dB; texturizing unit 94.8 dB; compressor house 99.5 dB	—	Typical exposure is 48 hr per week in these areas. Author recommending engineering controls and hearing conservation, including use of hearing protection	Shaikh [1996]
Saudi Arabia	78 factories producing food, chemicals, plastics, metals, paper and other products	86% exceeded 85 dB, at least in part of the factory. In 12%, all of the factory exceeded 85 dB	—	None of the factories practiced noise protection	Alidrisi et al. [1990]
Singapore	Audiometric testing of noise-exposed workers is mandatory in Singapore. Most cases of noise-induced deafness (NID) are in those employed in shipping and metal manufacturing, the remainder in transport, quarrying and other manufacturing	Noise dosimetry on 46 of these cases showed a mean time-weighted exposure of 90 dB	127 cases of NID identified from 1985–1994. On average, after 24 years of exposure, the mean hearing threshold at 1, 2 and 3 kHz was 62 dB	Author stated that NID is the leading occupational disease in Singapore, with >500 new cases per year	Tay [1996]
South Africa	Gold mining (cross-sectional survey of 2,667 workers in Johannesburg)	Authors quoted a noise survey in which the majority of underground and surface gold mining occupations were exposed above 85 dB	Hearing impairment was defined as average hearing loss of >25 dB for 500, 1,000 and 2,000 Hz, with 5 times weighting of better ear. None of the miners <22 years old had hearing impairment, rising progressively to 22% of those ≥58 years old	Use of hearing protection increased from 13% in 1979 to 17% in 1982	Hessel and Sluis-Cremer [1987]
Sudan	Cotton ginning	99–107 dB	—	Newly mechanized facility	Khogali [1970]
United Arab Republic	Textile industry (El-Mehalla El-Kobra)	Average of 98 dB in 1,200–4,800 Hz range; up to 103 dB	92% (60/73) of workers exposed to noise for ≥10 years in weaving departments had mean hearing impairment of 60 dB compared to 20 dB for control group	Audiometric test methods not described; hearing impairment not defined	Noweir et al. [1968]
Zambia	Copper mines (based on author's experiences as ear, nose, and throat specialist in Zambian copperbelt in 1975–1977)	“Continuous noise”	100 miners tested audiometrically. Of those with over 20 years, 23% were completely deaf	No hearing protection worn by miners	Obiako [1979]

—, no data.

Exposure Assessment

Estimation of exposed population

Occupational exposure to elevated noise levels is dependent on a variety of factors, including: (a) occupation and industry, and (b) workplace-specific factors, such as type of facility and process, raw materials, machinery, tools, the existence of engineering and work practice controls, and existence, condition, and use of personal protective devices. As noise exposure data were available according to occupations, the exposure assessment began with the distribution of the labor force into occupational categories, modified to reflect different noise exposures in occupations in different economic sectors (Eq. 1):

$$PEP(r, g, a) = EAR(r, g, a) * EPF(r) \sum_{i=1}^{63} (PW(oc(r, g)i) * PEW(oc(r, g)i)) \tag{1}$$

Where: PEP (r, g, a) = proportion of the population occupationally exposed to noise in that region, by gender, and age, at moderately high or high levels; EAR(r, g, a) = economic activity rate, by region, gender, and age (calculated as the ratio of the Economically Active Population (EAP) to the total population); EPF(r) = exposure partitioning factor, by region, to delineate proportion exposed to noise at moderately high or at high levels; PWoc(r, g,i) = proportion of the population working in occupational category (i), by region and gender; PEWoc(r, g,i) = proportion of workers in occupational category (i) with exposure to noise, by region and gender.

The calculation was completed for each of the 14 WHO subregions, by gender and age group, to determine the proportion of the population exposed at moderately high or at high noise levels. Factors specific to this analysis of NIHL are discussed below; see Nelson et al. [2005] for details on WHO subregions and on EAR(r, g, a) and PW(oc(r, g)i).

Estimation of the proportion of workers in occupational category (i) with exposure to noise: PEW(oc(r, g)i)

Our estimation of the proportion of workers in each occupational category with exposure to noise at or above 85 dB was based on US data on the extent of noise exposure at or above 85 dB among production workers in nine economic sectors [USDHHS, 1986; NIOSH, 1998] (see Table II). The values in the column labeled “Production” were calculated from the US National Occupational Exposure Survey, conducted during 1981–1983 [NIOSH, 1998], which estimated the number of production workers exposed to noise at or above 85 dB, by economic sector. A value of 0.05 was estimated for professional, administrative, and clerical workers in agriculture, mining, manufacturing, electricity, and construction under the rationale that a small percentage of these primarily office-based workers would spend some time in noisier areas of the workplace. All other values were estimated by us based on the NIOSH values for production workers.

NIOSH [1998] noted that effective use of hearing protective devices would reduce the rate of NIHL in noise-exposed workers. However, due to lack of worldwide data on use of hearing protection, and wide variations observed in

TABLE II. Estimated Proportion of US Workers Exposed to Noise ≥85 dB, by Economic Sector, 1981 – 1983

Economic sector	Occupational category						
	Professional and technical workers	Administrative and managerial workers	Clerical workers	Sales workers	Service workers	Agriculture and forestry workers, fishermen and hunters	Production workers and laborers
Agriculture	0.05	0.05	0.05	0.12	0.12	0.20	0.20
Mining	0.05	0.05	0.05	0.12	0.12	0.20	0.85
Manufacturing	0.05	0.05	0.05	0.12	0.12	0.20	0.22
Electricity	0.05	0.05	0.05	0.12	0.12	0.20	0.15
Construction	0.05	0.05	0.05	0.12	0.12	0.20	0.18
Trade	0.02	0.02	0.02	0.12	0.12	0.20	0.13
Transportation	0.02	0.02	0.02	0.12	0.12	0.20	0.12
Finance ¹	0.02	0.02	0.02	0.12	0.12	0.20	0.02
Services	0.02	0.02	0.02	0.12	0.12	0.20	0.03

Source: Estimates for all economic sectors except mining were adapted from Table 2-1 [NIOSH, 1998], which was based on data collected from 1981–1983 for the National Occupational Exposure Survey. Estimates on noise exposure in mining were adapted from Table 2-2 [NIOSH, 1998], which was based on qualitative data collected 1984–1989 for the National Occupational Health Survey of Mining (NOHSM).

¹Based on 1.5% of workers exposed to noise in “business services.”

actual use of hearing protectors in noise-exposed workplaces, it was assumed in this study that hearing protection is not used. This would result in an overestimate of the rate of NIHL, particularly in industrialized regions with widespread, effective hearing conservation programs.

Estimation of exposure partitioning factor, by region, to delineate the proportions of workers exposed at moderately high and high levels of noise: EPF(r)

The values for proportions of workers exposed to noise at or above 85 dB were then partitioned into moderately high and high noise exposures, i.e., ≥ 85 to 90 dB, and >90 dB to estimate the proportion of workers exposed to moderately high levels and to high levels of noise (EPF(r), exposure partitioning factor). Data from the US [USDHHS, 1986], taken from the 1981 Occupational Safety and Health Administration Final Regulatory Analysis for the Hearing Conservation Amendment, provide the distribution of noise exposure of over nine million US production workers (see Table III). Of the 6,063,000 production workers with exposure at or above 85 dB, slightly over half were exposed above 90 dB (3,407,000, or 56%). The distribution of noise exposure levels among workers exposed over 90 dB was used also to determine that 95 dB is a reasonable level of noise to estimate risks among the workers in the high exposure group (>90 dB). (While the data in Table III are somewhat dated, they were used only to determine the ratio between workers exposed to moderately high versus high noise levels, during an exposure period of interest to determining impacts in the year 2000.)

The partitioning of workers by occupational category and noise level for the A subregions was assigned as follows: Among production workers exposed at or above 85 dB, half were considered as exposed at ≥ 85 –90 dB, and half exposed at >90 dB. Of the agricultural workers and sales and service workers exposed at or above 85 dB, it was assumed that

approximately 70% are exposed at ≥ 85 –90 dB, and 30% at >90 dB. All professional, administrative, and clerical workers with noise exposure at or above 85 dB were assumed to be at the ≥ 85 –90 dB level. These values were adjusted by subregional data on the distribution of the work force by occupational category and economic sector, and the economic activity rate (EAR) to determine the proportion of the population with occupational exposure to noise in each of the A subregions [see Nelson et al., 2005].

In the A regions, the proportion of males exposed to moderately high and high noise levels is consistently higher than for females, due both to higher rates of participation in the labor force, and higher rates of females working in the services sector. The age groups from 30–44 and 45–59 have the largest proportions exposed to occupational noise, corresponding to the ages of peak labor force participation. (The application of US data to the BCDE regions is described in the next section.)

Our analysis included only those who were economically active in the year 2000 and who were in noise-exposed occupations. This assumption would underestimate the population with occupational NIHL by not including those who had previously been in noise-exposed occupations but who were retired at that time. Further, it was assumed that noise-exposed workers aged 30 or younger had been exposed for 5–10 years, and that those over 30 years old had been exposed for greater than 10 years.

Application of US data to other subregions

As described above, this method requires data on the proportion of the population with occupational exposure to excess noise, and the level of those noise exposures, for all 14 WHO subregions, by economic sectors and occupational categories. Such comprehensive data were identified only for the US, requiring application of this data to other subregions. This is a reasonable assumption for the A subregions, given the similarities between occupational health environments in the US and Western Europe, Australia, etc. However, the assumption that noise exposures are at least as widespread and at least as high in the industrializing and non-industrialized nations requires further consideration. Extensive search of the literature indicated that sound level measurements have been reported in at least a dozen developing countries in South America, Asia, and Africa, and have included a wide range of manufacturing and extractive workplaces (see Table I). Most studies provided ranges of sound levels, with the lowest reported noise levels often below 80 dB and the upper levels always above 90 dB. For example, Evans and Ming [1982] reported 8-h time-weighted average exposures in five industries: weaving, 102 dB; bottling, 94 dB; metal working, 96 dB; spinning, 97 dB; and airport, 80–90 dB. Noise levels of 102–104 dB were

TABLE III. Distribution of 9,368,000 Production Workers who had Noise Exposure Levels of 80 dB or Greater—United States

Noise-exposure level (dB)	Number of workers
80–85	3,305,000
86–90	2,656,000
91–95	1,936,000
96–100	965,000
>100	506,000
Total >85	6,063,000
Total >90	3,407,000

Source: adapted from [USDOL OSHA, 1981, cited in NIOSH, 1991].

reported by Bhattacharya et al. [1981] for textile mill weavers. Car assembly in Nigeria was reported to produce noise exposure levels of 94–108 dB [Oleru et al., 1990]. Alidrisi et al. [1990] found that of 78 factories producing a variety of products, in 86% some of the noise levels exceeded 85 dB, and in 12%, all of the noise levels exceeded 85 dB. All the studies that examined the hearing ability of workers revealed increased rates of hearing impairment in noise-exposed workers compared to nonexposed controls.

These reports do not provide comprehensive data on the extent and levels of noise exposures in developing countries by economic sector and occupational category. They do, however, provide evidence that the US-based estimates in Table II are conservative. Noise exposures in the developing countries are probably more widespread and higher than in the US; however, it is not possible to be more precise.

In the absence of global data, it was thus assumed that in the occupational categories described above, the same proportion of workers in the developing countries would be exposed to noise levels at or above 85 dB (B, C, D, and E subregions). Given the rarity of hearing conservation programs in the developing regions, it was assumed that 5% of the production workers would be exposed in the ≥ 85 –90 dB category, and 95% in the > 90 dB category (as opposed to 50/50 for the A subregions). Additionally, because mechanization is not widespread for DE subregions, the majority (95%) of the agricultural workers exposed at or above 85 dB were assigned to the lower of the two categories, i.e., ≥ 85 –90 dB. Assignment of all other occupational categories was the same as for the A subregions. These values were adjusted by subregional data on the distribution of the work force by occupational category and economic sector, and the economic activity rate (EAR) to determine the proportion of the population with occupational exposure to noise in each of the B, C, D, and E subregions [see Nelson et al., 2005].

The proportions of workers with moderately high and high noise exposures in the BCDE regions is higher than in the A regions. Further, the ratios of those exposed at high levels compared to moderately high levels are also higher for the BCDE regions than for the A regions. Worldwide, males and persons in the age groups from 30–40 and 45–59 in the BCDE regions have higher noise exposures than females and other age groups.

Estimating Risk Factor-Disease Relationships

Davis [1989] reported on the prevalence of hearing loss as a function of age in the adult population of Great Britain. Audiometric analyses on adults ranging in age from 17 to over 80 were conducted in four cities in Great Britain. Hearing impairment was reported for > 25 , > 45 , and > 65 dBHL (decibels hearing loss). Davis found a “significant”

level of hearing loss (> 25 dBHL) in 16% of the adult population (17–80+).

NIOSH [1998] in a reanalysis of the data from the NIOSH Occupational Noise and Hearing Survey (ONHS) [Prince et al., 1997] derived excess risk¹ estimates with a model that used the average of 1,000, 2,000, 3,000, and 4,000 Hz and a hearing loss > 25 dBHL. We used this information to develop excess risk estimates for workers exposed at 85–90 dB (defined by us as moderately high exposure) and > 90 dB (defined by us as high noise exposure, equivalent to 95 dB). The data show that at any noise level, hearing impairment increases with age and/or length of exposure. Also, the highest risk is found at the highest levels of exposure. Prince et al. [1997] found a small increase in excess risk in workers exposed to 80–84 dB versus the < 80 dB control group; however, these risk estimates are imprecise due to low numbers of workers in the study exposed to noise at these levels.

As seen in Table IV, excess risk estimates for workers at different ages, with exposure to various levels of noise for different time periods, were obtained directly from or adapted from NIOSH [1998].

Extrapolating from risks at > 25 dB dBHL to risks at ≥ 41 dB dBHL

WHO estimates the prevalence of hearing loss based on a loss of ≥ 41 dBHL, which is considered to be a moderate hearing loss that is easier to quantify around the world, as opposed to the definition of > 25 dBHL, material hearing impairment, which is used by ISO, NIOSH, OSHA, and most industrial standards.² This difference in definition required adjustments of risk values found in the literature. Data from a US nationwide hearing survey [USDOL OSHA, 1981 Final Regulatory Analysis for the Hearing Conservation Amendment, reported in NIOSH, 1991] provided a means of adjusting data on material hearing impairment at > 25 dBHL to > 40 dBHL, a level of hearing loss assumed for this project to be equivalent to the WHO definition of 41 dBHL or greater. Specifically, the number of excess cases of hearing impairment at > 40 dBHL (473,000) was divided by the number of excess cases at > 25 dBHL (1,060,000). The resulting correction factor, 0.446, was used to correct excess risk at

¹ Percentage of the workers with a hearing impairment in an occupationally noise-exposed population after subtracting the percentage who would normally incur such impairment from aging in an unexposed population.

² In 1959 the American Academy of Ophthalmology and Otolaryngology published a method to estimate hearing loss. > 25 dBHL was established as the lower threshold where there was “impairment,” the inability to understand everyday speech under everyday conditions. This value of beginning impairment (a slight impairment) has become the accepted standard for evaluating hearing impairment by most organizations throughout the world. The WHO selected 41 dB or a moderate impairment where a raised voice would have to be used to understand everyday speech under everyday conditions. WHO considered this value to be a more practical value to measure hearing loss worldwide [AAOO, 1959].

TABLE IV. Excess Risk (%) Estimates for Material Hearing Impairment >25 dBHL, by Age and Duration of Exposure

Average daily exposure (dB)	<Age 30	Age 30	Age 40	Age 50	Age 60
	5–10 years of exposure		>10 years of exposure		
	Excess risk (%)				
95	19.5 ^a	24 ^b	31 ^b	38 ^b	38.3 ^c
90	5.4 ^d	10.3 ^d	17.5 ^d	24.1 ^d	24.7 ^d
85	1.4 ^d	2.3 ^d	4.3 ^d	6.7 ^d	7.9 ^d
80	0.2b ^d	0.3 ^d	0.6 ^d	1 ^d	1.3 ^d

^aNIOSH [1998], Appendix, Figure 4, page 100.

^bEstimated from footnotes (a) and (d).

^cNIOSH [1998], Appendix, Table IV (page 98).

^dNIOSH [1998], Table 3–3, page 23.

>25 dBHL from the NIOSH excess risk in Table IV to the excess risk at 41 dBHL or greater as presented in Table V.

Relative risk estimation for NIHL at 41 dB or greater

The relative risk values were extrapolated using Equation 2:

$$\text{Relative risk} = 1 + (\text{excess risk/expected risk}) \quad (2)$$

Excess risk is defined in this study as “the percentage of the workers with a hearing impairment in an occupationally noise-exposed population after subtracting the percentage who would normally incur such impairment from aging in an unexposed population.” The expected risk is the risk for the general unexposed population. Data from Davis [1989], which estimated the prevalence of hearing loss >45 dBHL as a function of age in the adult population of Great Britain, were used to create Table VI.

Where necessary to adjust our estimates to fit the age groups utilized in the WHO Global Burden of Disease Study, these adjustments were made using geometric means of excess risk estimates, worker-population weighted averages, and/or estimates from the nearest age group for which data

were available (children under age 15 were not included in this study, as consistent data on economic activity levels, exposures, and risks of exposures are not available. Also, WHO calculates DALYs for adult-onset hearing loss beginning at age 15).

After retirement, no further occupational noise exposure loss would occur and, therefore, no additional occupational NIHL would take place. However, as NIHL is an irreversible condition, workers who develop hearing loss prior to retirement will continue to have any pre-existing hearing loss. Therefore, the excess risk values from the age group 60–69 were applied to the older groups. For workers who do not retire at ages 60–69, the relative risk would decrease due to the increasing expected risk of presbycusis. Data indicate that by age 80, the relative risk would be essentially equal to 1.0. The excess risk of NIHL for these older noise-exposed workers would essentially equal the expected general population disabling hearing loss (i.e., the attributable fraction would drop to zero). The same relative risks were applied to each subregion and both sexes. Table VII presents our calculated relative risks, based on Equation 2 and the excess and expected risks discussed above.

The attributable fraction (AF) of hearing loss due to occupational exposure to noise was determined by combin-

TABLE V. Estimated Excess Risk for Hearing Impairment at 41 dBHL or Greater, by Age and Duration of the Exposure

Average daily exposure (dB)	<Age 30	Age 30	Age 40	Age 50	Age 60
	5–10 years of exposure		>10 years of exposure		
	Excess risk (%)				
95	8.7	10.7	13.8	16.9	17.0
90	2.4	4.6	7.8	10.7	11.0
85	0.6	1.0	1.9	3.0	3.5
80	0.1	0.1	0.3	0.4	0.6

TABLE VI. Prevalence of Hearing Loss >45 dBHL for the General Population in Great Britain [Davis, 1988]

Age group	Prevalence
17–30	1.25
31–40	1.90
41–50	4.75
51–60	6.40
61–70	9.35
71–80	16.55
81+	25.35

ing the fraction of the population (f_i) exposed to occupational noise at moderately high or high levels and the corresponding relative risks of that exposure (RR_i), as shown in Equation 3.

$$AF = \frac{(\sum_{i=0}^k f_i RR_i - 1)}{(\sum_{i=0}^k f_i RR_i)} \quad (3)$$

The subregion-, gender-, and age-specific AFs thus determined were then multiplied by the subregion-, gender-, and age-specific DALYs resulting from adult-onset hearing loss (previously determined by WHO using a wide range of data sources, including disease registers, population surveys, epidemiological studies, and health facility data). These specific values were summed to determine the regional and global burdens of hearing loss resulting from occupational exposure to noise, expressed as DALYs. Further details on the WHO methodology for calculating DALYs are provided in Nelson et al. [2005].

RESULTS

Worldwide, the burden attributed to occupational noise is 16%, ranging from 7% in the Western Pacific A subregion to 21% in the Western Pacific B subregion. Table VIII and Figure 1 show the AFs by sex and age group in all subregions. The effects of the exposure to occupational noise are larger for males than females in all subregions. Males usually experience greater exposure to noise at work than females, due to differences in occupational categories, economic sectors of employment, and working lifetime. In this study,

TABLE VII. Calculated Relative Risks by Age Group and Level of Exposure

Level of exposure	Age, years					
	15–29	30–44	45–59	60–69	70–79	80+
<85 dB	1.00	1.00	1.00	1.00	1.00	1.00
85–90 dB	1.96	2.24	1.91	1.66	1.12	1.00
>90 dB	7.96	5.62	3.83	2.82	1.62	1.00

AF decreases by age group after 30–44, indicating the heavy impact of occupational noise in the burden of hearing loss in younger ages. (A hearing loss sustained at a younger age will result in a longer duration of disability, thus contributing more years to the DALY calculation.) The burden of occupational NIHL is generally higher in the less developed regions of the world.

Table IX provides estimates of the number of DALYs (in thousands) produced by occupational NIHL by WHO subregion and age group in the year 2000. Occupational NIHL accounted for more than four million DALYs, all of them produced by the disability associated with the hearing loss (years lived with disability, or YLDs). The number of DALYs is greater in males than in females in all subregions.

DISCUSSION

A significant proportion of the disabling hearing difficulties around the world—16%—results from excessive exposure to noise in the workplace. The first signs of NIHL can be observed in the typical 4000-Hz “notch” observed on audiograms, indicating a loss of hearing ability in the middle of the frequency range of human voices. The notch grows deeper and wider with continued noise exposure, causing increasing impacts on speech communications (leading to social isolation and difficulties at home, work, and school), and disrupting the lives of those directly impacted, as well as their families, friends, and co-workers.

This burden is not distributed evenly among all workers, but is heaviest among certain occupations (e.g., production workers) and economic sectors (e.g., manufacturing, mining, and construction). A heavier burden is borne by males (2.8 million DALYs) as compared to females (1.4 million DALYs). Worldwide, males enter the work force at an earlier age than females, and remain there at higher participation rates than females throughout their lives in all regions of the world [refer to economic activity rate tables in Nelson et al., 2005]. Males are also represented at higher rates in economic sectors with high noise exposures: mining, manufacturing, utilities, and construction.

The BCDE regions (with 83% of the world’s working age population) account for 85% of all adult-onset hearing loss, while the A regions (with 17% of the working age population) account for 15%. However, the occupational NIHL burden is much heavier in the developing world, with over 3.8 million DALYs in the BCDE regions, and only about 0.3 million in the A regions. On a per capita basis, workers aged 15 and above in these regions experience more than twice the DALYS experienced in the A regions. The implications of hearing loss from any cause are more serious in the developing world, where services, staff, and awareness are in limited supply [Smith, 2004].

This analysis could not have been conducted without making a number of assumptions. Several uncertainties

TABLE VIII. Fraction (%) of Adult-onset Hearing Loss Attributable to Occupational NIHL, by WHO Subregion, Age Group and Gender

Subregion	Age group, years ^a												All
	15 to 29		30 to 44		45 to 59		60 to 69		70 to 79		Total		
	M	F	M	F	M	F	M	F	M	F	M	F	
AFR-D	25	11	26	14	18	10	12	6	3	1	23	11	17
AFR-E	25	13	26	14	18	11	12	6	3	1	23	12	18
AMR-A	20	9	20	9	14	6	9	3	2	1	12	5	9
AMR-B	30	15	28	14	19	10	13	5	3	1	19	9	15
AMR-D	29	16	27	15	18	10	12	5	3	1	18	9	14
EMR-B	29	13	27	12	19	8	12	5	3	1	20	9	15
EMR-D	25	15	25	17	18	12	12	7	3	1	20	13	16
EUR-A	20	9	20	9	14	6	9	3	2	1	13	5	9
EUR-B	36	21	33	20	23	14	15	8	4	1	24	13	19
EUR-C	38	24	35	22	25	15	16	8	5	2	24	13	18
SEAR-B	33	23	32	23	22	16	14	9	4	2	23	16	19
SEAR-D	28	15	30	12	22	8	14	4	3	1	24	9	16
WPR-A	20	12	20	12	14	8	8	4	2	1	9	6	7
WPR-B	34	21	32	20	23	14	15	8	4	1	26	15	21
World	29	16	29	16	21	11	13	6	3	1	22	11	16

^aAttributable fraction was set to zero for ≥ 80 .

arising from the assumptions made in this analysis regarding exposure assessment and estimates of relative risks have been discussed: modification of US data on extent and levels of noise exposure for use in all subregions; exclusion of children under age 15 and older retired workers; exposure duration in persons ≤ 30 as compared to those >30 years old; not considering use of hearing protection; and use of data on

material hearing impairment at >40 dBHL as compared to WHO's threshold of ≥ 41 dBHL.

Further, it was assumed that given the same level of exposure, all persons (males and females, in developed and developing countries) would develop the same hearing loss. The published literature indicates, for example, that construction workers in the US and in Germany have nearly

Attributable fraction (%) for occupational NIHL by WHO subregion and gender

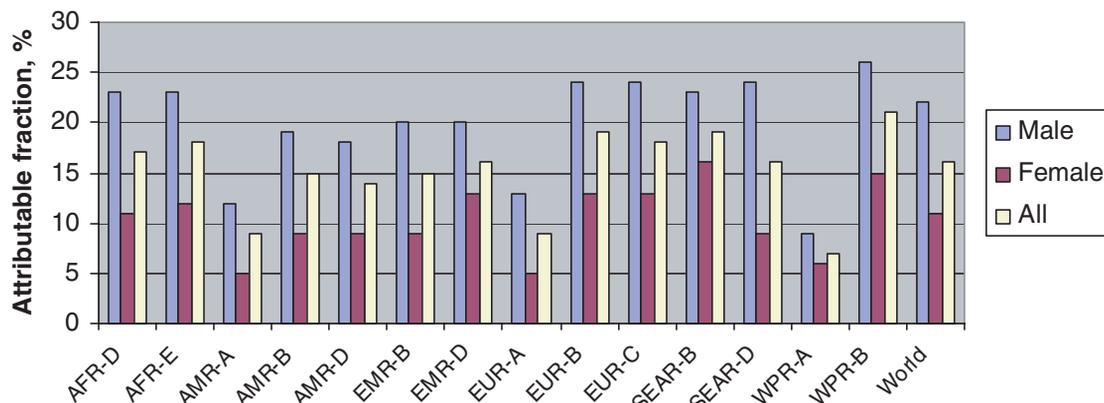


FIGURE 1. Attributable fraction (%) of adult-onset hearing loss due to occupational noise exposure, by WHO subregion and gender.

TABLE IX. Attributable DALYs (in thousands) due to Occupational NIHL by Age Group, Sex and Subregion

Subregion	Age group, years ^a												All
	15 to 29		30 to 44		45 to 59		60 to 69		70 to 79		Total		
	M	F	M	F	M	F	M	F	M	F	M	F	
AFR-D	32	15	60	22	13	10	4	2	1	0	109	49	157
AFR-E	53	19	55	26	13	12	5	2	0	0	127	60	186
AMR-A	6	4	31	9	39	13	13	5	3	1	92	31	123
AMR-B	6	2	56	15	41	19	16	6	2	1	122	43	165
AMR-D	1	1	6	2	5	2	2	1	0	0	15	6	20
EMR-B	6	3	18	7	30	10	6	2	0	0	60	21	81
EMR-D	21	13	54	32	55	36	11	7	1	0	142	88	230
EUR-A	13	5	45	20	39	13	18	9	3	1	117	47	164
EUR-B	17	8	37	20	25	14	11	7	1	1	92	50	142
EUR-C	13	6	43	29	52	39	26	17	2	2	136	92	228
SEAR-B	21	16	75	62	94	83	28	23	1	1	219	185	404
SEAR-D	99	53	324	115	317	113	55	21	3	1	799	303	1101
WPR-A	1	1	5	6	10	10	9	5	1	1	26	22	48
WPR-B	137	62	336	166	192	108	66	28	4	2	735	365	1100
World	425	206	1144	530	925	482	271	136	23	9	2788	1362	4151

^aAttributable fraction was set to zero for ≥ 80 .

equal hearing loss for similar length of exposure [see Arndt et al., 1996; Waitzman and Smith, 1999]. As Evans and Ming [1982] found no differences between Western groups and Cantonese Chinese, it was assumed that the relative risk estimates apply to all regions.

Another source of uncertainty is the fact that the comparison group for occupational studies is typically the white-collar population in a variety of industries [e.g., Prince et al., 1997]. In reality, this group does have some noise exposure, although very low, and they may in fact develop some hearing loss in excess of the general population, again at a low rate. The use of the white-collar group as the comparison would tend to reduce the relative risk values determined in the epidemiologic studies. This is not considered to be as significant a source of uncertainty as the difference in general environmental noise in different locations.

Some of these assumptions would lead to an underestimate of the burden of occupational NIHL, including the exclusion of children under 15, and the use of white-collar workers as the comparison group in occupational studies. Not considering the benefits of using hearing protection would lead to an overestimate. In other cases, e.g. applying the same relative risk values to males and to females, and in the developing and developed world, or the slightly different age groups used in different reference sources [e.g., in Davis, 1988; NIOSH, 1998], it is far more difficult to know the impact of the assumption. While there are many uncertainties

in our estimates due to lack of global data on extent and level of occupational noise exposure, this project has established an analytical framework which can contribute to the case for committing public health resources to occupational health programs. Developing better data will allow future researchers to build an even stronger case to support the critical need to protect workers from occupational NIHL [see, e.g., WHO, 2004].

CONCLUSION

Our findings indicate that occupational noise is an important risk factor of hearing loss in workers at most ages, ranging from 7% to 21% (averaging 16%) of the adult-onset hearing loss around the world. The burden of hearing loss caused by exposure to occupational noise has multiple consequences at both the individual and the societal levels. While multiple factors contribute to the occurrence of occupational NIHL, lack of prevention is the major contributor. Most occupational noise exposure can be minimized by the use of engineering controls to reduce the generation of noise at its source. Complete hearing loss prevention programs that include noise assessments, noise controls, audiometric monitoring of workers' hearing, appropriate use of hearing protectors, worker education, record keeping, and program evaluation are needed to effectively reduce the global burden of occupational NIHL. Successfully implementing hearing loss prevention pro-

grams does require commitment and resources; however, they are proven to be effective. The use of such programs in the developed countries has resulted in the currently decreasing incidence of hearing loss secondary to high noise levels in the workplace.

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