

Environmental Burden of Disease Series, No. 9

Occupational noise

Assessing the burden of disease from work-related hearing impairment at national and local levels

Marisol Concha-Barrientos
Diarmid Campbell-Lendrum
Kyle Steenland

Series Editors

Annette Prüss-Üstün, Diarmid Campbell-Lendrum, Carlos Corvalán, Alistair Woodward



World Health Organization
Protection of the Human Environment
Geneva 2004

WHO Library Cataloguing-in-Publication Data

Concha-Barrientos, Marisol.

Occupational noise : assessing the burden of disease from work-related hearing impairment at national and local levels / Marisol Concha-Barrientos, Diarmid Campbell-Lendrum, Kyle Steenland.

(Environmental burden of disease series / series editors: Annette Prüss-Üstün [et al.] ; no. 9)

1.Noise, Occupational - adverse effects 2.Hearing loss, Noise-induced - epidemiology 3.Risk factors 4.Occupational exposure - analysis 5.Cost of illness 6.Risk assessment - methods 7.Guidelines I.Campbell-Lendrum, Diarmid H. II.Steenland, Kyle. III.Prüss-Üstün, Annette. IV.Series.

ISBN 92 4 159192 7
ISSN 1728-1652

(NLM classification: WA 470)

Suggested citation

Concha-Barrientos M, Campbell-Lendrum D, Steenland K. *Occupational noise : assessing the burden of disease from work-related hearing impairment at national and local levels*. Geneva, World Health Organization, 2004. (WHO Environmental Burden of Disease Series, No. 9).

© World Health Organization 2004

All rights reserved. Publications of the World Health Organization can be obtained from Marketing and Dissemination, World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland (tel: +41 22 791 2476; fax: +41 22 791 4857; email: bookorders@who.int). Requests for permission to reproduce or translate WHO publications – whether for sale or for noncommercial distribution – should be addressed to Publications, at the above address (fax: +41 22 791 4806; email: permissions@who.int).

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by the World Health Organization in preference to others of a similar nature that are not mentioned. Errors and omissions excepted, the names of proprietary products are distinguished by initial capital letters.

The World Health Organization does not warrant that the information contained in this publication is complete and correct and shall not be liable for any damages incurred as a result of its use.

The named authors alone are responsible for the views expressed in this publication.

Printed by the WHO Document Production Services, Geneva, Switzerland.

Table of contents

Preface	v
Affiliations and acknowledgements	vi
Summary	vii
1. Introduction	1
2. Summary of the methodology	2
3. The risk factor and its health outcomes	3
3.1 Measuring noise levels	3
3.2 Disease outcomes related to the risk factor	3
3.3 The strength of the evidence for disease outcomes	4
3.4 Health outcomes to include in the burden of disease assessment	8
4. Exposure	10
4.1 Definition of the exposure indicator	10
4.2 Determining the distribution of exposure in the population	10
5. Estimating relative risks for health outcomes, by exposure level	16
6. Estimating the attributable fraction and the disease burden	18
6.1 Calculating the attributable fraction	18
6.2 Calculating the disease burden	18
7. Uncertainty	20
7.1 Uncertainty in exposure estimates	20
7.2 Uncertainty in relative risk estimates	20
8. Policy implications	21
9. References	23
Annex 1. Summary results of the Global Burden of Disease assessment for occupational noise	26
References to Annex 1	32

List of tables

Table 1	Assessment of reported responses to occupational noise exposure	5
Table 2	Prevalence ratio for occupational noise-induced hearing impairment	7
Table 3	Definition of hearing impairment	9
Table 4	Proportion of workers in each occupational category and economic subsector exposed to noise levels >85 dB(A)	12
Table 5	Assessing occupational exposure to noise	14
Table 6	Proportion of the working-age population in the USA occupationally exposed to noise levels of 85–90 dB(A) and >90 dB(A), by gender	15
Table 7	Relative risks for hearing loss by sex, age group and level of occupational exposure	17
Table A.1	Country groupings for the WHO subregions in the Global Burden of Disease assessment	27
Table A.2	Proportions of the working-age population occupationally exposed to different noise levels, by sex and subregion	29
Table A.3	DALYs attributable to occupational noise for the 14 WHO global subregions	31

Figure

Figure A.1	Subregional country groupings for the global disease burden	26
------------	---	----

Preface

Policy-makers increasingly rely on measurements of the disease burden of risk factors, and how the burden is distributed by socioeconomic status, to develop rational policies and effective interventions. Despite the growing importance of objective measurements, the health effects of many occupational risk factors have not been quantified. In addition, many workplace risk factors contribute only to disability and not to mortality, and are therefore poorly described by estimates of the number of deaths. Both of these issues have contributed to an underestimation of the effects of occupational risks on the overall health of communities. One of the clearest examples of a risk that has been underestimated is occupational noise that leads to hearing impairment.

The World Health Organization (WHO) carried out an assessment of the global disease burden from occupational noise, as part of a larger initiative to assess the impact of 25 risk factors in a standardized manner (WHO, 2002). This guide builds on the global assessment, by providing a tool for occupational health professionals to carry out more-detailed estimates of the disease burden associated with hearing loss from occupational noise at both national or subnational levels. It is complemented by an introductory volume on methods for assessing the environmental burden of disease (Prüss-Üstün et al., 2003).

The present guide describes how to quantify the burden of disease associated with hearing impairment from occupational noise. The following topics are described:

- noise characteristics and their relevance to workers' health;
- criteria for selecting health outcomes for the burden of disease assessment;
- methods of assessing exposure to workplace noise, for all segments of a population;
- relative risk data for the main health outcome of occupational noise;
- procedures for generating a summary measure of the burden of disease from occupational noise;
- sources of uncertainty in disease burden estimates;
- policy implications.

Affiliations and acknowledgements

This document was prepared by Marisol Concha-Barrientos, Diarmid Campbell-Lendrum and Kyle Steenland. The Environmental Burden of Disease series is edited by Annette Prüss-Üstün, Diarmid Campbell-Lendrum, Alistair Woodward and Carlos Corvalán. Marisol Concha-Barrientos is at the Asociacion Chilena de Seguridad. Diarmid Campbell-Lendrum, Carlos Corvalán and Annette Prüss-Üstün are at the World Health Organization. Kyle Steenland is at the Rollins School of Public Health, Emory University, and Alistair Woodward is at the School of Population Health, University of Auckland.

In preparing this document, we drew on methods developed for estimating the global burden of disease caused by occupational noise. We therefore thank the additional co-authors of the global analysis, Deboral Imel Nelson and Marilyn Fingerhut, as well as all the reviewers of that report.

We also thank the US Environmental Protection Agency for supporting the development of the Environmental Burden of Disease approaches. Finally, we are grateful to Kevin Farrell for editorial comments, and to Eileen Brown for putting this document into its final format.

Glossary of terms and list of abbreviations

AF	Attributable fraction (also referred to as the impact fraction). The proportion of the disease burden in a population that can be attributed to a specific risk factor.
DALY	Disability-adjusted life year.
dB	Decibel – units used to measure sound pressure levels on a logarithmic scale.
dB(A)	A-weighted decibel – a measure of sound levels as experienced by humans, calculated using a spectral sensitivity factor (A-filter) that weights sound pressure levels by frequency to correspond to the sensitivity of the human ear.
DBHL	Decibel hearing loss – units used to measure the degree of hearing loss at a specified frequency, relative to a standard of normal hearing.
ILO	International Labour Organization.
$L_{Aeq, 8h}$	Equivalent sound levels, measured over an exposure period of 8 h.
NIHL	Noise-induced hearing loss.
USA	United States of America.
WHO	World Health Organization.

Summary

This guide outlines a method for estimating the disease burden of hearing loss caused by high levels of noise in the workplace, at national, city or local levels. The method assesses exposure at two noise levels (85–90 and >90 dB(A)), and by occupational category and economic subsector. These measurements are combined with the proportions of the working population in different occupations and subsectors, and with the proportion of the working-age population that is employed, by gender. All of the data can be obtained either from national statistics, the International Labour Organization (ILO), WHO, or by extrapolating from existing studies.

The information on exposure is then combined with estimates of the relative risks of developing noise-induced hearing loss (NIHL), derived from literature reviews. This gives the attributable fraction (i.e. the proportion of the total burden of NIHL in the study population that is caused by occupational noise). To give the total disease burden caused by occupational NIHL, the attributable fraction is multiplied by the total disease burden for NIHL. Total disease burden statistics can be obtained either from national statistics, national burden of disease studies, or from WHO. Depending on the aim of the assessment, the attributable burden can be expressed in terms of the incidence of NIHL, or as disability-adjusted life years (DALYs).

In addition to providing aggregate estimates, the method in the guide can be used to highlight the health impacts on population subgroups at particular risk, such as occupational subgroups or women, provided that exposure in these subgroups is assessed separately. The quantification of the health impacts also provides an opportunity to highlight the disease burden that could be avoided by interventions to reduce occupational noise exposures. This can motivate policy action to reduce exposure to this risk factor and thus reduce the disease burden of the population.

1. Introduction

Physically, there is no difference between sound and noise. Sound is a sensory perception and noise corresponds to undesired sound. By extension, noise is any unwarranted disturbance within a useful frequency band (NIOSH, 1991). Noise is present in every human activity, and when assessing its impact on human well-being it is usually classified either as occupational noise (i.e. noise in the workplace), or as environmental noise, which includes noise in all other settings, whether at the community, residential, or domestic level (e.g. traffic, playgrounds, sports, music). This guide concerns only occupational noise; the health effects of environmental noise are covered in a separate publication (de Hollander et al., 2004).

High levels of occupational noise remain a problem in all regions of the world. In the United States of America (USA), for example, more than 30 million workers are exposed to hazardous noise (NIOSH, 1998). In Germany, 4–5 million people (12–15% of the workforce) are exposed to noise levels defined as hazardous by WHO (WHO, 2001). Although noise is associated with almost every work activity, some activities are associated with particularly high levels of noise, the most important of which are working with impact processes, handling certain types of materials, and flying commercial jets. Occupations at highest risk for NIHL include those in manufacturing, transportation, mining, construction, agriculture and the military.

The situation is improving in developed countries, as more widespread appreciation of the hazard has led to the introduction of protective measures. Data for developing countries are scarce, but available evidence suggests that average noise levels are well above the occupational level recommended in many developed nations (Suter, 2000; WHO/FIOH, 2001). The average noise levels in developing countries may be increasing because industrialization is not always accompanied by protection.

There are therefore several reasons to assess the burden of disease from occupational noise at country or subnational levels. Occupational noise is a widespread risk factor, with a strong evidence base linking it to an important health outcome (hearing loss). It is also distinct from environmental noise, in that it is by definition associated with the workplace, and is therefore the responsibility of employers as well as individuals. An assessment of the burden of disease associated with occupational noise can help guide policy and focus research on this problem. This is particularly important in light of the fact that policy and practical measures can be used to reduce exposure to occupational noise (WHO/FIOH, 2001).

2. Summary of the methodology

The approach used in this guide has the following steps:

Describe the risk factor and its health outcomes (Section 3):

- characterize the risk factor;
- identify all disease outcomes related to the risk factor;
- describe the strength of evidence of their association.

Assess exposure (Section 4):

- choose an indicator;
- compile exposure data.

Select risk levels and corresponding relative risk values (Section 5).

Estimate the attributable fraction and disease burden (Section 6).

Describe the sources of uncertainty (Section 7).

These steps are now described in more detail in Sections 3–7.

3. The risk factor and its health outcomes

3.1 Measuring noise levels

There are a variety of metrics for quantifying noise levels, the most useful of which for measuring sound as a health hazard is described in de Hollander et al. (2004). In general, these metrics are based on physical quantities, which are “corrected” to account for the sensitivity of people to noise. These corrections depend on the noise frequency and characteristics (impulse, intermittent or continuous noise levels), and the source of noise. The following measures are most relevant for assessing occupational noise levels.

Sound pressure level. The sound pressure level (L) is a measure of the air vibrations that make up sound. Because the human ear can detect a wide range of sound pressure levels (from 20 μ Pa to 200 Pa), they are measured on a logarithmic scale with units of decibels (dB) to indicate the loudness of a sound.

Sound level. The human ear is not equally sensitive to sounds at different frequencies. To account for the perceived loudness of a sound, a spectral sensitivity factor is used to weight the sound pressure level at different frequencies (A-filter). These A-weighted sound pressure levels are expressed in units of dB(A).

Equivalent sound levels. When sound levels fluctuate in time, which is often the case for occupational noise, the equivalent sound level is determined over a specific time period. In this guide, the A-weighted sound level is averaged over a period of time (T) and is designated by $L_{Aeq,T}$. A common exposure period, T, in occupational studies and regulations is 8 h, and the parameter is designated by the symbol, $L_{Aeq,8h}$.

3.2 Disease outcomes related to the risk factor

In general, the health consequences of a given level of occupational noise are likely to be similar, regardless of the country or region in which the exposure occurs. A single review has therefore been carried out of all well-designed epidemiological studies that link occupational noise exposure to health outcomes, regardless of where the study was conducted.

The review of the literature indicates that noise has a series of health effects, in addition to hearing impairment (Table 1). Some of these, such as sleep deprivation, are important in the context of environmental noise, but are less likely to be associated with noise in the workplace. Other consequences of workplace noise, such as annoyance, hypertension, disturbance of psychosocial well-being, and psychiatric disorders have also been described (de Hollander et al., 2004).

For occupational noise, the best characterized health outcome is hearing impairment. The first effects of exposure to excess noise are typically an increase in the threshold of hearing (threshold shift), as assessed by audiometry. This is defined as a change in hearing thresholds of an average 10 dB or more at 2000, 3000 and 4000 Hz in either ear (poorer hearing) (NIOSH, 1998). NIHL is measured by comparing the threshold

of hearing at a specified frequency with a specified standard of normal hearing, and is reported in units of decibel hearing loss (dBHL).

Threshold shift is the precursor of NIHL, the main outcome of occupational noise. It corresponds to a permanent increase in the threshold of hearing that may be accompanied by tinnitus. Because hearing impairment is usually gradual, the affected worker will not notice changes in hearing ability until a large threshold shift has occurred. Noise-induced hearing impairment occurs predominantly at higher frequencies (3000–6000 Hz), with the largest effect at 4000 Hz. It is irreversible and increases in severity with continued exposure.

The consequences of NIHL include:

- social isolation;
- impaired communication with coworkers and family;
- decreased ability to monitor the work environment (warning signals, equipment sounds);
- increased injuries from impaired communication and isolation;
- anxiety, irritability, decreased self-esteem;
- lost productivity;
- expenses for workers' compensation and hearing aids.

3.3 The strength of the evidence for disease outcomes

The mechanisms linking occupational noise to the health outcomes described in the following section are relatively direct, and are unlikely to be specific to particular countries or regions. Therefore, although it is useful to obtain local data on the strength of relationships, other studies are usually relevant for assessing the strength of evidence for causality.

Evidence is usually assessed on the grounds of biological plausibility, strength and consistency of association, independence of confounding variables and reversibility (Hill, 1965). From a review of the literature, de Hollander et al. (2004) concluded that psychosocial well-being, psychiatric disorders, and effects on performance are plausible outcomes, but are only weakly supported by epidemiological evidence. Other plausible outcomes include biochemical effects, immune system effects, and birth-weight effects, but again there is limited evidence to support these outcomes.

Table 1 Assessment of reported responses to occupational noise exposure^a

Outcome	Evidence^b	Observation threshold (dB(A))
Performance	limited	
Biochemical effects	limited	
Immune effects	limited	
Birth weight	limited	
Annoyance	sufficient	<55 (office) <85 (industry)
Hypertension	sufficient	55–116
Hearing loss (adults)	sufficient	75
(unborn children)	sufficient	<85

^a Source: adapted from HCN (1999) and de Hollander et al. (2004).

^b Evidence describes the strength of evidence for a causal relationship between noise exposure and the specified health endpoint.

There is stronger evidence of noise-based annoyance, defined as “a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with someone’s thoughts, feelings or daily activities” (Passchier-Vermeer, 1993). Noise annoyance is always assessed at the level of populations, using questionnaires. There is consistent evidence for annoyance in populations exposed for more than one year to sound levels of 37 dB(A), and severe annoyance at about 42 dB(A). Studies have been carried out in Western Europe, Australia and the USA, but there are no comparable studies in developing countries. There is little doubt that annoyance from noise adversely affects human well-being.

A recent meta-analysis reviewed the effects of occupational and environmental noise on a variety of cardiovascular risks, including hypertension, use of anti-hypertension drugs, consultation with a general practitioner or specialist, use of cardiovascular medicines, angina pectoris, myocardial infarction and prevalence of ischaemic heart disease (van Kempen et al., 2002). The analysis showed an association with hypertension, but only limited evidence for an association with the other health outcomes. Reasons for the limited evidence included methodological weaknesses, such as poor (retrospective) exposure assessment, poorly controlled confounding variables, and selection bias (such as the “healthy worker” effect, where the studied populations exclude the least healthy individuals, who may already be absent from work through disability). The meta-analysis showed inconsistencies among individual studies, and summary relative risks were statistically significant in only a limited number of cases. Overall, the causal link is plausible, and the meta-analysis provides support for further investigation of cardiovascular effects in the future. However, the evidence base was not considered to be strong enough for inclusion in the meta-analysis. Consequently, cardiovascular effects were not included in the Global Burden of Disease study, and methods for estimating the cardiovascular effects of noise were not defined (Concha-Barrientos et al., 2004). This guide does not therefore provide information for assessing the cardiovascular effects of noise at national or local levels.

In contrast, it is generally accepted that the link between occupational noise and hearing loss is biologically obvious (i.e. there is a clear mechanistic pathway between the physical properties of noise and damage to the hearing system). The link is also supported by epidemiological studies that compared the prevalence of hearing loss in different categories of occupations, or in particularly noisy occupations (e.g. Arndt et al., 1996; Waitzman & Smith, 1998; Hessel, 2000; Palmer, Pannett & Griffin, 2001). The studies showed a strong association between occupational noise and NIHL, an effect that increased with the duration and magnitude of the noise exposure. For example, the risk for “blue-collar” construction workers was 2 to >3.5-fold greater than that for “white-collar” workers in other industries (Waitzman & Smith, 1998) (Table 2). Although other factors may also contribute to hearing loss, such as exposure to vibrations, ototoxic drugs and some chemicals, the association with occupational noise remains robust after accounting for these influences. There is also epidemiological evidence for an effect of high levels of occupational exposure on hearing loss in unborn children (e.g. Lalande, Hetu & Lambert, 1986), but there was not considered to be enough information to calculate associated impacts for the Global Burden of Disease study, and it is not covered further in this guide.

Table 2 Prevalence ratio for occupational noise-induced hearing impairment^a

Country	Source	Definition of hearing impairment	Population group	Prevalence ratio	95% CI ^b
Germany	Arndt et al. (1996)	Greater than 105 dBHL at 2, 3 or 4 kHz (corresponds to >35 dBHL).	Carpenters	1.77	1.48–2.12
			Unskilled workers	1.75	1.47–2.09
			Plumbers	1.49	1.19–1.85
			Painters	1.20	0.96–1.49
			Plasterers	1.29	1.05–1.59
			Blue-collar workers	1.00	
			Overall	1.50	1.29–1.82
Canada	Hessel (2000)	Greater than 105 dB HL at 2, 3 or 4 kHz (corresponds to >35 dBHL).	Plumbers	2.91	NA ^c
			Boilermakers	3.88	NA
			Electricians	1.46	NA
			White-collar workers	1.00	NA
Great Britain ^d	Palmer, Pannett & Griffin (2001)	Severe: wearing a hearing aid, or having great difficulty in both ears in hearing conversation in a quiet room (equivalent to >45 dBHL). Moderate and worse: reported moderate difficulty in hearing conversation in a quiet room (equivalent to 45 dBHL).	Male	2.90	NA
			Female	1.80	NA
			Male	3.60	NA
			Female	2.90	NA

^a The data are taken from all available studies. ^b CI = confidence interval. ^c NA = not available in the original study.

^d Prevalence ratios are based on self-reported hearing impairment. Prevalence of “ever employed in a noisy job” was compared against “never exposed in a noisy job”. A noisy job was defined as one “where there was a need to shout to be heard”.

3.4 Health outcomes to include in the burden of disease assessment

The selection of a health outcome should be made principally on the strength of the evidence of causality and on the availability of information for quantifying health impacts. It is also important that the health outcome has been assessed within the study population, or can reasonably be extrapolated from other populations. There are several possible sources for health statistics, including national health statistics, a national burden of disease study, or “prior estimates” provided by WHO. More details about these sources are provided in the introductory volume to this series (Prüss-Üstün et al., 2003).

Depending on the aim of the study, it may be preferable to assess disease burden in terms of attributable disease incidence, or overall disease burden, using summary measures of population health such as DALYs (Murray, Salomon & Mathers, 2000). This will allow the health burden to be compared for different geographical areas, and with the health burden from other risk factors. A goal of burden of disease assessments is to maximize the compatibility of frameworks for assessing the burden of disease for risk factors. Using the same framework promotes this goal by ensuring that the same method is used to measure the incidence and severity of disability associated with each disease.

Applying these criteria, it is clear that NIHL should be included in any national assessment, as it is strongly supported by epidemiological evidence, and is one of the health outcomes often assessed in national health statistics and as part of WHO burden of disease assessments. It is generally most straightforward to exclude outcomes such as annoyance, as they are not a formally defined health outcome *per se*. Should annoyance cause other health outcomes, such as hypertension and associated cardiovascular disease, then other outcomes could be considered. If there is a strong local reason for including such outcomes, then it is possible either to assess comparative disability weights independently, to take them from other studies (e.g. de Hollander et al., 2004), or to extrapolate them from similar health outcomes. You should be aware that an independent assessment of the severity of such outcomes introduces additional uncertainty when the results are compared with other risk factors or geographical areas.

This guide follows the previous global assessment of occupational noise, in that only the effects of occupational noise on NIHL are assessed. Several definitions of hearing impairment are available in the literature. In the occupational setting, hearing impairment is generally defined as “a binaural pure-tone average for the frequencies of 1000, 2000, 3000 and 4000 Hz of greater than 25 dBHL” (NIOSH, 1998; Sriwattanatamma & Breysse, 2000). While this definition is widely used, it does not correspond to the WHO definition of disabling hearing loss (i.e. with an associated disability weight, and corresponding to a quantifiable burden of disease). This level of hearing impairment is defined as “permanent unaided hearing threshold level for the better ear of 41 dBHL or greater for the four frequencies 500, 1000, 2000 and 4000 kHz” (Table 3). In this guide, we describe the steps necessary to calculate a prevalence of hearing loss that corresponds to the WHO definition, as it is preferable for burden of disease assessments. A straightforward procedure for converting

between the different levels of impairment is described in Section 5. This conversion procedure is supported by large epidemiological studies, and should therefore introduce only a small additional uncertainty into the estimation.

Table 3 Definition of hearing impairment^a

Grade of hearing Impairment	Audiometric ISO value^b	Performance
0 no impairment	≤25 dB (better ear)	No, or very slight, hearing problems. Able to hear whispers.
1 slight impairment	26–40 dB (better ear)	Able to hear and repeat words spoken in normal voice at 1 m.
2 moderate impairment	41–60 dB (better ear)	Able to hear and repeat words using raised voice at 1 m.
3 severe impairment	61–80 dB (better ear)	Able to hear some words when shouted into better ear.
4 profound impairment, including deafness	≥81 dB (better ear)	Unable to hear and understand even a shouted voice.

^a Source: based on WHO (1991).

^b International Organization for Standardisation, average of 500, 1000, 2000, 4000 Hz.

4. Exposure

4.1 Definition of the exposure indicator

The most appropriate exposure measurement for occupational noise is the A-weighted decibel, dB(A), usually averaged over an 8-hour working day ($L_{Aeq,8h}$ see Section 3). There is a strong correlation between this parameter and the ability of the noise hazard to damage human hearing. It is frequently measured in the workplace, and is also the most commonly used epidemiological measurement of exposure. Exposure is initially measured as a continuous variable, and theoretically could be treated as such in assessing the burden of disease. This is impractical, however, as many surveys report exposure above and below cut-off values, rather than as a distribution. For example, the following categories are widely applied because they correspond to regulatory limits in developed (usually 85 dB(A)) and many developing (usually 90 dB(A)) countries for an 8-hour day (Hessel & Sluis-Cremer, 1987; Alidrisi et al., 1990; Shaikh, 1996; Hernandez-Gaytan et al., 2000; Osibogun, Igweze & Adeniran, 2000; Sriwattanatamma & Breyse, 2000; Ahmed et al., 2001):

- minimum noise exposure: <85 dB(A)
- moderately high noise exposure: 85–90 dB(A)
- high noise exposure: >90 dB(A).

4.2 Determining the distribution of exposure in the population

The most accurate assessments of health impacts at the national level are obtained from local exposure data, since population exposure distributions can vary between countries. The most commonly used methods to assess health impacts are:

- area surveys: noise levels are measured at different sites across an area, such as sites throughout a factory;
- dosimetry: a person's cumulative exposure to noise over a period of time is measured with a dosimeter;
- engineering surveys: noise is measured using a range of instruments.

Ideally, representative data will be available on the average levels of occupational noise for all major occupations within the country, either from the published scientific literature or from other sources of data. If such data are not available, epidemiological surveys can be carried out to determine the distribution of noise exposure by occupation. In practice, such data often will not be available, and the distribution will have to be estimated from existing sources of information. To do so, assumptions will need to be made, which will increase the uncertainty of the estimation, and this should be made explicit in the results.

A reasonable estimate of the exposure distribution can be obtained by extrapolating from existing data for studies undertaken elsewhere, provided that the data are from similar occupational environments. Studies have shown that the most important

determinant of exposure level is worker occupation. Industry-specific studies in the USA showed that 44% of carpenters and 48% of plumbers reported they had a perceived hearing loss, and 90% of coal miners have hearing impairment by age 52 years. Also, it is estimated that 70% of male metal/nonmetal miners will have hearing impairment by age 60 years (NIOSH, 1991). Within an occupation, several workplace-specific factors will also influence the level of exposure. These factors include the type of facility and process; the raw materials, machinery and tools used; whether there are engineering and work practice controls; and whether personal protective devices are used and properly maintained. These factors are likely to vary between countries (e.g. personal protective devices may be more commonly used in developed countries than in developing countries). Such factors should be taken into consideration when estimating the distribution of exposure for a workforce, and extrapolations should be made from data for comparable occupations in comparable countries.

The Global Burden of Disease study estimated exposure distributions using an occupational category approach, modified to reflect the different noise exposures for occupations in different economic subsectors. This approach can be applied at the national level, using country data where available, or by extrapolating from data for other studies if local data are not available.

The first step is to assess the proportion of workers in each occupational category that is exposed to at least moderately high occupational noise levels (>85 dB(A)); see Table 4). If these data are not available from national surveys, the distribution can be based on the results of a large survey in the USA (DHHS, 1986; NIOSH, 1998).

Table 4 Proportion of workers in each occupational category and economic subsector exposed to noise levels >85 dB(A)^a

Economic subsector	Occupational category						
	Profession- ional	Adminis- trative	Clerical	Sales	Services	Agriculture	Production ^b
Agriculture	0.05	0.05	0.05	<i>0.12</i>	<i>0.12</i>	<i>0.20</i>	0.20
Mining	0.05	0.05	0.05	<i>0.12</i>	<i>0.12</i>	<i>0.20</i>	0.85
Manufacturing	0.05	0.05	0.05	<i>0.12</i>	<i>0.12</i>	<i>0.20</i>	0.22
Electricity	0.05	0.05	0.05	<i>0.12</i>	<i>0.12</i>	<i>0.20</i>	0.15
Construction	0.05	0.05	0.05	<i>0.12</i>	<i>0.12</i>	<i>0.20</i>	0.18
Trade	0.02	0.02	0.02	<i>0.12</i>	<i>0.12</i>	<i>0.20</i>	0.13
Transportation	0.02	0.02	0.02	<i>0.12</i>	<i>0.12</i>	<i>0.20</i>	0.12
Finance ^c	0.02	0.02	0.02	<i>0.12</i>	<i>0.12</i>	<i>0.20</i>	0.02
Services	0.02	0.02	0.02	<i>0.12</i>	<i>0.12</i>	<i>0.20</i>	0.03

^a Source: NIOSH (1998).

^b Figures shown in normal typeface are derived by expert judgement. Figures in italics are derived by extrapolation from the most relevant subsector in the production worker survey. Figures in bold indicate direct measurements.

^c Based on a figure of 1.5% for the proportion of “business services” workers exposed to noise.

For each occupational category, the proportion of production workers exposed to high noise levels (i.e. >90 dB(A)) is estimated from a survey of over 9 million production workers in the USA carried out by the USA Occupational Safety and Health Administration in 1981 (cited in NIOSH 1991; DHHS, 1986). These figures are shown in bold font in Table 4. Of the 6 063 000 production workers with exposures at or above 85 dB(A), 3 407 000 (or 56%) were exposed to noise levels above 90 dB(A). We therefore estimate that among production workers exposed at or above 85 dB(A), half were exposed at 85–90 dB(A), and half were exposed at >90 dB(A). Exposures in the remaining occupational categories and economic subsectors are estimated either by extrapolation from the most relevant subsector of the survey of production workers (figures shown in italics in Table 4), or by expert judgement (shown in normal typeface). It is also assumed, based on expert judgement, that of the agricultural workers and sales and service workers exposed at or above 85 dB(A), approximately 70% are exposed at 85–90 dB(A), and 30% at >90 dB(A). All professional, administrative, and clerical workers with noise exposure at or above 85 dB(A) are assumed to be in the 85–90 dB(A) exposure level.

It may be necessary to adjust these proportions, depending on the characteristics of the country in which the assessment is undertaken. In developing countries, because hearing conservation programmes are rare, the global assessment assumed that only 5% of the production workers would be exposed at the 85–90 dB(A) level, and 95% would be exposed at the >90 dB(A) level. Also, 95% of the agricultural workers exposed at or above 85 dB(A) are assigned to the 85–90 dB(A) level, because

mechanization is not widespread in countries in WHO developing subregions (e.g. WHO D and E subregions; see Annex 1).

The second step consists of defining the proportions of workers in each economic subsector, by occupational category. These data may be available from national labour offices, or from statistics reported to the ILO. The third step simply consists of multiplying the previous tables together (i.e. for each economic subsector, the proportion of workers in each occupation is multiplied by the proportion of workers in the occupation exposed to moderately high, or high, noise levels). Next, the proportion of the working population in each economic subsector is determined by gender. In the fifth step, these values are multiplied by the proportion of workers in the occupational category exposed to the specific noise level. The series of calculations is performed for all economic subsectors, and the results summed to give the proportion of the total working population that is exposed at each noise level.

The next step accounts for the fact that not all of the population is involved in formal work, by defining the proportion of the working-age population that is currently employed. This should be done separately for males and females. Accuracy can be further improved by specifying levels of employment for different age groups within the working-age population. Finally, the overall population exposure is given by multiplying the proportion of the working population exposed at each exposure level, by the proportion of the total population in work.

Table 5 summarizes these steps and the sources of data necessary to complete them, and gives example calculations for the proportion of the male working-age population in the USA that is exposed to moderately high noise levels. To give a complete assessment of the exposure distribution, the calculations would be repeated for exposure to high noise levels, and for females as well as males.

Table 5 Assessing occupational exposure to noise

Step	Data source	Example for exposure to moderately high noise (85–90 dB(A)), USA males
1. For each occupational group within each economic subsector, estimate the proportion of workers exposed to moderately high (85–90 dB(A)) and high (>90 dB(A)) levels of noise.	National noise–exposure surveys, or NIOSH study (Table 4).	22% of workers in the production occupational category of the manufacturing economic subsector are exposed to noise above 85 dB(A). Half of these (11%) are exposed to noise levels of 85–90 dB(A) (the remaining half are exposed to >90 dB(A)).
2. Determine the distribution of occupations between the nine economic subsectors.	National labour offices or the ILO.	12% of workers in the manufacturing subsector are in the professional category, 13% in administration, 10% in clerical, 4% in sales, 1% in service, none in agriculture, 59% in production.
3. Using the tables developed for Step 1 and Step 2, estimate the proportion of the working population exposed to moderately high noise levels for each of the nine economic subsectors, and sum the results.	Derived from the outputs of Steps 1 and 2.	11% × 59%, or 6.5% of production workers in manufacturing in the USA are exposed to noise levels of 85–90 dB(A). Repeating the calculation for other occupations in manufacturing, and summing, gives a value of 8.8% for all workers in manufacturing exposed to noise levels 85–90 dB(A).
4. For each gender, determine the proportion of the labour force working in the nine economic subsectors.	National labour offices or ILO.	Approximately 4% of males work in agriculture, 1% in mining, 22% in manufacturing, etc.
5. Determine the proportion of the labour force exposed to elevated noise levels for each of the nine economic subsectors, and sum the values.	Derived from the outputs of Steps 3 and 4.	8.8% of manufacturing workers are exposed to noise levels of 85–90 dB(A), and 22% of the male labour force works in manufacturing. Multiplying these figures gives 1.9% of the male labour force is exposed to noise levels of 85–90 dB(A) in manufacturing. Repeating for the other economic subsectors, and summing, gives a figure of 6.6% for the proportion of the total male labour force exposed to moderately high noise levels.
6. Determine the overall proportion of the working-age population, 15–64 years old, in the labour force, as well as the corresponding proportions for males and females.	National labour offices or ILO.	87% of males 15–64 years old participate in the labour force.
7. Determine the overall population exposure by adjusting the proportion of the labour force exposed to elevated noise levels for the participation of the population in the labour force.	Derived from the outputs of Steps 5 and 6.	The value of 6.6% for the proportion of the male labour force exposed to noise levels of 85–90 dB(A) is adjusted by multiplying this figure by the participation of males in the labour force (87%). The result is that 5.7% of the male population 15–64 years old is exposed to moderately high noise levels.

Estimates for the prevalence of noise exposure, determined using the described method, are shown in Table 6. The figures assume there are equal employment rates in all age groups of the working-age population.

Table 6 Proportion of the working-age population in the USA occupationally exposed to noise levels of 85–90 dB(A) and >90 dB(A), by gender^a

Gender	Labour force exposed		Proportion in labour force	Working-age population exposed	
	85–90 dB(A)	>90 dB(A)		85–90 dB(A)	>90 dB(A)
Males	0.066	0.038	0.870	0.057	0.033
Females	0.054	0.026	0.740	0.040	0.019

^a Adapted from Concha-Barrientos et al. (2004).

5. Estimating relative risks for health outcomes, by exposure level

It may be possible to obtain relative risks by exposure level from the literature, or from epidemiological surveys in your own population, or populations with similar socioeconomic and working conditions. However, as for evidence of causality, there is little reason to believe that the relative risks of hearing loss should differ between countries, so that in most cases it will be more straightforward, and probably more accurate, to use relative risks based on all previous studies.

As with other disease burdens, the major challenge in estimating relative risks for NIHL is in converting different measures of hearing loss into a single standardized definition for assessing exposure, as is done in the method presented here. As outlined in Section 3, the criteria used by WHO to define disabling hearing impairment is different from the criteria used by most of the studies in the occupational field, so an adjustment of the published relative risk values is usually necessary to calculate burden of disease in DALYs. Again, the conversion procedure described in Step 2 below should be equally applicable in all countries.

A procedure to estimate the increase in risk associated with different exposure levels has been defined in the Global Burden of Disease study (Cocha-Barrientos et al., 2004). In brief, the main steps are:

1. Estimate the excess risk for different levels of exposure, and for different ages. The data can be obtained from a large study carried out in the USA (Prince et al., 1997). The study uses an average of 1000, 2000, 3000 and 4000 Hz, and a hearing loss >25 dBHL to define hearing impairment. Excess risk is defined as the percentage of workers with a hearing impairment in the population exposed to occupational noise, minus the percentage of people in an unexposed population who have a hearing impairment that is the natural result of aging. Most studies follow the NIOSH practice of measuring the outcome as “material hearing impairment” (i.e. at the level of 25 dB).
2. Adjust the hearing levels. A correction factor can be used to adjust the excess risks measured using the NIOSH definition of the threshold, to the level at which WHO defines an associated disability weighting for burden of disease calculations (>41 dB; Concha-Barrientos et al., 2004). In this guide, we use a correction factor of 0.446, which is the ratio of the number of excess cases at >40 dB divided by the number of excess cases at >25 dB (NIOSH, 1991).
3. Estimate relative risk by age. The relative risk values by age can be estimated using the formula: $\text{relative risk} = 1 + (\text{excess risk} / \text{expected risk})$. The expected risk in the Global Burden of Disease study is based on a study of the prevalence of hearing loss as a function of age in the adult population of Great Britain (Davis, 1989).

The final relative risks of hearing loss at various exposure levels defined by this procedure are given in Table 7. Unless there is strong evidence that the relative risks are different in your country of interest, then it is advisable to use these values.

Table 7 Relative risks for hearing loss by sex, age group and level of occupational exposure

Sex	Exposure level	15–29	30–44	45–59	60–69	70–79	80+
Male	<85 dB(A)	1.00	1.00	1.00	1.00	1.00	1.00
Male	85–90 dB(A)	1.96	2.24	1.91	1.66	1.66	1.66
Male	>90 dB(A)	7.96	5.62	3.83	2.82	2.82	2.82
Female	<85 dB(A)	1.00	1.00	1.00	1.00	1.00	1.00
Female	85–90 dB(A)	1.96	2.24	1.91	1.66	1.66	1.66
Female	>90 dB(A)	7.96	5.62	3.83	2.82	2.82	2.82

6. Estimating the attributable fraction and the disease burden

The burden of disease caused by exposure to occupational noise is given by combining the following information:

- the proportion of people exposed to the defined noise levels (Section 4);
- the relative risk of developing NIHL for each exposure level (Section 5);
- the total disease burden (incidence or number of DALYs) from NIHL within the country, obtained from other sources (e.g. Prüss-Üstün et al., 2003).

6.1 Calculating the attributable fraction

The first step in the calculation is to determine the fraction of the total burden of NIHL in the study population that is attributable to the risk factor, by combining the exposure distribution and relative risk information. The attributable fraction (AF), also called the impact fraction in this context, is given by the following formula (Prüss-Üstün et al., 2003):

$$AF = \frac{\sum P_i RR_i - 1}{\sum P_i RR_i}$$

where:

P_i = proportion of the population in each exposure category, i (i.e. $P_{\text{unexposed}}$, $P_{\text{low exposure}}$, $P_{\text{high exposure}}$).

RR_i = relative risk at exposure category, i , compared to the reference level (= 1.0 for an unexposed population).

For example, the fraction of NIHL in the USA male population 15–29 years old that is attributable to occupational noise is given by:

$$AF = \frac{(91\% \times 1) + (5.7\% \times 1.96) + (3.3\% \times 7.96) - 1}{(91\% \times 1) + (5.7\% \times 1.96) + (3.3\% \times 7.96)} = 22\%$$

6.2 Calculating the disease burden

The disease burden attributable to occupationally-related NIHL can be estimated by multiplying the attributable fraction by the total disease burden in the country caused by NIHL (i.e. the total number of cases, or total number of DALYs, attributable to NIHL). The disease burden should be estimated separately for males and females, and for different age groups.

Possible sources of country data for estimating the incidence of NIHL, or the number of DALYs caused by NIHL, are described in Prüss-Üstün et al. (2003). Preferred sources are national statistics for the outcome of interest, or a national burden of disease study. Otherwise, WHO will supply “prior estimates” of national disease burdens, upon request from official representatives of the country (e.g. the Minister of Health). The prior estimates are based on statistics and epidemiological studies collected by WHO. Finally, if none of these sources is available, then national disease-specific burdens could be approximated by multiplying subregional DALY estimates (available at www.who.int/evidence) by the ratio of the country population to the subregional population. However, this approach should be used with caution and results should be quoted as preliminary, as the method assumes that the disease rates are the same in all countries of the subregion.

7. Uncertainty

There are two principal sources of uncertainty in the disease burden estimates for occupational noise.

7.1 Uncertainty in exposure estimates

In the method used in this guide, the main uncertainties are in estimates of the proportion of people in each occupational group or economic subsector that is exposed to the specified level of noise. This has been thoroughly assessed for one occupation in the USA, and extrapolated to other occupations and subregions based on expert judgement. However, the assumptions used to make these extrapolations have not been tested, and local surveys would help to reduce the uncertainty around the estimates. In some countries, there may also be uncertainty around the distribution of the working population between occupational groups or economic subsectors. This uncertainty can be reduced by using the most recent data from authoritative sources (e.g. statistics from the Ministry of Labour).

7.2 Uncertainty in relative risk estimates

Uncertainty in relative risk estimates may arise from the original epidemiological studies, and includes errors in exposure estimates, confounding factors, and in measurement of hearing loss.

Errors in exposure estimates may arise because most studies of the association between noise and hearing impairment are retrospective measurements of the hearing sensitivities of individuals, correlated with their noise exposure over an extended period (typically, many years). Noise exposure often varies over time, so that it may be difficult to measure the precise level that the subject has experienced, particularly if they have been subject to intermittent exposures. Uncertainty is also introduced by variation in the subject (e.g. previous audiometric experience, attention, motivation, upper respiratory problems, and drugs). However, well-designed epidemiological studies (of the type used to define the relative risks in this guide) should account for the most important confounding factors (e.g. age and sex), and ensure that the relative risks are reasonably accurate. The large populations of the studies used to calculate the relative risks in this guide, and the consistency of results between studies, suggest that the data closely approximate the risks of noise exposure.

Some additional uncertainty in the method used in this guide comes from adjusting hearing loss measurements made at different thresholds (e.g. 25 dBL and 41 dBL). The uncertainty should be relatively small, as the adjustment is based on a large sample size, but it could be reduced further if more studies measure hearing loss at both 25 dBL and 41 dBL.

8. Policy implications

Estimates of the incidence of occupationally-related NIHL in your country or study population, or of the number of attributable DALYs, will provide quantitative information on the importance of the problem in the study area, and can help to motivate interventions to reduce these risks and associated health impacts.

NIHL is, at present, incurable and irreversible. It is preventable, however, and it is essential that preventive programmes be implemented. The following recommendations on effective hazard prevention and control mechanisms are based on Goelzer (2001).

Hearing conservation programmes should not be isolated efforts, but should be integrated into the overall hazard prevention and control programme for the workplace.

Hazard prevention and control programmes require:

- political will and decision-making;
- commitment from top management, with a clear and well-circulated policy;
- commitment from workers;
- well-defined goals and objectives;
- adequate human and financial resources;
- technical knowledge and experience;
- adequate implementation of the programme and competent management;
- multidisciplinary teams;
- communication mechanisms;
- monitoring mechanisms (indicators);
- continuous programme improvement.

Within an overall hazard prevention and control programme, specific noise-prevention and control strategies usually involve the following elements:

- the work process (including tools and machinery): for example, install quieter equipment, promote good maintenance;
- the workplace: for example, use noise enclosures or acoustic equipment;
- the workers: for example, set up work practices and other administrative controls on noise exposures, and provide audiometry tests and hearing protection, and workers' education programmes.

Control measures should be realistically designed to meet the needs of each situation, and the different options should be considered in view of factors such as effectiveness, cost, technical feasibility, and sociocultural aspects. Control interventions should follow the following hierarchy: control the noise source → control the noise propagation → control noise at the worker level.

The first priority is to reduce noise through technical measures. When engineering controls are not applicable or are insufficient, exposure to noise can be reduced

through measures such as introducing hearing protection for workers. The protective equipment must be properly selected, worn and maintained. Administrative controls can also be used. These are changes in the work schedule, or in the order of operations and tasks. For example, the time spent in a noisy environment can be limited (in addition to wearing hearing protection), and noisy operations can be performed outside the normal shift, or during a shift with very few workers (wearing hearing protection), or at a distant location.

Some better known measures for reducing noise, such as noise enclosures and personal protective equipment, may be too expensive, impractical, inefficient or unacceptable to workers, particularly in hot jobs or climates. Approaches to prevention should be broadened, with proper consideration of other control options, particularly options for source control, such as substituting materials and modifying processes, as well as for good work practices.

Finally, it should be recognized that in developing countries a large proportion of the population works in the informal sector. A major challenge is to extend occupational hazard prevention and control programmes to this section of the population.

9. References

- Ahmed HO, Dennis JH, Badran O, Ismail M, Ballal SG, Ashoor A, Jerwood D (2001). Occupational noise exposure and hearing loss of workers in two plants in eastern Saudi Arabia. *Annals of Occupational Hygiene*, 45(5):371–380.
- Alidrisi M, Jamil ATM, Jiffry MSA, Jefri MA, Erturk F (1990). Evaluation of noise stresses in Jeddah Industrial State. *Journal of Environment Science and Health*, A25(8):873–896.
- Arndt V, Rothenbacher D, Brenner H, Fraisse E, Zschenderlein B, Daniel U, Schuberth S, Fliedner TM (1996). Older workers in the construction industry: results of a routine health examination and a five-year follow up. *Occupational and Environmental Medicine*, 53(10):686–691.
- Concha-Barrientos M, Nelson DI, Driscoll T, Steenland NK, Punnett L, Fingerhut M, Prüss-Üstün A, Corvalán C, Leigh J, Tak S (2004). Selected occupational risk factors. In: Ezzati M, Lopez A, Rodgers A, Murray C, eds. *Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors*. Geneva, World Health Organization.
- Davis AC (1989). The prevalence of hearing impairment and reported hearing disability among adults in Great Britain. *International Journal of Epidemiology*, 18(4):911–917.
- de Hollander AEM, van Kempen EEMM, Houthuijs DJM, van Kamp I, Hoogenveen RT, Staatsen BAM (2004). *Environmental noise: an approach for estimating health impacts at national and local level*. Geneva, World Health Organization (Environmental Burden of Disease series, in press).
- DHHS (1986). Perspectives in disease prevention and health promotion, leading work-related diseases and injuries – United States. Noise-induced loss of hearing. *Morbidity and Mortality Weekly Report*, 35(12). Reprinted in 1991, Washington, DC, US Department of Health and Human Services, National Institute for Occupational Safety and Health publications on noise and hearing.
- Goelzer BIF (2001). Hazard prevention and control programmes. In: Goelzer BIF, Hansen CH, Sehrndt GA, eds. *Occupational exposure to noise: evaluation, prevention and control*. Geneva, World Health Organization.
- HCN (1999). *Public health impact of large airports*. The Hague, Health Council of the Netherlands (Report 1999/14E).
- Hernandez-Gaytan SI, Santos-Burgo AC, Becker-Meyer JP, Macias-Carrillo C, Lopez-Cervantes M (2000). Prevalence of hearing loss and correlated factors in a cement plant. *Salud Publica de Mexico, [Public Health of Mexico,]* 42(2):106–111.
- Hessel P (2000). Hearing loss among construction workers in Edmonton, Alberta, Canada. *Journal of Occupational and Environmental Medicine*, 42(1):57.
- Hessel PA, Sluis-Cremer GK (1987). Hearing loss in white South African gold-miners. *South African Medical Journal*, 71:364–367.

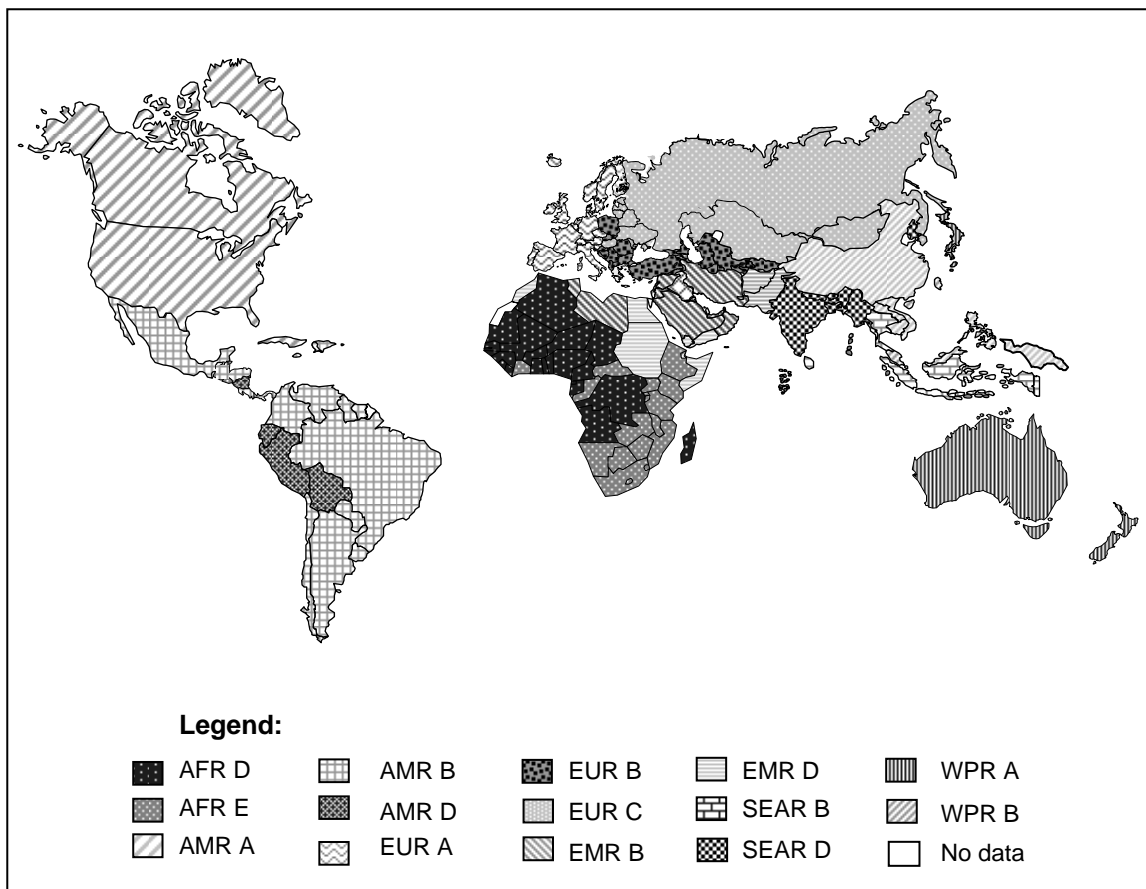
- Hill AB (1965). The environment and disease: association or causation? *Proceedings of the Royal Academy of Medicine*, 58:295–300.
- Lalande NM, Hetu R, Lambert J (1986). Is occupational noise exposure during pregnancy a risk factor of damage to the auditory system of the fetus? *American Journal of Industrial Medicine*, 10(4):427–435.
- Murray CJ, Salomon JA, Mathers C (2000). A critical examination of summary measures of population health. *Bulletin of the World Health Organization*, 78(8):981–994.
- NIOSH (1991). *Noise-induced loss of hearing*. Cincinnati, OH, National Institute for Occupational Safety and Health.
- NIOSH (1998). *Criteria for a recommended standard: occupational noise exposure. Revised criteria 1998*. Cincinnati, OH, National Institute for Occupational Safety and Health. Available at (<http://www.cdc.gov/niosh/98-126.html>).
- Osibogun A, Igweze IA, Adeniran LO (2000). Noise-induced hearing loss among textile workers in Lagos Metropolis. *The Nigerian Postgraduate Medical Journal*, 7(3):104–111.
- Palmer K, Pannett B, Griffin M (2001). *Occupational exposure to noise and hearing difficulties in Great Britain*. (Contract Report 361/2001). University of Southampton for the Health and Safety Executive.
- Passchier-Vermeer W (1993). *Noise and health*. The Hague, Health Council of the Netherlands (Publication No. A93/02E).
- Prince MM, Stayner LT, Smith RJ, Gilbert SJ (1997). A re-examination of risk estimates from the NIOSH Occupational Noise and Hearing Survey (ONHS). *Journal of the Acoustic Society of America*, 101:950–963.
- Prüss-Üstün A, Mathers C, Corvalán, Woodward A (2003). Introduction and methods: assessing the environmental burden of disease at national and local levels. Geneva, World Health Organization (WHO Environmental Burden of Disease series, No. 1).
- Shaikh GH (1996). Noise problem in a polyester fiber plant in Pakistan. *Industrial Health*, 34:427–431.
- Sriwattanatamma P, Breyse P (2000). Comparison of NIOSH noise criteria and OSHA hearing conservation criteria. *American Journal of Industrial Medicine*, 37:334–338.
- Suter A (2000). *Standards and regulations*. In: Berger EH, Royster LH, Rozster JD, Driscoll DP, Layne M, eds. *The noise manual*, 5th ed. American Industrial Hygiene Association, Fairfax, VA.
- van Kempen EE, Kruize H, Boshuizen HC, Ameling CB, Staatsen BA, de Hollander AE (2002). The association between noise exposure and blood pressure and ischemic heart disease: a meta-analysis. *Environmental Health Perspectives*, 110(3):307–317
- Waitzman N, Smith K (1998). *Unsound conditions: work-related hearing loss in construction, 1960–75*. Washington, DC, Center to Protect Worker's Rights.

- WHO (1991). *Report of the Informal Working Group of Deafness and Hearing Impairment Programme Planning*. Geneva, World Health Organization.
- WHO (2001). *Occupational and community noise*. Geneva, World Health Organization (Fact Sheet No. 258).
- WHO (2002). *World Health Report: reducing risks, promoting healthy life*. Geneva, World Health Organization.
- WHO/FIOH (2001). In: Goelzer B, Hansen CH, Sehrndt GA, eds. *Occupational exposure to noise: evaluation, prevention and control*. Geneva, World Health Organization, and Dortmund/Berlin, the Federal Institute for Occupational Safety and Health.

Annex 1. Summary results of the Global Burden of Disease assessment for occupational noise

A global analysis of the disease burden caused by exposure to occupational risk factors, including occupational noise, was performed on the basis of the approach described in this guide (WHO, 2002; Concha-Barrientos et al., 2004). The analysis was performed for the year 2000, and for 14 subregions of the world, grouped as shown in Figure A1 and Table A1, and by age and sex groups.

Figure A.1 Subregional country groupings for the global disease burden



This is only a schematic representation. The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Table A.1 Country groupings for the WHO subregions in the Global Burden of Disease assessment^a

Subregion ^b		WHO Member States
AFR	D	Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Togo.
AFR	E	Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.
AMR	A	Canada, Cuba, United States of America.
AMR	B	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela.
AMR	D	Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru.
EMR	B	Bahrain, Cyprus, Iran (Islamic Republic of), Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates.
EMR	D	Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen.
EUR	A	Andorra, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom.
EUR	B	Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Slovakia, Tajikistan, The Former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Uzbekistan, Yugoslavia.
EUR	C	Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine.
SEAR	B	Indonesia, Sri Lanka, Thailand.
SEAR	D	Bangladesh, Bhutan, Democratic People's Republic of Korea, India, Maldives, Myanmar, Nepal, Timor Leste.
WPR	A	Australia, Brunei Darussalam, Japan, New Zealand, Singapore.
WPR	B	Cambodia, China, Cook Islands, Fiji, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Micronesia (Federated States of), Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Viet Nam

^a Source: WHO (2003).

^b Subregions: AFR = Africa; AMR = Americas; EMR = Eastern Mediterranean; EUR = Europe; SEAR = South-East Asia; WPR = Western Pacific; A: Very low child, very low adult mortality; B: Low child, low adult mortality; C: Low child, high adult mortality; D: High child, high adult mortality; E: High child, very high adult mortality.

Estimates of the proportions of populations exposed in each subregion were based on the distribution of the Economically Active Population¹ into nine economic subsectors. The estimates took into account the proportion of workers in each economic subsector with exposure to the risk factor, and the workers were partitioned into high and low exposure levels. Turnover accounted for previous exposures. The primary data sources for estimating exposures included the World Bank (World Bank, 2001), the International Labour Organization (ILO, 1995, 2001, 2002), and literature on the prevalence and level of exposure.

The exposure variable used in this analysis is a direct measure of the risk factor (occupational exposure to noise is the causative agent of NIHL). As global data on the frequency of occurrence, duration and intensity of noise exposure do not exist, it was necessary to model this exposure for workers employed in various occupational categories. The theoretical minimum is based on expected background levels of noise, and is consistent with national and international standards. Most experts agree that levels below 80 dB(A) result in minimal risk of developing hearing loss.

For the analysis, three levels of exposure were estimated:

- minimum exposure (<85 dB(A))
- moderately high noise (85–90 dB(A))
- high noise (>90 dB(A)).

The proportion of workers in each occupational category with exposure to noise at or above 85 dB(A) was based on data for the prevalence of noise exposure at or above 85 dB(A) among USA production workers in nine economic subsectors (DHHS, 1986; NIOSH, 1998; see Table A2). The prevalence of exposure in other occupational categories was based on values from similar subsectors of the production category (e.g. exposure for agricultural workers in production was applied to all agricultural workers), or on expert judgement. It was estimated that 50% of workers exposed at >85 dB(A) in developed subregions were exposed at the higher level (>90 dB(A)) (NIOSH, 1998). In developing subregions (B, C, D and E), exposure estimates were adjusted to take into account the absence of hearing protection programmes, and in D and E subregions, estimates were adjusted for the absence of widespread mechanization of agriculture.

¹ Includes people in paid employment, the self-employed, and people who work to produce goods and services for their own household consumption.

Table A.2 Proportions of the working-age population occupationally exposed to different noise levels, by sex and subregion

Subregion	Sex	Exposure level	Age group (years)			
			15–29	30–44	45–59	60–69
AFR D	Male	<85 dB(A)	0.87	0.84	0.84	0.86
		85–90 dB(A)	0.09	0.12	0.11	0.10
		>90 dB(A)	0.04	0.04	0.04	0.04
	Female	<85 dB(A)	0.92	0.90	0.90	0.92
		85–90 dB(A)	0.07	0.09	0.09	0.07
		>90 dB(A)	0.01	0.01	0.01	0.01
AFR E	Male	<85 dB(A)	0.87	0.84	0.84	0.86
		85–90 dB(A)	0.09	0.12	0.11	0.10
		>90 dB(A)	0.04	0.04	0.04	0.04
	Female	<85 dB(A)	0.92	0.90	0.90	0.92
		85–90 dB(A)	0.07	0.08	0.08	0.07
		>90 dB(A)	0.01	0.01	0.01	0.01
AMR A	Male	<85 dB(A)	0.92	0.90	0.90	0.91
		85–90 dB(A)	0.05	0.06	0.06	0.06
		>90 dB(A)	0.03	0.04	0.04	0.03
	Female	<85 dB(A)	0.96	0.95	0.95	0.96
		85–90 dB(A)	0.03	0.03	0.03	0.03
		>90 dB(A)	0.01	0.01	0.01	0.01
AMR B	Male	<85 dB(A)	0.90	0.87	0.88	0.89
		85–90 dB(A)	0.05	0.06	0.06	0.05
		>90 dB(A)	0.06	0.07	0.07	0.06
	Female	<85 dB(A)	0.95	0.94	0.94	0.95
		85–90 dB(A)	0.03	0.03	0.04	0.03
		>90 dB(A)	0.02	0.03	0.03	0.02
AMR D	Male	<85 dB(A)	0.91	0.89	0.89	0.90
		85–90 dB(A)	0.03	0.04	0.04	0.04
		>90 dB(A)	0.05	0.07	0.07	0.06
	Female	<85 dB(A)	0.95	0.94	0.94	0.96
		85–90 dB(A)	0.02	0.03	0.03	0.02
		>90 dB(A)	0.03	0.03	0.03	0.02
EMR B	Male	<85 dB(A)	0.91	0.88	0.89	0.90
		85–90 dB(A)	0.04	0.05	0.05	0.04
		>90 dB(A)	0.05	0.07	0.07	0.06
	Female	<85 dB(A)	0.96	0.95	0.95	0.96
		85–90 dB(A)	0.02	0.03	0.03	0.02
		>90 dB(A)	0.02	0.02	0.02	0.02
EMR D	Male	<85 dB(A)	0.88	0.85	0.85	0.86
		85–90 dB(A)	0.09	0.11	0.11	0.10
		>90 dB(A)	0.04	0.04	0.04	0.04
	Female	<85 dB(A)	0.91	0.89	0.89	0.92
		85–90 dB(A)	0.07	0.09	0.09	0.07
		>90 dB(A)	0.02	0.02	0.02	0.02

Subregion	Sex	Exposure level	Age group (years)			
			15–29	30–44	45–59	60–69
EUR A	Male	<85 dB(A)	0.92	0.90	0.90	0.91
		85–90 dB(A)	0.05	0.06	0.06	0.06
		>90 dB(A)	0.03	0.04	0.04	0.03
	Female	<85 dB(A)	0.96	0.96	0.95	0.97
		85–90 dB(A)	0.03	0.03	0.03	0.02
		>90 dB(A)	0.01	0.01	0.01	0.01
EUR B	Male	<85 dB(A)	0.88	0.85	0.85	0.87
		85–90 dB(A)	0.05	0.06	0.06	0.05
		>90 dB(A)	0.07	0.09	0.09	0.08
	Female	<85 dB(A)	0.93	0.91	0.91	0.93
		85–90 dB(A)	0.04	0.05	0.05	0.04
		>90 dB(A)	0.03	0.04	0.04	0.03
EUR C	Male	<85 dB(A)	0.88	0.85	0.85	0.87
		85–90 dB(A)	0.04	0.05	0.05	0.04
		>90 dB(A)	0.08	0.10	0.10	0.09
	Female	<85 dB(A)	0.93	0.92	0.92	0.94
		85–90 dB(A)	0.02	0.03	0.03	0.02
		>90 dB(A)	0.04	0.05	0.05	0.04
SEAR B	Male	<85 dB(A)	0.88	0.84	0.84	0.87
		85–90 dB(A)	0.06	0.08	0.08	0.06
		>90 dB(A)	0.06	0.08	0.08	0.07
	Female	<85 dB(A)	0.92	0.88	0.88	0.91
		85–90 dB(A)	0.05	0.08	0.08	0.05
		>90 dB(A)	0.04	0.04	0.04	0.03
SEAR D	Male	<85 dB(A)	0.87	0.79	0.80	0.84
		85–90 dB(A)	0.09	0.15	0.15	0.11
		>90 dB(A)	0.04	0.05	0.05	0.05
	Female	<85 dB(A)	0.91	0.94	0.95	0.96
		85–90 dB(A)	0.07	0.04	0.03	0.02
		>90 dB(A)	0.02	0.02	0.02	0.02
WPR A	Male	<85 dB(A)	0.92	0.90	0.90	0.92
		85–90 dB(A)	0.04	0.06	0.06	0.04
		>90 dB(A)	0.03	0.04	0.04	0.03
	Female	<85 dB(A)	0.95	0.94	0.94	0.96
		85–90 dB(A)	0.03	0.04	0.04	0.03
		>90 dB(A)	0.02	0.02	0.02	0.01
WPR B	Male	<85 dB(A)	0.87	0.84	0.84	0.86
		85–90 dB(A)	0.06	0.08	0.08	0.07
		>90 dB(A)	0.07	0.08	0.08	0.07
	Female	<85 dB(A)	0.93	0.91	0.91	0.93
		85–90 dB(A)	0.04	0.05	0.05	0.04
		>90 dB(A)	0.03	0.04	0.04	0.03

The exposure and relative risk information were combined to give the attributable fraction, which was then multiplied by the total burden of deafness in the population to give the burden attributable to occupational NIHL.

Occupational noise exposure does not cause mortality, but does induce significant morbidity through deafness. The global analysis indicates that 16% of deafness is due to occupational noise, with a higher proportion in males (22%) than in females (11%), owing to differences in occupational categories, economic sectors of employment and working lifetime. Approximately 89% of the total burden is in the 15–59 years age group, with the remaining 11% in people over 60 years of age. Overall, more than four million DALYs were lost to NIHL (Table A3). SEAR D and WPR B accounted for more than half of the years of healthy life lost, as they have large populations, with a relatively high proportion working in high-exposure occupations.

Table A.3 DALYs^a attributable to occupational noise for the 14 WHO global subregions^b

Subregion	Attributable DALYs (thousands)	Percentage of total DALYs in the subregion
AFR D	158	0.1
AFR E	187	0.1
AMR A	123	0.3
AMR B	165	0.2
AMR D	21	0.1
EMR B	81	0.4
EMR D	230	0.2
EUR A	164	0.3
EUR B	142	0.4
EUR C	224	0.4
SEAR B	404	0.7
SEAR D	1102	0.3
WPR A	48	0.3
WPR B	1100	0.4
World	4149	0.3

^a DALYs = disability-adjusted life years.

^b Source: WHO (2002).

References to Annex 1

- Concha-Barrientos M, Nelson DI, Driscoll T, Steenland NK, Punnett L, Fingerhut M, Prüss-Üstün A, Corvalán C, Leigh J, Tak S (2004). Selected occupational risk factors. In: Ezzati M, Lopez A, Rodgers A, Murray C, eds. *Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors*. Geneva, World Health Organization.
- DHHS (1986). Perspectives in disease prevention and health promotion, leading work-related diseases and injuries – United States. Noise-induced loss of hearing. *Morbidity and Mortality Weekly Report*, 35(12). Reprinted in 1991, Washington, DC, US Department of Health and Human Services, National Institute for Occupational Safety and Health publications on noise and hearing.
- ILO (1995). *Economically active population, by industry and by occupation. Year Book of Labour Statistics, 54th issue*. Geneva, International Labour Organization.
- ILO (2001). Laborsta, the labour statistics database. Geneva, International Labour Organization (<http://laborsta.ilo.org/>).
- ILO (2002). *Economically active population 1950–2010, 4th ed., rev. 2*. Geneva, International Labour Organization.
- NIOSH (1998). *Criteria for a recommended standard: occupational noise exposure. Revised criteria 1998*. Cincinnati, OH, National Institute for Occupational Safety and Health (<http://www.cdc.gov/niosh/98-126.html>).
- WHO (2002). *World Health Report 2002 – reducing risks, promoting health life*. Geneva, World Health Organization.
- WHO (2003). *World Health Report 2003 – shaping the future*. Geneva, World Health Organization.
- World Bank (2001). *World development indicators, 2001*. (Available at <http://worldbank.com>).