INTERNATIONAL STANDARD

ISO 389-7

Third edition
2019-10

Acoustics — Reference zero for the calibration of audiometric equipment —

Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions

Acoustique — Zéro de référence pour l'étalonnage d'équipements audiométriques —

Partie 7: Niveau liminaire de référence dans des conditions d'écoute en champ libre et en champ diffus

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Reference number
ISO 389-7:2019(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

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

This third edition cancels and replaces the second edition (ISO 389-7:2005), which has been technically revised to incorporate the Amendment ISO 389-7:2005/Amd.1:2016. The main changes compared to the previous edition are as follows:

— the reference thresholds of hearing at 20 Hz under the conditions of free-field and diffuse-field listening and the reference threshold of hearing at 18 000 Hz under the condition of free-field listening were recalculated using additional experimental data;

— the Bibliography was updated.

A list of all parts in the ISO 389 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

In some audiological applications, the test signals are delivered by means of loudspeakers, either in a free sound field or in a diffuse sound field. This document specifies the reference zero for the calibration of audiometric equipment used for sound field audiometry. Corresponding audiometric test methods are specified in ISO 8253-1 and ISO 8253-2.

In common with other subjective phenomena, the threshold of hearing varies in detail from person to person but, for a group of otologically normal persons within a restricted age range, values for the central tendency can be determined to characterize the group. This document and other parts of ISO 389 specify threshold data applicable to otologically normal persons in the age range from 18 years to 25 years.

The data specified in this document relate to

a) pure tones heard under conditions of binaural listening in free progressive plane waves with the subject directly facing the source of sound (frontal incidence), and with the sound pressure level measured in the free progressive wave at the centre position of the listener's head with the listener absent;

b) one-third-octave bands of (white or pink) noise heard under conditions of binaural listening in a diffuse sound field with the sound pressure level measured in the sound field at the centre position of the listener's head with the listener absent.

For frequencies up to 8 kHz, each set of data may be equally applied to any other bands of (white or pink) noise for which the bandwidth is less than the critical bandwidth.

The data are based on an assessment of technical information provided by laboratories in different countries representing the most reliable data available at the time. For information, a note on the derivation of the reference values and the origin of the data is given in Annex A.

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Acoustics — Reference zero for the calibration of audiometric equipment —

Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions

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1 Scope

This document specifies a reference threshold of hearing for the calibration of audiometric equipment used under the following conditions.

a) The sound field in the absence of the listener consists of either a free progressive plane wave (free field) or a diffuse sound field, as specified in ISO 8253-2. In the case of a free field, the source of sound is directly in front of the listener (frontal incidence).

b) The sound signals are pure (sinusoidal) tones in the case of free-field conditions and one-third-octave bands of (white or pink) noise in the case of diffuse-field conditions.

c) 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.

d) Listening is binaural.

NOTE 1 Correction values for the threshold of hearing under free-field listening conditions and selected angles of sound incidence (45° and 90°) deviating from frontal incidence are given in ISO 8253-2 for information.

NOTE 2 Other conditions are given in Reference [1].

The data 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, in addition, for some intermediate audiometric frequencies up to 18 000 Hz.

The threshold data differ from the audiometric zero specified in ISO 389-1, ISO 389-2, ISO 389-5 and ISO 389-8, since the latter refer to monaural listening through earphones with sound pressure levels referred to specified couplers and ear simulators. Direct comparison between the data in the parts of ISO 389 mentioned above and in this document is therefore not appropriate.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

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3.1
threshold of hearing
level of a sound at which, under specified conditions, a person gives 50 % of correct detection responses on repeated trials

Note 1 to entry: The results of threshold determination depend to a certain degree on the test procedure used. The data presented in the ISO 389 series are all based on the use of the threshold test procedures defined in ISO 8253-1. When a test procedure with other characteristics is used, differences of up to several decibels on average may be expected.

3.2
otologically normal person
person in a normal state of health who is free from all signs or symptoms of ear disease and from obstructing wax in the ear canals, and who has no history of undue exposure to noise, exposure to potentially ototoxic substances, or familial hearing loss

3.3
reference threshold of hearing
at a specified frequency, sound pressure level of a pure tone or a one-third-octave band of noise corresponding to the median value of the binaural thresholds of hearing of *otologically normal persons* (3.2) within the age limits from 18 years to 25 years inclusive

3.4
free sound field
sound field where the boundaries of the room exert a negligible effect on the sound waves

3.5
diffuse sound field
sound field consisting of sound waves arriving at a given location more or less simultaneously from all directions with equal probability and level

4 Specification

The reference thresholds of hearing for the listening conditions specified in Clause 1 are given in Table 1. This table also gives the differences between sound pressure levels of one-third-octave bands of noise in a diffuse sound field and the sound pressure levels of pure tones in a frontally incident free progressive wave for equal thresholds of hearing. A graphical illustration of the reference thresholds of hearing is given in Figure 1.

Table 1 — Reference thresholds of hearing for the listening conditions specified in Clause 1 and differences between sound pressure levels in the two types of sound field

Frequency	Reference threshold of hearing under the condition of		Difference
	free-field listening (frontal incidence)	diffuse-field listening	
f	T_f (ref. 20 µPa)	T'_f (ref. 20 µPa)	$\Delta L = T_f - T'_f$
Hz	dB	dB	dB
20	78,1	78,1	0
25	68,7	68,7	0
31,5	59,5	59,5	0
40	51,1	51,1	0
50	44,0	44,0	0
63	37,5	37,5	0
80	31,5	31,5	0
100	26,5	26,5	0

[a] At 16 000 Hz, experimental data for ΔL was reported from one laboratory only.

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Table 1 *(continued)*

Frequency f Hz	Reference threshold of hearing under the condition of free-field listening (frontal incidence) T_f (ref. 20 µPa) dB	 diffuse-field listening T'_f (ref. 20 µPa) dB	Difference $\Delta L = T_f - T'_f$ dB
125	22,1	22,1	0
160	17,9	17,9	0
200	14,4	14,4	0
250	11,4	11,4	0
315	8,6	8,4	0,2
400	6,2	5,8	0,4
500	4,4	3,8	0,6
630	3,0	2,1	0,9
750	2,4	1,2	1,2
800	2,2	1,0	1,2
1 000	2,4	0,8	1,6
1 250	3,5	1,9	1,6
1 500	2,4	1,0	1,4
1 600	1,7	0,5	1,2
2 000	−1,3	−1,5	0,2
2 500	−4,2	−3,1	−1,1
3 000	−5,8	−4,0	−1,8
3 150	−6,0	−4,0	−2,0
4 000	−5,4	−3,8	−1,6
5 000	−1,5	−1,8	0,3
6 000	4,3	1,4	2,9
6 300	6,0	2,5	3,5
8 000	12,6	6,8	5,8
9 000	13,9	8,4	5,5
10 000	13,9	9,8	4,1
11 200	13,0	11,5	1,5
12 500	12,3	14,4	−2,1
14 000	18,4	23,2	−4,8
16 000	40,2	43,7	−3,5[a]
18 000	70,4	—	—

[a] At 16 000 Hz, experimental data for ΔL was reported from one laboratory only.

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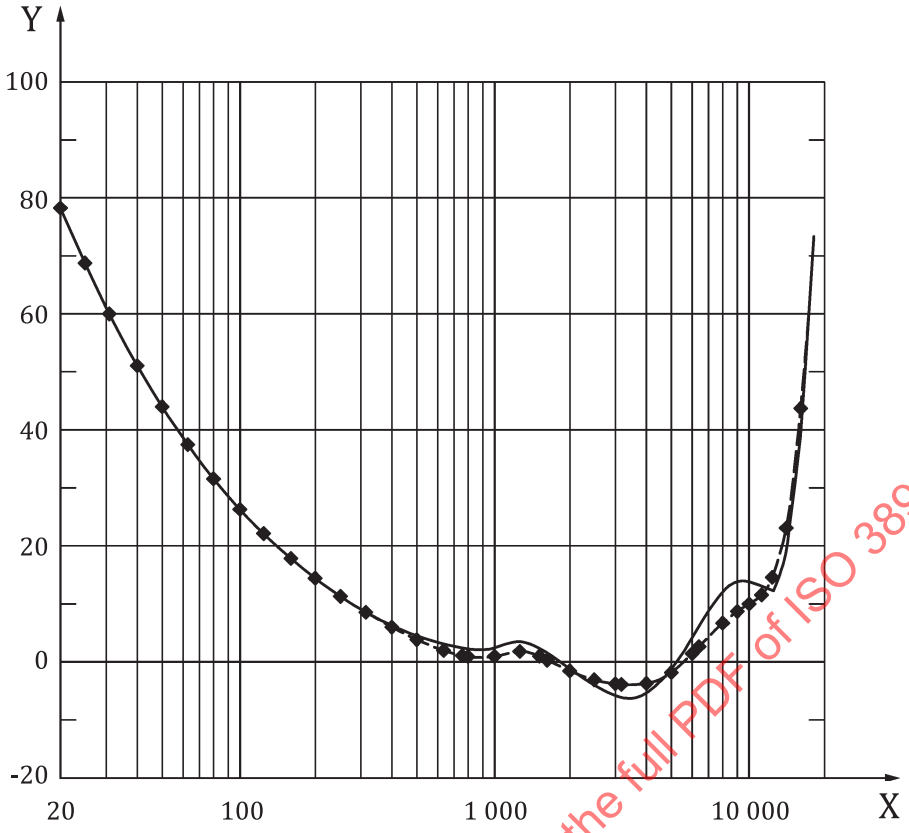

Key

X frequency, Hz

Y sound pressure level, dB

free field

diffuse field

Figure 1 — Reference thresholds of hearing for pure tones under binaural free-field listening conditions (frontal incidence) and for one-third-octave bands of noise under binaural diffuse-field listening conditions

NOTE Contrary to other parts of ISO 389, the reference thresholds of hearing in Table 1 are given with a resolution of 0,1 dB. The reason is that the reference threshold of hearing for free-field listening was taken together with this resolution from ISO 226 in order to avoid having two standards containing free-field thresholds with different resolutions.

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Annex A
(informative)

Notes on the derivation of the reference thresholds of hearing

A.1 Under free-field listening conditions

From 20 Hz to 12 500 Hz, the reference thresholds of hearing under free-field listening conditions specified in this document are taken from ISO 226. The values for the nine additional audiometric frequencies between 750 Hz and 18 000 Hz have been determined using the same fitting process as for the other threshold data given in ISO 226, using the 15 literature references given in that International Standard (see Figure A.1 below).

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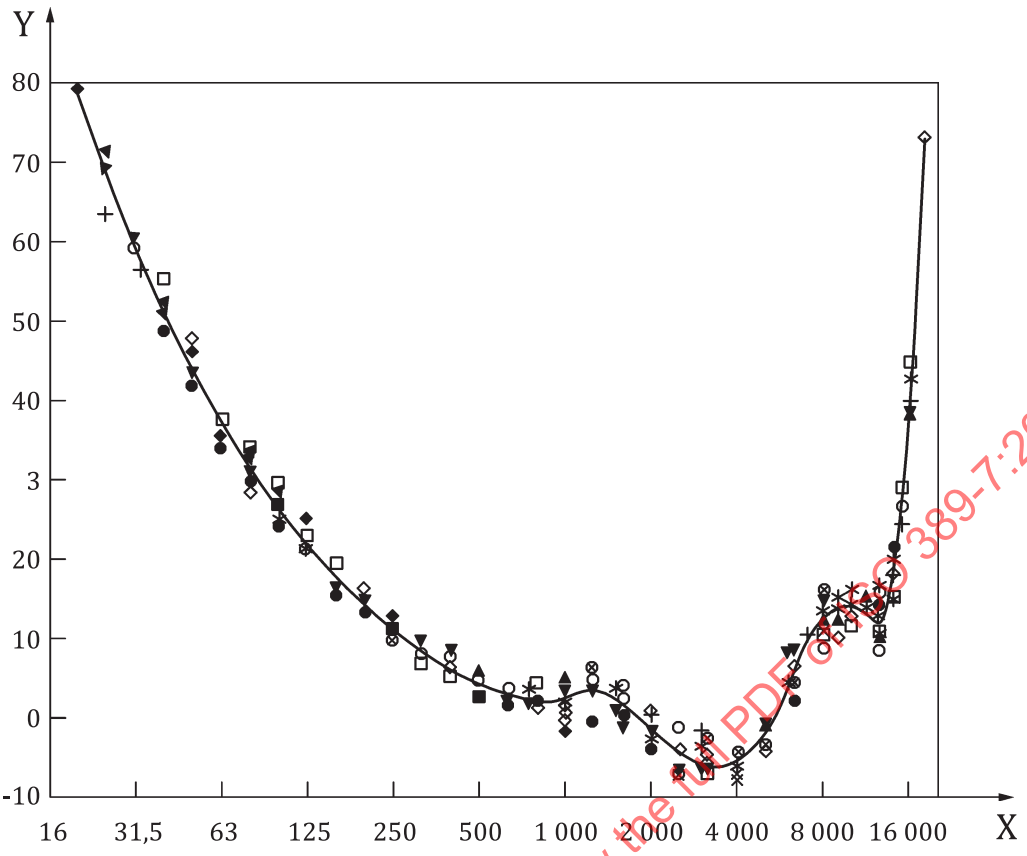

Key

X frequency, Hz
Y sound pressure level, dB
+ Robinson and Dadson (1956)
⅄ Teranishi (1965)
× Brinkmann (1973)
● Betke and Mellert (1989)
○ Suzuki et al. (1989)
■ Fastl et al. (1990)
◆ Watanabe and Møller (1990)
✳ Vorländer (1991)
▲ Poulsen and Thøgersen (1994
□ Takeshima et al. (1994)
▼ Lydolf and Møller (1997)
◀ Lydolf and Møller (1997) PF
✳ Poulsen and Han (2000)
◇ Takeshima et al. (2001)
⊗ Takeshima et al. (2002)

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Figure A.1 — Experimental data used for the derivation of the reference thresholds of hearing under free-field listening conditions and the calculated curve giving best fit to these data

The following fitting procedure was used.

With the exception of two studies (References [21] and [22]), where the mean values were presented and used in this fitting procedure, thresholds of hearing from 20 Hz to 18 000 Hz are represented by taking the mean of the median results of the individual studies for each frequency, then smoothing and interpolating by a cubic B-spline function. The resulting values are shown in Figure A.1. The number of subjects was not taken into account in the calculation of the B-spline function. For most of these investigations, i.e. those that give data for threshold and equal loudness, an overview of the used parameters is given in ISO 226. For the remaining five investigations, i.e. those that only give data for the threshold, an overview is given in Table A.1.

Furthermore, the values at 20 Hz and 18 000 Hz were replaced with the average of the median threshold values of two studies (References [25] and [26]) and those of three studies (References [27] to [29]),

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respectively, to increase the number of subjects involved and, thereby, improve the reliability of the threshold values. Weighting on the basis of the number of subjects was not carried out in the averaging. The resulting values are shown as T_f in Table 1.

NOTE As a result of this replacement, the reference thresholds at 20 Hz given in this document differ from those given in ISO 226:2003.

Table A.1 — Investigations of threshold of hearing under free-field listening conditions in addition to those given in ISO 226:2003, Table C.1

Investigation	Reference [20]	Reference [21]	Reference [22]	Reference [23]	Reference [24]
Year	1956	1965	1973	1991	2000
Country	United Kingdom	Japan	Germany	Germany	Denmark
Sound field	Free field	Free field	Free field	Free field	Free field
Measured range, Hz	25, 33, 50, 100, 200, 500, 1 000, 2 000, 3 000, 4 000, 5 000, 6 000, 7 000, 8 000, 10 000, 12 000, 15 000	63, 125, 250, 500, 1 000, 2 000, 3 000, 4 000, 5 000, 6 000, 8 000, 10 000	63, 125, 250, 500, 1 000, 2 000, 4 000, 8 000	1 000, 4 000, 8 000, 9 000, 10 000, 11 200, 12 500, 14 000, 16 000	125, 250, 500, 750, 1 000, 1 500, 2 000, 3 000, 4 000, 6 000, 8 000 9 000, 10 000, 11 200, 12 500, 14 000, 16 000
Number of subjects	51[a]	11	34 to 42[b]	31	31
(age)	(20)	(18 to 24)	(18 to 25)	(18 to 25)	(18 to 25)

[a] Below 200 Hz: 120 subjects.

[b] Depending on frequencies.

Table A.2 — Additional investigations of threshold of hearing used for determining the thresholds at 20 Hz and 18 000 Hz

Investigation	Reference [25]	Reference [26]	Reference [27]	Reference [28]	Reference [29]
Year	1997	2008	2001	2003	2005
Country	Denmark	Japan	Japan	Japan	Japan
Sound field	Pressure field[a]	Pressure field[a]	Free field	Free field	Free field
Measurement frequency adopted for the threshold determination, Hz	20	20	18 000	18 000	18 000
Number of subjects	23	51	32	51	38
(age)	(19 to 25)	(19 to 25)	(18 to 25)	(19 to 24)	(18 to 24)

[a] It is empirically known that, at low frequencies, the threshold measurement in a pressure field yields the same value as that in a free field.

A.2 Under diffuse-field listening conditions

The differences between reference threshold data under free-field and diffuse-field listening conditions were obtained from 9 independent experimental investigations, partly taken from the literature and partly communicated directly to ISO/TC 43 (see References [12] to [19]).

Brief particulars of the tests are as follows:

a) loudness comparison by 5 subjects, artificial diffuse field versus free field[12];

b) probe tube measurements in both types of sound field, 6 subjects, diffuse field in a reverberation room[13];

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c) objective and subjective measurements;

   1) objective measurements: free-field and diffuse-field responses in human ears, 20 subjects, probe microphones, diffuse field generated in a reverberation room[14];

   2) subjective measurements: loudness comparison by 26 subjects, artificial diffuse field versus free field[14];

d) determination of differences between the 20 phon and 40 phon equal loudness level curves in free and diffuse sound fields, 12 subjects[15];

e) measurements of free-field and diffuse-field responses of 7 pinna replicas and a geometric ear model[16];

f) probe tube measurements of diffuse-field to eardrum transformation, 16 subjects, diffuse sound field: these data were used together with free-field to eardrum transformation data from Reference [16] to calculate ΔL values[17];

g) measurements of impulse response of human ears by means of maximum length sequences in a free sound field, 37 directions of sound incidence, probe microphones, 12 subjects, diffuse-field characteristics calculated from directional characteristics[18];

h) measurements of impulse response of human ears by means of maximum length sequences in a free sound field, 97 directions of sound incidence, probe microphones, 40 subjects, diffuse-field characteristics calculated from directional characteristics[19].

A polynomial relationship of 11th order was determined giving best fit to the experimental data. From this relationship, values for ΔL were calculated at the preferred one-third-octave frequencies and at intermediate audiometric frequencies.

Figure A.2 shows the data from the investigations of References [12] to [19], and the fitted curve.

The reference threshold data for diffuse-field listening conditions (T'_f in Table 1) were then calculated by subtracting the values of ΔL from the free-field data.

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