INTERNATIONAL STANDARD

ISO 1999

Third edition
2013-10-01

Acoustics — Estimation of noise-induced hearing loss

Acoustique — Estimation de la perte auditive induite par le bruit

Reference number
ISO 1999:2013(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. www.iso.org/directives

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The committee responsible for this document is ISO/TC 43, *Acoustics*.

This third edition cancels and replaces the second edition (ISO 1999:1990), of which it constitutes a minor revision.

Introduction

This International Standard presents, in statistical terms, the relationship between noise exposures and the "noise-induced permanent threshold shift" (NIPTS) in people of various ages. It provides procedures for estimating the hearing loss due to noise exposure of populations free from auditory impairment other than that due to noise (with allowance for the effects of age) or of unscreened populations whose hearing capability has been measured or estimated. NIPTS is treated here as an additive term independent of other components of hearing threshold levels. For any given noise exposure, it has a range of positive values representing the variability of noise-damage susceptibility between individuals of a population.

Persons regularly exposed to noise can develop hearing loss of varying severity. Due to this hearing loss, their understanding of speech, perception of everyday acoustic signals, or appreciation of music may be impaired. With the exception of exposure to blast, high-impulse noise and extremely high levels of steady noise, permanent impairment of the hearing organ takes time and is progressive over months, years, or decades of exposure. NIPTS is usually preceded by a reversible temporary effect on hearing called noise-induced "temporary threshold shift" (TTS). The severity of TTS and recovery from it depend upon exposure level and duration. For a single individual, it is not possible to determine precisely which changes in hearing threshold level are caused by noise and which changes are caused by other factors, although, in doubtful individual cases, the data in this International Standard might provide an additional means for estimating the most probable causes in audiological diagnosis. However, for a large population exposed to a specific noise, changes in the statistical distributions of hearing threshold levels can be determined. Parameters, such as the mean NIPTS and the median NIPTS, can be used to describe differences in hearing threshold levels between two populations that are similar in all relevant respects except that one population has had a well-defined (usually occupational) noise exposure. Throughout this International Standard, the term NIPTS is applied to changes in the noise-induced permanent threshold shift of statistical distributions of groups of people; it is not to be applied to individuals.

This International Standard can be applied to the calculation of the risk of sustaining hearing loss due to regular occupational noise exposure or due to any daily repeated noise exposure. In some countries, hearing loss caused by occupational noise exposure can have legal consequences with respect to responsibility and compensation. The hearing threshold level at the various frequencies, at which a hearing impairment is deemed to exist (fence), depends not only on the hearing loss per se, but frequently on legal definitions and interpretations based on social and economic considerations. In addition, the definition of a hearing impairment depends on the quality of speech recognition desired, the average level of background noise, and with respect to the relative importance of the various frequencies, perhaps even on the language. Consequently, this International Standard does not stipulate (in contrast to the first edition of ISO 1999) a specific formula for assessment of the risk of impairment, but specifies uniform methods for the prediction of hearing loss, which can be used for the assessment of impairment according to the formula desired or stipulated in a specific country. The results obtained by this International Standard may also be used for estimating the permanent effects of noise on the perception of everyday acoustic signals, the appreciation of music, or the effect of one specific frequency not necessarily stipulated by a hearing impairment formula.

Since noise-induced hearing loss is the result not only of occupational noise exposure but also of the total noise exposure of the population, it may be important to take the non-occupational exposure of individuals (during commuting to and from their jobs, at home, and during recreational activities) into account. Only if this non-occupational exposure is negligible compared with the occupational exposure does this International Standard allow prediction of the occurrence of hearing loss due to occupational noise exposure. Otherwise, it should be used to calculate the hearing loss to be expected from the combined (occupational plus non-occupational) total daily noise exposure. The contribution of the occupational noise exposure to the total hearing loss can then be estimated, if desired.

The selection of maximum tolerable or maximum permissible noise exposures and protection requirements, as well as the selection of specific formulae for impairment risk assessment or compensation purposes, require consideration of ethical, social, economic, and political factors not amenable to international standardization. Individual countries differ in their interpretation of these factors and these factors are therefore considered outside the scope of this International Standard.

For reasons given above, this International Standard, by itself, does not comprise a complete guide for risk assessment and protection requirements, and for practical use, it has to be complemented by national standards or codes of practice delineating the factors which are here left open.

Acoustics — Estimation of noise-induced hearing loss

1 Scope

This International Standard specifies a method for calculating the expected noise-induced permanent threshold shift in the hearing threshold levels of adult populations due to various levels and durations of noise exposure; it provides the basis for calculating hearing disability according to various formulae when the hearing threshold levels at commonly measured audiometric frequencies, or combinations of such frequencies, exceed a certain value.

NOTE 1 This International Standard does not specify frequencies, frequency combinations, or weighted combinations to be used for the evaluation of hearing disability; nor does it specify a hearing threshold level (fence) which it is necessary to exceed for hearing disability to exist. Quantitative selection of these parameters is left to the user. All sound pressure levels stated in this International Standard do not consider the effect of hearing protectors which would reduce effective exposure levels and modify the spectrum at the ear.

The measure of exposure to noise for a population at risk is the noise exposure level normalized to a nominal 8 h working day, $L_{\text{EX,8h}}$, for a given number of years of exposure. This International Standard applies to noise at frequencies less than approximately 10 kHz which is steady, intermittent, fluctuating, irregular. Use of this International Standard for sound pressures exceeding 200 Pa (140 dB relative to 20 µPa) is recognized as extrapolation.

Formulae are presented to calculate the hearing loss, including statistical distribution, at a range of audiometric frequencies due to exposure to noise as a function of level of noise exposure and duration of exposure (in years). The formulae do not distinguish between male and female populations.

NOTE 2 Although the models of hearing loss are based on data assumed to stem primarily from populations exposed to occupational noise, they may be used, with some caution, for estimating the effects of comparable non-occupational and combined exposures.

NOTE 3 The prediction method presented is based primarily on data collected with essentially broadband, steady, non-tonal noise.

To calculate hearing threshold levels and the risk of acquiring hearing loss due to noise exposure, it is necessary to make use of a comparable population. This International Standard contains a definition of a highly screened otologically normal population (in accordance with ISO 7029) and three examples of unscreened populations of three typical industrialized societies. The users of this International Standard may choose a comparable population according to their particular requirements.

NOTE 4 All data and procedures presented in this International Standard are based on deliberate simplifications of experimental data where the daily sound exposure duration did not exceed 12 h. The resulting approximations restrict the validity to the stated ranges of the variables, percentages, sound exposure levels, and frequency ranges.

This International Standard is based on statistical data and therefore cannot be applied to the prediction or assessment of the hearing loss of individual persons except in terms of statistical probabilities.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7029, *Acoustics — Statistical distribution of hearing thresholds as a function of age*

ISO 9612, *Acoustics — Determination of occupational noise exposure — Engineering method*

ISO/TR 25417, *Acoustics — Definitions of basic quantities and terms*

3 Terms and definitions

For the purposes of this document, the terms and definitions in ISO/TR 25417 and the following apply.

3.1
A-weighted noise exposure level normalized to a nominal 8 h working day
$L_{\text{EX,8h}}$
level, in decibels, given by the formula

$$L_{\text{EX,8h}} = L_{p\,\text{Aeq},T\text{e}} + 10 \lg \left(T_\text{e} / T_0 \right) \text{ dB}$$

where

$L_{p\text{Aeq},T\text{e}}$ is the A-weighted equivalent continuous sound pressure level for T_e;

T_e is the effective duration of the working day in hours;

T_0 is the reference duration (T_0 = 8 h).

Note 1 to entry: The quantity "noise exposure level normalized to a nominal 8 h working day" may also be called "daily noise exposure level".

Note 2 to entry: If the exposure averaged over n days is desired, for example if noise exposure levels normalized to a nominal 8 h working day for weekly exposures are considered, the average value of $L_{\text{EX,8h}}$, in decibels, over the whole period may be determined from the values of $(L_{\text{EX,8h}})_i$ for each day using the following formula:

$$\overline{L_{\text{EX,8h}}} = 10 \lg \left[\frac{1}{c} \sum_{i=1}^{n} 10^{0,1 (L_{\text{EX,8h}})_i} \right] \text{ dB}$$

The value of c is chosen according to the purpose of the averaging process: it will be equal to n if an average value is desired; it will be a conventional fixed number if the exposure is to be normalized to a nominal number of days (for example, when n = 7, c = 5 will lead to a daily noise exposure level normalized to a nominal week of 5 eight-hour working days). For consideration of irregular exposures over an extended time period, see ISO 9612.

3.2
hearing loss
deviation or a change for the worse of the threshold of hearing from normal

Note 1 to entry: The term hearing loss may sometimes only refer to a change.

3.3
hearing disability
effect of hearing loss on activities in daily living

Note 1 to entry: This is sometimes called "activity limitation" (WHO).

3.4
fence
hearing threshold level above which degrees of hearing disability are deemed to exist

3.5
risk of hearing disability
percentage of a population sustaining hearing disability

3.6
risk of hearing disability due to noise
risk of hearing disability in a noise-exposed population minus the risk of hearing disability in a population not exposed to noise but otherwise equivalent to the noise-exposed population

3.7
hearing threshold level associated with age
HTLA
H
for a specified fraction of a population, the hearing threshold level observed as a function of age without any exposure to occupational noise

Note 1 to entry: HTLA can be directly observed only in the absence of other causes of hearing impairment, for example, pathological conditions or noise exposure.

3.8
noise-induced permanent threshold shift
NIPTS
N
for a specified fraction of a population, the permanent shift, actual or potential, in decibels, of the hearing threshold level estimated to be caused solely by exposure to noise, in the absence of other causes

3.9
hearing threshold level associated with age and noise
HTLAN
H'
permanent hearing threshold level for a specified fraction of a population

Note 1 to entry: Hearing threshold levels (HTL), as defined in ISO 389, are expressed in decibels.

Note 2 to entry: The value HTLAN is a combination of the components associated with noise (NIPTS, see 3.8) and with age (HTLA, see 3.7), as defined in 6.1.

4 Principle

Annex A gives the procedure for calculating the statistical distribution of hearing threshold levels relative to the hearing threshold levels at the age of 18 years as a function of age for an otologically normal population (highly screened) in accordance with ISO 7029.

Annex B gives three examples of the second database representing the statistical distribution of hearing threshold levels as a function of age for unscreened populations of three typical industrialized societies. These databases are derived from three recent studies in different countries and the data differ significantly from those of database B in the previous edition of this International Standard. In two of the examples, the test subjects have not been exposed to hazardous occupational noise but otherwise represent all other factors that may affect hearing, e.g. age, genetic dispositions, non-occupational noise, and ear diseases. The third database concerns a completely unscreened population, as explained in B.3.

Annex C describes an example of hearing risk assessment using this International Standard.

Annex D presents tables with examples of NIPTS as a function of exposure duration (10 years, 20 years, 30 years, and 40 years) and daily A-weighted sound exposure ($3,64 \times 10^3$ Pa^{2}s, $1,15 \times 10^4$ Pa^{2}s, $3,64 \times 10^4$ Pa^{2}s and $1,15x\ 10^5$ Pa^{2}s or equivalent continuous A-weighted sound pressure level for nominal 8 h working day of 85 dB, 90 dB, 95 dB, and 100 dB) for six frequencies (0,5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz) and three percentages (10 %, 50 %, and 90 %).

5 Description and measurement of noise exposure

Methods for the determination of occupational noise exposure are specified in ISO 9612.

6 Prediction of the effects of noise on hearing threshold

6.1 Statistical distribution of hearing threshold levels of a noise-exposed population

The hearing threshold level, in decibels, associated with age and noise (HTLAN), *H'*, of a noise-exposed population is calculated, for the purposes of this International Standard, by using Formula (1):

$$H' = H + N - \frac{H \times N}{120} \quad (1)$$

where

H is the hearing threshold level, expressed in decibels, associated with age (HTLA);

N is the actual or potential noise-induced permanent threshold shift (NIPTS), expressed in decibels.

This formula is applicable only to corresponding percentage values of *H'*, *H*, and *N*.

NOTE The relationship expressed in Formula (1) is an approximation to the biological events and is considered accurate enough for the purposes of this International Standard. The term $(H \times N)/120$ starts to significantly modify the result only when $H + N$ is more than approximately 40 dB.

6.2 Databases for hearing threshold levels associated with age (HTLA)

6.2.1 General

The hearing of a non-noise-exposed population as a function of age depends on the degree to which other factors besides aging are inadvertently included; diseases, history of ototoxic drugs, and unknown noise exposure of occupational or non-occupational origin may modify the HTLA. Different approaches to screening such data have been used and the selection of the most appropriate database depends on the purpose of the application (see 6.2.4). This International Standard permits two databases (databases A and B) to be used for HTLA in 6.1. Database A is fully specified, whereas database B is at the discretion of the user. Three examples of database B are presented.

NOTE The databases presented in Annexes A and B are from populations of European and North American countries. These populations may or may not be representative for the populations of other geographical areas. Even if there are no differences in natural aging between different ethnic populations, differences in life style, non-occupational noise exposure, incidence of disease, and ototoxic drugs are nevertheless liable to occur.

6.2.2 Database A

Database A derives from otologically normal persons, i.e. persons in a normal state of health who are free from all signs or symptoms of ear disease and from obstructing wax in the ear canals and who have no history of undue exposure to noise. The statistical distributions of the thresholds of such highly screened populations have been standardized in ISO 7029 separately for male and female populations. Formulae for calculating database A are specified in A.1. The selected values of the statistical distribution of hearing threshold levels (in decibels) from database A are provided in Table A.3.

6.2.3 Database B

For database B, a set of data collected on a control population not occupationally exposed to noise of the country under consideration, but exposed to other risk factors to a degree similar to occupationally exposed populations, is recommended. When such an ideal control population is unavailable and in countries where risk factors such as non-occupational noise are more prevalent in occupationally exposed populations than in the general population, a totally unscreened control population may be preferable.

A separate HTLA database for both men and women is required unless it can be shown that there are no substantial gender differences. It is essential that the sample size be large enough to allow calculations of a valid statistical distribution.

Therefore, the user should apply appropriate selection criteria to compile a database of hearing threshold levels to compare to the levels given in Annex B of this International Standard. For instance, the average HTLA of both ears or the ear showing the greatest hearing loss can be taken as the basis for database B.

Three examples of database B are presented in Annex B for an unscreened population (males and females). These examples are compiled from representative data from three industrialized countries: Sweden (B.2), Norway (B.3), and the United States (B.4).

It is emphasized that for practical situations the accuracy of the prediction of the hearing threshold level of a noise-exposed population will largely be a function of the accuracy of the selected database for HTLA. Since audiometric measurement techniques affect threshold measurements, the same measurement technique should be used in the establishment of a specific HTLA database as might be used to obtain or verify the threshold of hearing of the noise-exposed population.

6.2.4 Choice of database

Whether database A or B is the more appropriate (or whether the numerical examples for database B in Annex B are suitable) depends on what question is to be answered. For example, if the amount of compensation that could be due to a population of noise-exposed workers is to be estimated, and otological irregularities and non-occupational noise exposure are not considered in compensation cases, and in most cases when the occupationally exposed population is not highly screened, unscreened populations will form the more appropriate databases.

6.3 Calculation of noise-induced permanent threshold shift, N

6.3.1 Calculation of N_{50}

The median potential noise-induced permanent threshold shift (NIPTS) values to be used in 6.1 are functions of audiometric frequency, the exposure duration, the ratio t/t_0, and the noise exposure level normalized to a nominal 8 h working day, $L_{EX,8h}$ (see 3.1), and 5 days per week, averaged over the exposure duration t.

For exposure durations between 10 years and 40 years, the median potential NIPTS values, N_{50}, in decibels, are given for both genders by Formula (2):

$$N_{50} = \left[u + v \lg \left(t / t_0\right)\right]\left(L_{EX,8h} - L_0\right)^2 \tag{2}$$

where

$L_{EX,8h}$	is the noise exposure level normalized to a nominal 8 h working day (see 3.1), expressed in decibels;
L_0	is the sound pressure level, defined as a function of frequency in Table 1, expressed in decibels, below which the effect on hearing is negligible;
t	is the exposure duration, expressed in years;
t_0	is 1 year;
u and v	are given as a function of frequency in Table 1.

This formula applies to $L_{EX,8h}$ greater than L_0. In cases where $L_{EX,8h}$ is less than L_0, it shall be deemed equal to L_0 so that N_{50} is zero.

For exposure durations less than 10 years, N shall be extrapolated from the value of N_{50} for 10 years using Formula (3):

$$N_{50,t<10} = \frac{\lg(t+1)}{\lg(11)} N_{50,t=10} \tag{3}$$

Formula (3) is valid for exposure durations between 1 year and 10 years. For exposure durations of less than 1 year, the results of Formula (3) represent an extrapolation.

Table 1 — Values of u, v, and L_0 used to determine the NIPTS for the median value of the population, N_{50}

Frequency Hz	u	v	L_0 dB
500	−0,033	0,110	93
1 000	−0,020	0,070	89
2 000	−0,045	0,066	80
3 000	0,012	0,037	77
4 000	0,025	0,025	75
6 000	0,019	0,024	77

6.3.2 Statistical distribution of noise-induced permanent threshold shift, N

For the purposes of this International Standard, the statistical distribution of N is approximated by two different halves of two normal (Gaussian) distributions. The upper half, for the percentage with hearing worse than the median, is characterized by the parameter d_u; the lower half has a smaller dispersion characterized by the parameter percentage d_l. For a percentage of, Q, of the population such that 5 ≤ Q < 50 %, the NIPTS is given by Formula (4):

$$N_Q = N_{50} + kd_u \tag{4}$$

For a percentage of, Q, of the population such that 50 % < Q ≤ 95 %, the NIPTS is given by Formula (5):

$$N_Q = N_{50} - kd_l \tag{5}$$

The values for the multiplier k corresponding to the normal (Gaussian) distribution are given in Table 2 of 6.3.2.1; d_u and d_l shall be calculated in accordance with 6.3.2.2.

Tails of the statistical distributions for 0 % < Q < 5 % and for 95 % < Q < 100 % are unreliable and should not be estimated since few experimental data exist to validate these ranges.

N_Q has a range of positive values representing the variability of noise-damage susceptibility between individuals of a population. Following the calculations, negative N_Q may occur, mostly for percentages of 55 % to 95 % for exposure durations less than 12 years and for percentages 5 % to 45 % for exposure durations less than 1 year. In such cases, N_Q should be set to zero.

6.3.2.1 Values of k

Values of the multiplier k are given in Table 2 in intervals of 5 % for Q.

Table 2 — Values of the multiplier k

Q %		k
5	95	1,645
10	90	1,282
15	85	1,036
20	80	0,842
25	75	0,675
30	70	0,524
35	65	0,385
40	60	0,253
45	55	0,126
50		0
NOTE Interpolations between the values presented can be obtained from ISO 7029.		

6.3.2.2 Parameters d_u and d_l

The parameters d_u and d_l, expressed in decibels, which are used in Formulae (4) and (5), respectively, are calculated as follows:

$$d_u = \left[X_u + Y_u \lg\left(t/t_0\right)\right]\left(L_{EX,8h} - L_0\right)^2 \tag{6}$$

$$d_l = \left[X_l + Y_l \lg\left(t/t_0\right)\right]\left(L_{EX,8h} - L_0\right)^2 \tag{7}$$

where

X_u, Y_u and X_l, Y_l	are given as a function of audiometric frequency in Table 3;
$L_{EX,8h}$	is the noise exposure level normalized to a nominal 8 h working day (see 3.1), expressed in decibels;
t	is the exposure duration, in years, ≥1 year;
t_0	is 1 year;
L_0	is the cut-off level (see 6.3.1) given in Table 1 for $L_{EX,8h}$ greater than L_0, expressed in decibels. Should $L_{EX,8h}$ be less than L_0, it shall be deemed equal to L_0.

Table 3 — Values of X_u, Y_u and X_l, Y_l used to determine, respectively, the parameters d_u and d_l characterizing the upper and lower parts of the statistical distribution of NIPTS ($N_{50} < Q < N_{95}$)

Frequency Hz	X_u	Y_u	X_l	Y_l
500	0,044	0,016	0,033	0,002
1 000	0,022	0,016	0,020	0,000
2 000	0,031	−0,002	0,016	0,000
3 000	0,007	0,016	0,029	−0,010
4 000	0,005	0,009	0,016	−0,002
6 000	0,013	0,008	0,028	−0,007

7 Assessment of noise-induced hearing loss and disability

7.1 Hearing loss

Potential hearing loss due to occupational exposure to noise is directly assessed by the noise-induced permanent threshold shift calculated in accordance with 6.3 for the exposure conditions and populations under consideration. The NIPTS can be

a) considered separately for each frequency of interest,

b) added for a certain number of frequencies to result in a “total” threshold shift, and

c) averaged for a number of selected frequencies usually representing the main speech intelligibility frequency range (see 7.2).

7.2 Hearing disability

For the calculation of hearing disability, a combination of hearing threshold levels at specified frequencies shall be used. The hearing threshold levels for the populations, their percentages, and exposure conditions of interest shall be calculated in accordance with Clause 6.

Users should consult national guidelines or criteria to determine how to assess hearing disability.

7.3 Risk of hearing disability

The risk of hearing disability due to noise exposure and age, or due to noise exposure alone, is a frequently used measure of the harmful effects of noise exposure on a population. A fence may be selected for the hearing threshold level above which a hearing disability is deemed to exist. Then the percentage of the population which has an average hearing threshold level equal to or exceeding the level selected for the fence may be calculated. The risks of hearing disability due to the combined effects of noise exposure and age and the risk of hearing disability due to noise alone may then be derived according to their definitions.

NOTE 1 The choice of formula and the height of the fence, though determined primarily by medico-legal considerations, can also be influenced by economic and ethical considerations.

NOTE 2 An example for the assessment of risk of hearing disability due to occupational noise exposure is illustrated in Annex C.

The risk of hearing disability due to noise should not be regarded as a single number descriptor. It varies with choice of frequency combination, choice of fence, and choice of HTLA. When quoting the risk of hearing disability due to noise, details of these parameters should also be provided.

NOTE 3 The risk of hearing disability due to noise gives the percentage of a population whose HTLAN exceeds the fence. It does not indicate the severity of the hearing disability as such.

NOTE 4 In the percentage of a population affected by hearing disability due to noise, the HTLAN is still a combination of components associated with both age and noise, of which the relative importance varies.

With some databases for HTLA and certain choices of frequency combinations and fence, the risk of hearing disability due to noise may decrease after a number of years of exposure. This is an inherent disadvantage of the concept "risk of hearing disability". It should not be interpreted as if the harmful effects of noise cease to exist. The explanation is that people who have crossed the fence because of age-related threshold shifts are no longer eligible for a risk of hearing disability due to noise. See also Notes 3 and 4.

Annex A
(informative)

Calculation of database A, statistical distribution of hearing thresholds as a function of age (HTLA) for an otologically normal population (highly screened)

A.1 Specification of database A

The values for database A are identical with the statistical distribution of normal threshold of hearing by air conduction specified as a function of age and sex in ISO 7029. The formulae applicable for the hearing threshold level, H, as a function of age, Y (years), for the various ranges of the percentage, Q, having hearing threshold level exceeding the value H_Q are:

for $Q = 50$ %:

$$H_{\mathrm{md,Y}} = a\left(Y - 18\right)^2 + H_{\mathrm{md;18}} \tag{A.1}$$

for 5 % ≤ Q < 50 %:

$$H_Q = H_{\mathrm{md,Y}} + ks_{\mathrm{u}} \tag{A.2}$$

for 50 % < Q ≤ 95 %:

$$H_Q = H_{\mathrm{md,Y}} - ks_{\mathrm{l}} \tag{A.3}$$

where

s_{u} is the standard deviation of the upper half of the distribution;

s_{l} is the standard deviation of the lower half of the distribution;

$H_{\mathrm{md,18}}$ is the median value of the hearing threshold of otologically normal persons of the same sex aged 18 years, which for practical purposes is taken as zero, as specified in the ISO 389 series. Hence, for the purpose of this International Standard, H_Q has been termed the hearing threshold level associated with age.

The values for the coefficient a are presented in Table A.1. The values for the multiplier k are the same as the ones given in 6.3.2.1 and in Table 2. The parameters s_{u} and s_{l} are given by Formulae (A.4) and (A.5):

$$s_{\mathrm{u}} = b_{\mathrm{u}} + 0{,}445 H_{\mathrm{md,Y}} \tag{A.4}$$

$$s_{\mathrm{l}} = b_{\mathrm{l}} + 0{,}356 H_{\mathrm{md,Y}} \tag{A.5}$$

Values of b_{u} and b_{l} are listed in Table A.2.

Table A.1 — Values of the coefficient a

Frequency Hz	a dB/year^2	
	Males	**Females**
125	0,003 0	0,003 0
250	0,003 0	0,003 0
500	0,003 5	0,003 5
1 000	0,004 0	0,004 0
1 500	0,005 5	0,005 0
2 000	0,007 0	0,006 0
3 000	0,011 5	0,007 5
4 000	0,016 0	0,009 0
6 000	0,018 0	0,012 0
8 000	0,022 0	0,015 0

Table A.2 — Values of b_u and b_l used to determine, respectively, the upper and lower parts of the statistical distribution H_Q

Frequency Hz	b_u dB		b_l dB	
	Males	**Females**	**Males**	**Females**
125	7,23	6,67	5,78	5,34
250	6,67	6,12	5,34	4,89
500	6,12	6,12	4,89	4,89
1 000	6,12	6,12	4,89	4,89
1 500	6,67	6,67	5,34	5,34
2 000	7,23	6,67	5,78	5,34
3 000	7,78	7,23	6,23	5,78
4 000	8,34	7,78	6,67	6,23
6 000	9,45	8,90	7,56	7,12
8 000	10,56	10,56	8,45	8,45

A.2 Selected values from database A

Selected values are given in Table A.3.

Table A.3 — Selected values of the statistical distribution of hearing threshold levels in decibels, from database A

Frequency Hz	**Hearing threshold level** dB														
	Age years														
	30			**40**			**50**			**60**			**70**		
	Percentages														
	90	50	10	90	50	10	90	50	10	90	50	10	90	50	10
Males															
500	−6	1	9	−5	2	11	−4	4	14	−3	6	18	−1	9	23
1 000	−6	1	9	−5	2	11	−4	4	14	−2	7	19	0	11	25
2 000	−7	1	11	−6	3	15	−3	7	21	−1	12	29	3	19	39
3 000	−7	2	13	−5	6	19	−2	12	29	3	20	42	9	31	59
4 000	−7	2	14	−4	8	23	0	16	36	7	28	55	15	43	79
6 000	−8	3	16	−5	9	26	0	18	41	8	32	62	17	49	>80
8 000	−9	3	19	−5	11	30	1	23	49	10	39	75	22	60	>80
Females															
500	−6	1	9	−5	2	11	−4	4	14	−3	6	18	−1	9	23
1 000	−6	1	9	−5	2	11	−4	4	14	−2	7	19	0	11	25
2 000	−6	1	10	−5	3	13	−3	6	18	−1	11	25	2	16	34
3 000	−7	1	11	−5	4	15	−3	8	21	0	13	30	4	20	41
4 000	−7	1	12	−6	4	17	−3	9	24	1	16	35	5	24	48
6 000	−8	2	14	−6	6	21	−2	12	31	2	21	45	9	32	62
8 000	−10	2	17	−7	7	25	3	15	38	4	27	55	11	41	77

Annex B
(informative)

Examples for database B

B.1 General

This annex includes three examples of database B for an unscreened population. These examples are compiled from data from three industrialized countries: Sweden (B.2), Norway (B.3), and the United States (B.4). B.2 and B.3 represent populations who have not been exposed to occupational noise, while subjects with occupational noise exposure are included in B.4.

B.2 Selected values from database B2

This example for database B comprises hearing threshold levels associated as function of age of a typical unscreened population (males and females) of an industrialized country where subjects with occupational noise exposure have been excluded. Data are for all the ears of the subjects tested in this study.

NOTE The data are adapted from the results of a particular survey (see Reference [17]). The hearing threshold values were determined using insert earphones calibrated according to ISO 389-2 and the measurements followed the ascending procedure in 5 dB steps according to ISO 8253-1.

Table B.1 — Selected values of the statistical distribution of hearing threshold levels in decibels of an unscreened population in Sweden[17]

Frequency Hz	**Hearing threshold level** dB														
	Age years														
	30			**40**			**50**			**60**			**70**		
	Percentages														
	90	50	10	90	50	10	90	50	10	90	50	10	90	50	10
Males															
500	−1	5	12	0	7	15	2	9	20	5	13	27	8	17	37
1 000	0	5	14	1	7	18	3	11	24	5	15	33	8	20	43
2 000	0	5	16	1	8	24	4	13	35	7	20	49	11	30	63
3 000	−2	5	21	0	9	31	4	16	44	10	28	57	19	43	69
4 000	−2	5	23	1	11	34	5	21	48	13	36	62	25	51	73
6 000	−2	5	21	−1	9	33	2	19	48	10	36	64	22	53	76
8 000	−2	4	16	−1	9	31	4	23	55	16	46	76	35	65	87
Females															
500	−1	5	13	0	6	15	1	8	21	4	13	30	8	20	42
1 000	−1	5	12	0	6	14	2	9	20	5	14	32	9	23	48
2 000	−1	5	13	0	7	17	3	10	26	6	18	39	11	30	53
3 000	−2	4	13	−1	6	18	1	11	27	6	19	41	12	32	55
4 000	−4	4	13	−3	5	17	0	9	27	5	20	43	14	36	59
6 000	−5	3	12	−4	5	17	1	10	28	5	22	48	14	41	66
8 000	−5	2	12	−3	5	19	1	13	37	9	31	61	21	55	77

B.3 Selected values from database B3

This example for database B comprises hearing threshold levels as a function of age of a typical unscreened population (males and females) of an industrialized country where subjects with occupational noise exposure have been excluded (data are for the more sensitive ears as determined for each test frequency and test subject).

NOTE The data are adapted from the results of a particular survey (see Reference [18]). The hearing threshold values were determined using supra-aural earphones calibrated according to ISO 389-1 and the measurements followed the ascending procedure in 5 dB steps according to ISO 8253-1.

Table B.2 — Selected values of the statistical distribution of hearing threshold levels in decibels of an unscreened population in Norway[18]

Frequency Hz	Hearing threshold level dB														
	Age years														
	30			**40**			**50**			**60**			**70**		
	Percentages														
	90	50	10	90	50	10	90	50	10	90	50	10	90	50	10
Males															
500	–5	3	13	–3	5	14	–2	6	16	–1	8	19	2	12	25
1 000	–5	2	11	–4	3	13	–3	5	15	–2	7	19	1	12	30
2 000	–7	1	13	–6	3	16	–4	6	19	–1	10	28	5	20	46
3 000	–8	1	13	–5	4	19	–3	8	26	1	15	45	9	31	60
4 000	–9	2	15	–4	7	25	1	13	35	6	24	56	17	45	68
6 000	–4	9	23	2	13	29	5	19	41	12	31	61	23	53	76
8 000	–6	4	19	–2	10	28	2	16	42	10	31	63	24	58	81
Females															
500	–3	5	14	–2	6	16	0	8	20	2	11	24	5	16	31
1 000	–5	2	11	–4	4	14	–2	6	18	0	9	23	3	15	33
2 000	–7	2	12	–5	4	15	–3	7	20	0	11	28	5	20	41
3 000	–8	0	10	–6	2	14	–4	6	20	0	12	29	6	21	45
4 000	–8	1	12	–6	4	16	–3	8	23	2	14	34	8	26	52
6 000	–3	8	21	0	12	25	3	16	32	9	22	46	15	36	65
8 000	–5	7	17	1	10	25	4	16	39	10	26	58	16	48	74

B.4 Selected values from database B4

This example for database B comprises hearing threshold levels as a function of age of a typical unscreened population (males and females) of an industrialized country (data are for the more sensitive ears as determined for each test frequency and test subject). These data represent a completely unscreened group that also includes subjects with occupational noise exposure. The argument for such a control group is that occupational noise exposure may be significantly associated with a number of factors, including educational level, non-occupational noise exposure, and smoking (see Reference [20]). In such cases, a control population that simply excludes people with occupational noise exposure will have lower prevalence of these and other risk factors for hearing loss than are found in the general population and especially in typical occupationally exposed populations. Such associations may, however, differ from country to country.

NOTE The data are adapted from the results of a particular survey (see Reference [19]). The hearing threshold values were determined using supra-aural earphones calibrated according to ISO 389-1 unless potential for collapsing ear canals was noted on the otoscopic examination. In such case, insert earphones were used, calibrated according to ISO 389-2. The measurements followed the ascending procedure in 5 dB steps according to ISO 8253-1.

Table B.3 — Selected values of the statistical distribution of hearing threshold levels in decibels of an unscreened population from the United States[19][22]

Frequency Hz	Hearing threshold level dB														
	Age years														
	30			40			50			60			70		
	Percentages														
	90	50	10	90	50	10	90	50	10	90	50	10	90	50	10
Males															
500	–1	7	16	–1	8	19	1	10	20	2	11	23	4	15	28
1 000	–2	4	14	–1	6	17	1	9	18	1	11	23	4	14	31
2 000	–5	4	14	–3	6	20	0	10	24	3	14	38	6	21	54
3 000	–5	4	17	–1	9	29	3	15	45	7	25	57	13	37	66
4 000	–2	7	23	2	13	39	6	22	57	13	35	65	20	49	73
6 000	0	11	27	4	17	41	9	25	64	16	40	74	26	56	84
8 000	–2	8	21	2	14	41	7	23	61	13	42	78	30	60	86
Females															
500	0	7	17	–1	7	19	1	9	21	4	13	27	5	17	32
1 000	–3	4	12	–2	5	15	–1	7	19	1	10	26	3	13	33
2 000	–4	4	12	–2	5	16	–1	7	21	1	11	28	4	17	35
3 000	–6	2	11	–2	4	15	–2	7	21	2	12	33	8	20	42
4 000	–5	4	14	–2	7	19	0	10	26	4	16	40	10	27	48
6 000	0	10	22	3	12	27	4	17	34	9	24	49	17	37	61
8 000	–2	7	17	1	10	25	4	16	39	10	26	58	16	48	74

Annex C
(informative)

Example of assessment of risk of noise-induced hearing loss and disability

Calculate the risk of noise-induced hearing loss for a highly screened male population, 50 years of age, which was exposed to an average daily noise exposure level, $L_{EX,8h}$ = 90 dB ($E_{A,8h}$ = 11,5 × 10^3 Pa^2s) for 30 years (8 h/day, 5 days/week, 50 weeks/year). The population is characterized by the following: no ear disease; no non-occupational noise exposure; and, no other hearing loss risk factors.

For disability assessment, the frequency combination 1 kHz, 2 kHz, and 4 kHz is assumed. The age-related hearing threshold level, H_Q, for the non-noise-exposed population is calculated as the arithmetic mean of the hearing threshold levels at 1 kHz, 2 kHz, and 4 kHz, which are taken from Table A.3. For most unscreened industrial populations, it would be more appropriate to calculate the age-related hearing threshold levels using the data in Annex B.

$$H_{90,50} = \left[(-4) + (-3) + 0\right]/3\text{ dB} = -2{,}3\text{ dB} \tag{C.1}$$

$$H_{50;50} = \left(4 + 7 + 16\right)/3\text{ dB} = 9{,}0\text{ dB} \tag{C.2}$$

$$H_{10,50} = \left(14 + 21 + 36\right)/3\text{ dB} = 23{,}7\text{ dB} \tag{C.3}$$

The noise-induced permanent threshold shift N is given by:

$$N - \frac{HN}{120} \approx N \tag{C.4}$$

(see 6.1).

The term $HN/120$ only starts to have a significant impact on the result when $(H + N)$ > approximately 40 dB. Therefore, when $(H + N)$ < 40 dB, the NIPTS can be taken directly from Table D.2. This is the case for the 90 %, 50 %, and 10 % for 1 kHz and 2 kHz, and the 90 % and 50 % for 4 kHz.

For 10 % at 4 kHz, $(H + N)$ > 40 dB; therefore, the NIPTS value of 19 dB from Table D.2 is reduced as follows:

$$19\text{ dB} - \frac{(36\times19)}{120}\text{ dB} = 13{,}3\text{ dB} \tag{C.5}$$

The NIPTS is taken to be the arithmetic mean of the NIPTS decibel values at 1 kHz, 2 kHz, and 4 kHz taken directly from or modified from the data in Table D.2 as follows:

$$N_{90;30} = \left(0 + 3 + 10\right)/3\text{ dB} = 4{,}3\text{ dB} \tag{C.6}$$

$$N_{50;30} = \left(0 + 5 + 14\right)/3\text{ dB} = 6{,}3\text{ dB} \tag{C.7}$$

$$N_{10;30} = (0 + 9 + 13{,}3)/3\ \text{dB} = 7{,}4\ \text{dB} \quad \text{(C.8)}$$

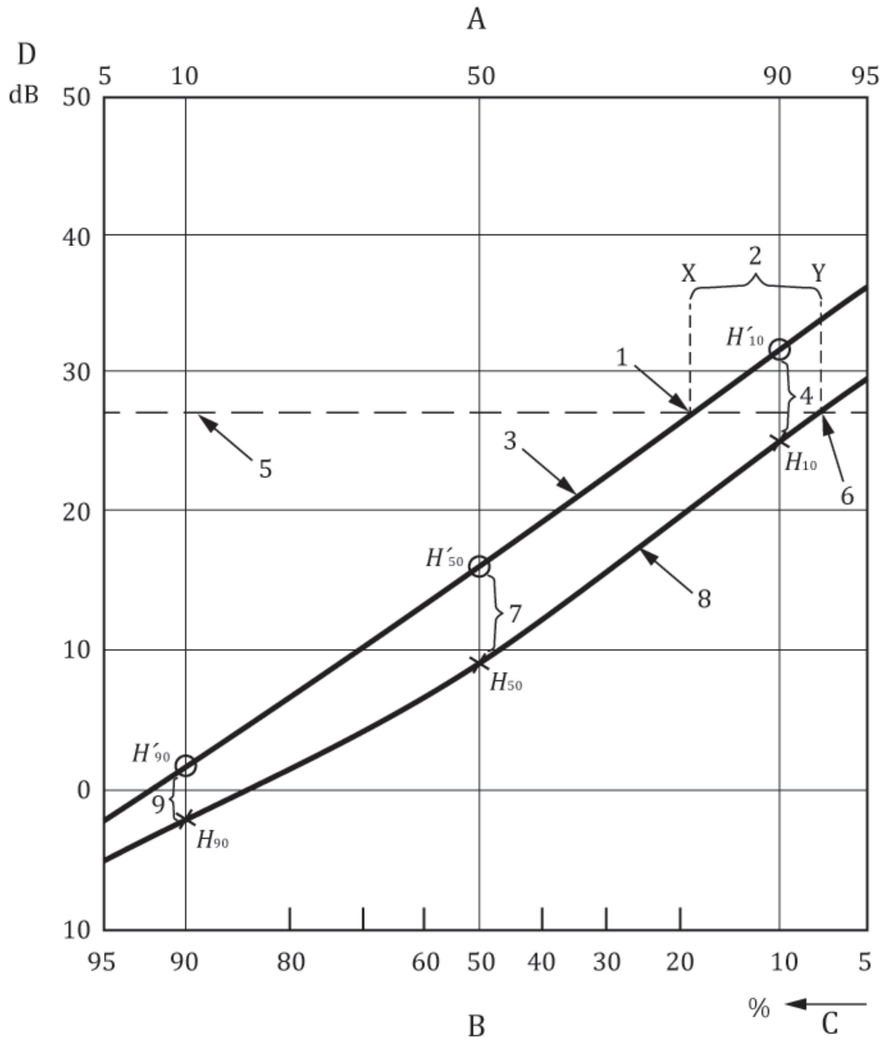
The hearing threshold level associated with the age and noise, H', for the noise-exposed population is calculated as the sum of the age-related hearing threshold levels (H) and the NIPTS values (N) (see Formula (1) in 6.1) as follows:

$$H'_{90} = (-2{,}3)\ \text{dB} + 4{,}3\ \text{dB} = 2{,}0\ \text{dB} \quad \text{(C.9)}$$

$$H'_{50} = 9{,}0\ \text{dB} + 6{,}3\ \text{dB} = 5{,}3\ \text{dB} \quad \text{(C.10)}$$

$$H'_{10} = 23{,}7\ \text{dB} + 7{,}4\ \text{dB} = 31{,}1\ \text{dB} \quad \text{(C.11)}$$

The resulting relationship is plotted in Figure C.1 on Gaussian coordinates with the various risks of disability illustrated for an arbitrary fence of 27 dB. The dependence of the risk values on the magnitude of the fence can easily be studied with such an illustration.



Key

A percentage with better hearing

B percentage with worse hearing

C % risk

D hearing threshold level, dB

1 risk of disability due to age and noise exposure, 18 % (point X)

2 risk of disability due to noise exposure, 11,5 % (difference between point X and point Y)

3 HTLA of noise-exposed population

4 NIPTS, 10 %

5 assumed fence, 27 dB

6 population risk of disability

7 NIPTS, 50 %

8 HTLA of non-noise-exposed population

9 NIPTS, 90 %

Figure C.1 — Example of hearing risk assessment noise exposure level $L_{EX,8h}$ = 90 dB **for 30 years exposure with HTLA data from database A**

Annex D
(informative)

Tables with examples for NIPTS data

Tables D.1 to D.4 show examples for NIPTS as a function of exposure duration, in years, noise exposure level, $L_{EX,8h}$ (85 dB, 90 dB, 95 dB, and 100 dB), and corresponding A-weighted sound exposures for six frequencies (0,5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz) and three percentages (10 %, 50 %, and 90 %) calculated in accordance with 6.3 of this International Standard.

Table D.1 — $L_{EX,8h}$ = 85 dB ($E_{A,8h}$ = 3,64 × 10^3 Pa^2s)

Frequency Hz	**NIPTS** dB											
	Exposure duration years											
	10			**20**			**30**			**40**		
	Percentages											
	90	50	10	90	50	10	90	50	10	90	50	10
500	0	0	0	0	0	0	0	0	0	0	0	0
1 000	0	0	0	0	0	0	0	0	0	0	0	0
2 000	0	1	1	1	1	2	1	1	2	1	2	2
3 000	2	3	5	3	4	6	3	4	7	3	5	7
4 000	3	5	7	4	6	8	5	6	9	5	7	9
6 000	1	3	4	2	3	5	2	3	6	2	4	6

Table D.2 — $L_{EX,8h}$ = 90 dB ($E_{A,8h}$ = 11,5 × 10^3 Pa^2s)

Frequency Hz	**NIPTS** dB											
	Exposure duration years											
	10			**20**			**30**			**40**		
	Percentages											
	90	50	10	90	50	10	90	50	10	90	50	10
500	0	0	0	0	0	0	0	0	0	0	0	0
1 000	0	0	0	0	0	0	0	0	0	0	0	0
2 000	0	2	6	2	4	8	3	5	9	4	6	10
3 000	4	8	13	7	10	16	8	11	18	9	12	19
4 000	7	11	15	9	13	18	10	14	19	11	15	20
6 000	3	7	12	4	8	14	5	9	15	6	10	15

Table D.3 — $L_{EX,8h}$ = 95 dB ($E_{A,8h}$ = 36,4 × 10^3 Pa^2s)

Frequency Hz	NIPTS dB											
	Exposure duration years											
	10			20			30			40		
	Percentages											
	90	50	10	90	50	10	90	50	10	90	50	10
500	0	0	1	0	0	1	0	1	1	0	1	1
1 000	1	2	4	2	3	5	2	3	5	2	3	6
2 000	0	5	13	5	9	17	7	12	20	9	14	22
3 000	8	16	25	13	19	31	16	22	34	18	23	37
4 000	13	20	27	16	23	32	18	25	34	19	26	36
6 000	5	14	23	8	16	26	10	18	28	12	19	29

Table D.4 — $L_{EX,8h}$ = 100 dB ($E_{A,8h}$ = 115 × 10^3 Pa^2s)

Frequency Hz	NIPTS dB											
	Exposure duration years											
	10			20			30			40		
	Percentages											
	90	50	10	90	50	10	90	50	10	90	50	10
500	2	4	8	3	5	9	4	6	11	5	7	11
1 000	3	6	12	6	9	15	7	10	17	8	11	19
2 000	0	8	23	8	16	31	13	21	35	16	24	39
3 000	13	26	41	21	32	51	26	35	56	29	38	60
4 000	20	31	42	25	36	49	28	39	53	30	41	56
6 000	9	23	37	14	27	42	17	29	46	19	30	48

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