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Acoustics — Statistical distribution of hearing thresholds of otologically normal persons in the age range from 18 years to 25 years under free-field listening conditions

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Acoustics — Statistical distribution of hearing thresholds of otologically normal persons in the age range from 18 years to 25 years under free-field listening conditions

Acoustique — Répartition statistique des niveaux liminaires d'audition de personnes otologiquement normales âgées de 18 à 25 ans dans des conditions d'écoute en champ libre

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Foreword

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ISO 28961 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

Introduction

The threshold of hearing in a free sound field is specified in ISO 226 and ISO 389-7. Threshold data in these documents were obtained from otologically normal persons in the age range 18 years to 25 years inclusive.

As described in ISO 389-7, the threshold of hearing varies among people; the documents merely present median values of hearing thresholds. However, other values on the threshold distribution of individuals are necessary to evaluate the hearing ability of a person in relation to that of the population. Those values have been used also in noise evaluation for estimating the ratio of young people with normal hearing in the population who might be able to detect a sound of concern, e.g. an unwanted sound emitted from a machine.

This International Standard provides a method for calculating percentiles of the hearing threshold distribution for one-third-octave-band and other audiometric frequencies from 20 Hz to 16 000 Hz. The mean value of distribution is set to be the threshold of hearing specified in ISO 226 and ISO 389-7. Furthermore, the method has been developed using many of the hearing threshold data on which those documents were based.

NOTE Percentiles of the hearing threshold distribution can also be determined for bands of noise. However, only percentiles for pure tones are specified in this International Standard because insufficient data for bands of noise are available. Nevertheless, it is possible that this International Standard is applicable to one-third-octave bands of noise.

Acoustics — Statistical distribution of hearing thresholds of otologically normal persons in the age range from 18 years to 25 years under free-field listening conditions

1 Scope

This International Standard provides descriptive statistics, percentiles, of the hearing threshold distribution whose mean is the reference threshold value specified in ISO 226 and ISO 389-7. The mean and percentile thresholds are specified under the following conditions:

a) the sound field in the absence of the listener consists of a free progressive plane wave (free field);

b) the sound source is directly in front of the listener (frontal incidence);

c) the sound signals are pure (sinusoidal) tones;

d) the sound pressure level is measured in the absence of the listener at the position where the centre of the listener's head would be;

e) listening is binaural;

f) the listeners are otologically normal persons within the age range 18 years to 25 years inclusive.

NOTE 1 The xth percentile threshold is the value of threshold below which x % of the individual thresholds of population fall. The threshold distributions in this International Standard have been derived from the results of comprehensive statistical analyses. See Annex D.

NOTE 2 The applicability of the percentiles and the values of parameters given in this International Standard to diffuse-field listening conditions has not been examined. They are expected to be applicable to the conditions for the frequencies from 20 Hz to 250 Hz where the threshold difference between free-field and diffuse-field listening conditions is zero as specified in ISO 389-7:2005, Table 1.

The percentiles are given in numerical form for the preferred frequencies in the one-third-octave series from 20 Hz to 16 000 Hz inclusive, in accordance with ISO 266, and for some intermediate audiometric frequencies.

The percentiles are applicable to the assessment of an individual's hearing in relation to the distribution of hearing thresholds under the above conditions. The percentiles can also be used to evaluate the audibility of low-level noise around hearing threshold.

NOTE 3 An application example of hearing threshold distribution to noise evaluation can be found in ISO 7779:2010, Annex D.

2 Normative references

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

ISO 226:2003, *Acoustics — Normal equal-loudness-level contours*

ISO 266, *Acoustics — Preferred frequencies*

ISO 389-7:2005, *Acoustics — Reference zero for the calibration of audiometric equipment — Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions*

3 Calculation of percentiles of hearing threshold distribution

3.1 General

The threshold distribution for the frequencies f below 10 000 Hz shall be approximated by a Gaussian distribution, which is determined using a mean value T_f and a standard deviation σ_f. Using T_f and σ_f, any percentile on the distribution is calculable as specified in 3.2.

Percentiles at 10 000 Hz and higher frequencies shall be calculated using a similar procedure, as specified in 3.3. However, a numerical transformation shall be performed first so that the threshold distribution can be approximated using a Gaussian distribution in the transformed domain.

For both frequency ranges, the mean value of the distribution shall be set to the reference threshold in free field T_f in decibels given in ISO 226 and ISO 389-7.

Examples of calculation are shown in Annex A. Selected values of the statistical threshold distribution which are calculated following those procedures are presented in tabular and graphical forms in Annex B.

3.2 Threshold distribution at frequencies lower than 10 000 Hz

The xth percentile $P_{x,f}$ of threshold distribution (reference value 20 μPa) in decibels at frequencies lower than 10 000 Hz shall be calculated using Equation (1):

$$P_{x,f} = T_f + z_x \sigma_f \tag{1}$$

where z_x is a z-score of the proportion of Gaussian distribution which corresponds to the xth percentile.

Selected values of z_x are presented in Annex C. The values of standard deviation σ_f for the threshold distribution at frequencies lower than 10 000 Hz are presented in Table 1. The values are the outcome of comprehensive statistical analyses. The accuracy provided is for calculation only.

NOTE As x approaches 0 or 100, $P_{x,f}$ becomes liable to a larger uncertainty of threshold estimation because of uncertainty in the experimental data on which this International Standard is based.

Table 1 — Standard deviation of threshold distribution, σ_f, at frequencies f lower than 10 000 Hz

f in Hz	σ_f in dB
20	6,14
25	6,38
31,5	6,48
40	6,37
50	6,04
63	5,40
80	4,58
100	4,03
125	3,79
160	3,78
200	3,84
250	3,84
315	3,75
400	3,61
500	3,54
630	3,63
750	3,81
800	3,91
1 000	4,29
1 250	4,69
1 500	4,94
1 600	5,00
2 000	5,09
2 500	5,02
3 000	4,91
3 150	4,89
4 000	4,86
5 000	5,03
6 000	5,30
6 300	5,38
8 000	5,75
9 000	5,95

3.3 Threshold distribution at 10 000 Hz and higher frequencies

The threshold distribution at 10 000 Hz and higher frequencies shall be approximated using a Gaussian distribution after individual thresholds are operated mathematically using the following power-transformation equation:

$$\dot{u} = \left(u - \alpha_f\right)^{\beta_f} \quad (2)$$

where

u is an individual threshold in the distribution in decibels (reference value 20 µPa);

α_f is the parameter that determines the origin of power transformation;

β_f is the exponent of power transformation.

Parameters α_f and β_f are shown in Table 2. The values are the outcome of comprehensive statistical analyses. The accuracy provided is for calculation only.

Hereinafter, a dotted variable denotes a value in the power-transformed domain.

Table 2 — Parameters for calculating the percentile threshold at frequencies f of 10 000 Hz and higher

f Hz	α_f	β_f	$\dot{\sigma}_f$	$\dot{T}_f$
10 000	–26,72	0,766 4	1,861	17,10
11 200	–11,03	0,567 5	0,932 3	6,075
12 000	–4,537	0,451 1	0,715 5	3,640
12 500	–2,219	0,384 9	0,621 5	2,800
14 000	–1,033	0,216 5	0,253 4	1,901
16 000	6,271	0,062 83	0,038 89	1,248

The xth percentile $\dot{P}_{x,f}$ of threshold distribution shall be given by Equation (3):

$$\dot{P}_{x,f} = \dot{T}_f + z_x \, \dot{\sigma}_f \quad (3)$$

where

$\dot{T}_f$ is the mean value of threshold distribution given in ISO 226 and ISO 389-7;

$\dot{\sigma}_f$ is the standard deviation of threshold distribution at frequencies of 10 000 Hz and higher.

Both variables are also shown in Table 2.

To derive a percentile threshold (reference value 20 µPa) in decibels, $\dot{P}_{x,f}$ shall be transformed using Equation (4), which is the inverse function of Equation (2), with u and $\dot{u}$ replaced by $P_{x,f}$ and $\dot{P}_{x,f}$:

$$P_{x,f} = \exp\left(\frac{\ln \dot{P}_{x,f}}{\beta_f}\right) + \alpha_f \quad (4)$$

NOTE As x approaches 0 or 100, $P_{x,f}$ becomes liable to a larger uncertainty of threshold estimation because of uncertainty in the experimental data on which this International Standard is based.

Annex A
(informative)

Numerical examples to illustrate the procedure

A.1 Example 1

The 10th percentile of hearing threshold of otologically normal persons at the audiometric frequency 1 000 Hz is calculated as follows.

Step 1: Table 1, $f = 1\,000$ Hz, gives $\sigma_{1\,000} = 4{,}29$ dB.

Step 2: Table C.1, $x = 10$, gives $z_x = -1{,}282$.

Step 3: ISO 226:2003, Table 1 and ISO 389-7:2005, Table 1, $f = 1\,000$ Hz, gives $T_{1\,000} = 2{,}4$ dB.

Step 4: Equation (1), $T_{1\,000} = 2{,}4$ dB, $z_x = -1{,}282$, $\sigma_{1\,000} = 4{,}29$ dB, gives $P_{10,\,1\,000} = -3{,}1$ dB.

Step 5: The result should be rounded to the nearest integer, i.e. –3 dB.

A.2 Example 2

The 75th percentile of hearing threshold of otologically normal persons at the audiometric frequency 12 500 Hz is calculated as follows.

Step 1: Table 2, $f = 12\,500$ Hz, gives $\alpha_{12\,500} = -2{,}219$, $\beta_{12\,500} = 0{,}384\,9$, $\dot{\sigma}_{12\,500} = 0{,}621\,5$, and $\dot{T}_{12\,500} = 2{,}800$.

Step 2: Table C.1, $x = 75$, gives $z_x = 0{,}674\,5$.

Step 3: Equation (3), $\dot{T}_{12\,500} = 2{,}800$, $z_x = 0{,}674\,5$, $\dot{\sigma}_{12\,500} = 0{,}621\,5$, gives $\dot{P}_{75,\,12\,500} = 3{,}219$

Step 4: Equation (4), $\dot{P}_{75,\,12\,500} = 3{,}219\ldots$, $\alpha_{12\,500} = -2{,}219$, $\beta_{12\,500} = 0{,}384\,9$, gives $P_{75,\,12\,500} = 18{,}6$ dB.

Step 5: The result should be rounded to the nearest integer, i.e. 19 dB.

Annex B
(informative)

Selected values of the statistical distribution of hearing thresholds of otologically normal persons in the age range 18 years to 25 years inclusive

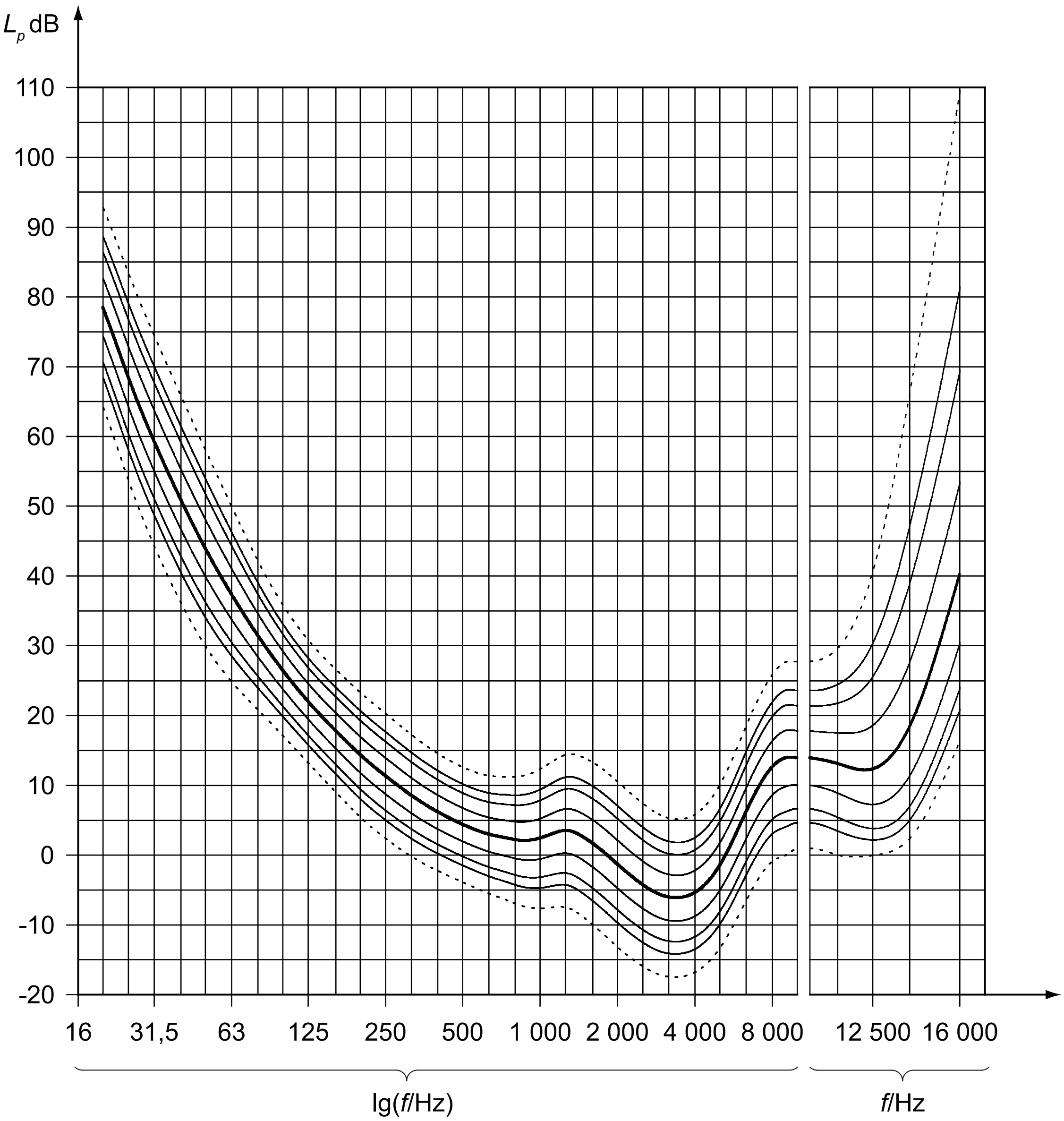
Table B.1 — $P_{x,f}$: the xth percentiles of threshold distribution at frequency f

f in Hz	$P_{x,f}$ in dB						
	$x = 5$	$x = 10$	$x = 25$	$x = 50$	$x = 75$	$x = 90$	$x = 95$
20	68	71	74	79	83	86	89
25	58	61	64	69	73	77	79
31,5	49	51	55	60	64	68	70
40	41	43	47	51	55	59	62
50	34	36	40	44	48	52	54
63	29	31	34	38	41	44	46
80	24	26	28	32	35	37	39
100	20	21	24	27	29	32	33
125	16	17	20	22	25	27	28
160	12	13	15	18	20	23	24
200	8	10	12	14	17	19	21
250	5	7	9	11	14	16	18
315	2	4	6	9	11	13	15
400	0	2	4	6	9	11	12
500	–1	0	2	4	7	9	10
630	–3	–2	1	3	5	8	9
750	–4	–3	0	2	5	7	9
800	–4	–3	0	2	5	7	9
1 000	–5	–3	–1	2	5	8	10
1 250	–4	–3	0	4	7	10	11
1 500	–6	–4	–1	2	6	9	11
1 600	–7	–5	–2	2	5	8	10
2 000	–10	–8	–5	–1	2	5	7
2 500	–13	–11	–8	–4	–1	2	4
3 000	–14	–12	–9	–6	–3	1	2
3 150	–14	–12	–9	–6	–3	0	2
4 000	–13	–12	–9	–5	–2	1	3
5 000	–10	–8	–5	–2	2	5	7
6 000	–4	–3	1	4	8	11	13
6 300	–3	–1	2	6	10	13	15
8 000	3	5	9	13	17	20	22
9 000	4	6	10	14	18	22	24

Table B.1 (*continued*)

f in Hz	$P_{x,f}$ in dB						
	$x = 5$	$x = 10$	$x = 25$	$x = 50$	$x = 75$	$x = 90$	$x = 95$
10 000	5	7	10	14	18	21	24
11 200	3	5	9	13	18	22	25
12 000	3	5	8	13	19	24	28
12 500	2	4	7	12	19	26	30
14 000	5	7	12	18	28	39	48
16 000	21	24	31	40	54	70	82

NOTE The percentiles were adopted from References [2] for frequencies from 20 Hz to 50 Hz, [3] and [4] for 63 Hz to 9 000 Hz, and [5] for 10 000 Hz to 16 000 Hz. The 50th percentiles are the reference thresholds T_f in ISO 226 and ISO 389-7.



Key

f frequency on a log scale for $f < 10\ 000$ and a linear scale for $f \geq 10\ 000$

L_p sound pressure level

From top to bottom, the curves are those for P_{99} (dotted), P_{95}, P_{90}, P_{75}, P_{50} (bold), P_{25}, P_{10}, P_5, and P_1 (dotted).

NOTE P_{99} and P_1 are on the tails of threshold distribution and therefore liable to a large uncertainty of estimation because of uncertainty in the experimental data on which this International Standard is based. The curves for those percentiles are presented for informative purposes only.

Figure B.1 — Percentile curves of hearing threshold distribution

Annex C
(informative)

Selected values of z_x

Table C.1 — Selected values of z_x of the Gaussian distribution corresponding to the xth percentile

x	z_x
1	−2,326
5	−1,645
10	−1,282
20	−0,841 6
25	−0,674 5
30	−0,524 4
40	−0,253 3
50	0,000 0
60	0,253 3
70	0,524 4
75	0,674 5
80	0,841 6
90	1,282
95	1,645
99	2,326

Annex D
(informative)

Notes on the derivation of the statistical distribution of normal hearing thresholds

D.1 Form of the threshold distribution at frequencies lower than 10 000 Hz

Statistical analyses of empirical hearing threshold data show that the form of normal hearing threshold distribution at frequencies lower than 10 000 Hz can be approximated by a Gaussian distribution (see References [2] to [4]).

The standard deviation of threshold distribution varies depending on frequency, as shown in Table 1.

D.2 Form of the threshold distribution at 10 000 Hz and higher frequencies

Deviation of threshold distribution from a Gaussian distribution becomes evident at 10 000 Hz and higher frequencies. The distribution is positively skewed, with a longer tail toward the higher sound pressure level (see Reference [5]).

Fitness to a Gaussian distribution is improved by a power-transformation of individual thresholds. After the transformation, the threshold distribution can be treated as a Gaussian distribution.

The standard deviation of threshold distribution varies depending on frequency and is expressed as a value in the transformed domain, as shown in Table 2.

D.3 Investigations of normal hearing thresholds used to derive the statistical distribution

Literature data were used to examine the normality of threshold distribution and estimate the standard deviations.

References [6] to [14] were those adopted for deriving the reference threshold of hearing under free-field listening conditions in ISO 226 and ISO 389-7. These nine references were selected from others cited in these documents because they provide statistics of threshold variability in numerical form, which enables a mathematical estimation of standard deviation.

Other data, in References [2] and [15] to [20], were not cited in ISO 226 and ISO 389-7, but were obtained under comparable measurement conditions with those for establishing the standards (see Reference [21]). References [2] and [15] to [20] were adopted to compensate for scarcity of threshold data at very low and high frequencies and, thereby, improved estimation accuracy of individual threshold variability.

The standard deviations of threshold distribution in Tables 1 and 2 were calculated by integrating those reported in the literature above. Details of the calculation method are presented in References [2] to [5].

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