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Acoustics — Standard reference zero for the calibration of pure-tone bone conduction audiometers

Acoustique — Zéro normal de référence pour l'étalonnage des audiomètres à sons purs en conduction osseuse

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 7566 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Acoustics — Standard reference zero for the calibration of pure-tone bone conduction audiometers

0 Introduction

A standard reference zero for the scale of hearing threshold level applicable to pure-tone air conduction audiometers is specified in ISO 389. For clinical diagnostic and other audiometric purposes, it is often necessary to compare the measured hearing threshold levels of a person for sound transmitted to the inner ear by the air conduction and bone conduction pathways, respectively. Bone-conducted sound is provided for this purpose by an electromechanical vibrator applied to the mastoid prominence or to the forehead of the person under test.

The standard reference zero for air conduction audiometry is defined in ISO 389 in terms of reference equivalent threshold sound pressure levels (RETSPLs), i.e. threshold sound pressure levels produced in a coupler or artificial ear of specified characteristics by supra-aural earphones of various patterns, when excited electrically at a level corresponding to the hearing threshold of young otologically normal persons. Similarly, this International Standard provides a reference zero for bone conduction audiometry in terms of reference equivalent threshold force levels (RETFLs), i.e. the vibratory force levels produced by a bone vibrator on a specified mechanical coupler when the vibrator is excited electrically at a level corresponding to the hearing threshold of young otologically normal persons. In some countries, the preferred location is the mastoid prominence; in other countries, the forehead location is used in addition to the mastoid prominence. Different RETFL values are valid for each of the two positions (see annex C).

For bone conduction measurements, it is necessary to specify the static force of application of the vibrator to the skull of the test subject and to the mechanical coupler, as well as certain geometrical features of the vibrator tip. In addition, it is usually necessary to apply masking noise to the ear not under test, since excitation of the skull by the vibrator may be heard by that ear instead of (or in addition to) the ear intended for the test. An appropriate specification of the masking noise is, therefore, required as an adjunct to the reference equivalent threshold force levels, and such a specification is given in this International Standard. Due to the so-called "occlusion effect" whereby the wearing of the transducer needed to provide the (air-conducted) masking noise causes a lowering of the bone conduction threshold of hearing of the ear receiving the masking signal, it is necessary for the level of masking noise to be raised to cancel out the occlusion effect and provide adequate masking of the ear not under test. The specification of masking noise given in this International Standard is based on the procedures used in the experimental investigations from which the reference zero of this International Standard is derived.

Use of this reference zero to calibrate audiometers will ensure that measured bone conduction hearing threshold levels of persons with unimpaired hearing or with hearing losses of purely sensorineural type (i.e. having unimpaired outer and middle ear function) will be compatible with the air conduction hearing threshold levels of the same persons when using the reference zero of ISO 389. Although exact equivalence of air conduction and bone conduction thresholds for any individual in these classes cannot be expected, due to biological variability of sound transmission through the external and middle ear and through the skull, this International Standard will ensure that systematic deviations averaged over groups of such persons are reduced to a practical minimum.

This International Standard is based on an assessment of technical data provided by laboratories in three countries using methods of threshold testing which, in the respects described, were essentially uniform. Examination of the data showed that the experimental results were consistent. It has, therefore, been possible to standardize a reference zero by means of RETFL values which are to be used for all bone vibrators used in audiometry having similar characteristics to those used by the laboratories. The systematic uncertainties introduced by this deliberate simplification will be small in comparison to the usual step size of hearing level controls in clinical audiometers (5 dB).

1 Scope and field of application

This International Standard specifies the following data applicable to the calibration of bone vibrators for pure-tone bone conduction audiometry :

a) Reference equivalent threshold force levels (RETFLs), corresponding to the hearing threshold of young otologically normal persons (see 3.9) by bone conduction audiometry. RETFL is the vibratory force level transmitted to a mechanical coupler of specified characteristics (see 5.3) by a vibrator when applied to the mechanical coupler under stated conditions of test and when energized at the voltage level corresponding to the normal hearing threshold for location on the mastoid prominence.

NOTE — Interim values for the differences in reference equivalent threshold force levels between location on the forehead and mastoid are included for information in annex C.

b) Essential characteristics of the bone vibrator and of its method of coupling to a person under test and to the mechanical coupler.

c) Essential characteristics and datum level of the masking noise applied to the ear not under test.

Guidance on the practical application of this International Standard in the calibration of audiometers is given in annex B.

NOTE — Recommended procedures for carrying out bone conduction audiometry are specified in ISO 8253.

2 References

ISO 389, *Acoustics — Standard reference zero for the calibration of pure tone air conduction audiometers.*

ISO 6189, *Acoustics — Pure tone air conduction threshold audiometry for hearing conservation purposes.*

ISO 7029, *Acoustics — Threshold of hearing by air conduction as a function of age and sex for otologically normal persons.*

ISO 8253, *Acoustics — Basic pure-tone audiometric test methods.* 1)

ISO 8798, *Acoustics — Reference levels for narrow-band masking noise.* 1)

IEC Publication 225, *Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations.*

IEC Publication 303, *IEC provisional reference coupler for the calibration of earphones used in audiometry.*

IEC Publication 318, *An IEC artificial ear, of the wideband type, for the calibration of earphones used in audiometry.*

IEC Publication 373, *Mechanical coupler for measurements on bone vibrators.* 2)

IEC Publication 645, *Audiometers.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 air conduction : The transmission of sound through the outer and middle ear to the inner ear.

3.2 acoustic coupler : A cavity of specified shape and volume which is used for the calibration of a supra-aural earphone in conjunction with a calibrated microphone to measure the sound pressure developed within the cavity.

NOTE — An acoustic coupler is specified in IEC Publication 303.

3.3 artificial ear : A device for the calibration of an earphone which presents to the earphone an acoustic impedance equivalent to the impedance presented by the average human ear. It is equipped with a calibrated microphone for the measurement of the sound pressure developed by the earphone.

NOTE — An artificial ear is specified in IEC Publication 318.

3.4 bone conduction : The transmission of sound to the inner ear primarily by means of mechanical vibration of the cranial bones.

3.5 bone vibrator : An electromechanical transducer intended to produce the sensation of hearing by vibrating the cranial bones.

3.6 vibratory force level (force level) (of a vibration) : The force level, in decibels, which is 20 times the common logarithm of the ratio of the r.m.s. value of the force transmitting the vibration to the reference value, 1 μN.

3.7 mechanical coupler : A device designed to present a specified mechanical impedance to a vibrator applied with a specified static force and equipped with an electromechanical transducer to measure the vibratory force level at the surface of contact between vibrator and mechanical coupler.

NOTE — A mechanical coupler is specified in IEC Publication 373.

3.8 hearing threshold : The sound pressure level or vibratory force level at which, under specified conditions, a person gives 50 % of correct detection responses on repeated trials.

3.9 otologically normal person : A 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 canal, and who has no history of undue exposure to noise.

3.10 equivalent threshold sound pressure level (monaural earphone listening) : For a given ear, at a specified frequency, for a specified type of earphone and for a stated force of application of the earphone to the human ear, the sound pressure level set up by the earphone in a specified acoustic coupler or artificial ear when the earphone is actuated by that voltage which, with the earphone applied to the ear concerned, would correspond to the hearing threshold.

3.11 reference equivalent threshold sound pressure level (RETSPL) : At a specified frequency, the modal value of the equivalent threshold sound pressure levels of a sufficiently large number of ears of otologically normal persons, of both sexes, aged between 18 and 30 years inclusive, expressing the hearing threshold in a specified acoustic coupler or artificial ear for a specified type of earphone.

NOTE — The relation between hearing threshold levels (for air conduction) and age is specified in ISO 7029.

1) At present at the stage of draft.

2) At present at the stage of draft. (Second edition of IEC Publication 373-1971.)

3.12 equivalent threshold force level (monaural listening) : For a given ear, at a specified frequency, for a specified configuration of bone vibrator and for a stated force of application of the bone vibrator to the human mastoid bone, the vibratory force level set up by the bone vibrator on a specified mechanical coupler when the bone vibrator is actuated by that voltage which, with the bone vibrator applied to the mastoid bone concerned, would correspond to the hearing threshold.

3.13 reference equivalent threshold force level (RETFL) : At a specified frequency, the mean value of the equivalent threshold force levels of a sufficiently large number of ears of otologically normal persons, of both sexes, aged between 18 and 30 years inclusive, expressing the hearing threshold in a specified mechanical coupler for a specified configuration of bone vibrator.

3.14 hearing level (of a pure tone) : At a specified frequency, for a specific type of transducer and for a specified manner of application, the vibratory force level (or the sound pressure level) of this pure tone, produced by the transducer in a specified mechanical coupler (or acoustic coupler or artificial ear) minus the appropriate reference equivalent threshold force level (or reference equivalent threshold sound pressure level) for bone conduction or air conduction, as applicable.

NOTE — By extension, this definition may be applied to a narrow band of noise.

3.15 hearing threshold level (of a given ear) : At a specified frequency and for a specified type of transducer, the hearing threshold, expressed as hearing level.

3.16 occlusion effect : The lowering of the hearing threshold level of a given ear, stimulated by bone conduction, when an earphone or earplug is placed over or in the entrance to the ear canal, thereby forming an enclosed air volume in the external ear. The effect is greatest at low frequencies.

3.17 masking :

(1) The process by which the hearing threshold of a sound is raised by the presence of another (masking) sound;

(2) The amount by which the hearing threshold level is so raised, expressed in decibels.

3.18 datum level of masking noise : The level, expressed as hearing level (see note to 3.14) of a one-third octave band of noise delivered by air conduction in the presence of which a pure tone at the centre frequency of the noise band and at a hearing level of 35 dB is just audible, on the basis of 50 % detection in repeated trials by an otologically normal person, having zero hearing threshold level by air conduction for that pure tone.

NOTES

1 The value of 35 dB has been adopted arbitrarily as lying within the range used in experimental studies on which this International Standard is based. It does not imply a recommendation to adopt this level of masking noise in clinical practice.

2 The relationship between the levels of a masking noise and a pure tone just masked by the presence of this noise is specified in ISO 8798.

3.19 critical bandwidth : The widest frequency band within which the loudness of a band of continuously distributed random noise of constant band sound pressure level is independent of its bandwidth.

3.20 vibrotactile threshold level : The level of a vibratory force at which a person gives 50 % of correct detection responses on repeated trials due to the sensation of vibration on the skin.

4 Reference equivalent threshold force levels (RETFLs)

Reference equivalent threshold force levels for location of the vibrator on the mastoid bone are given in table 1. They are derived from determinations of the hearing threshold by bone conduction of otologically normal persons as measured on the mastoid bone, in the conditions described in clause 5 (see annex A).

NOTES

1 It is emphasized that the data given in table 1 are derived from results obtained with different types of bone vibrators having different electromechanical properties, applied to the head in the specified manner. The procedures used to compensate for differences in the masking levels used in the three studies may also have contributed to differences among studies.

2 Values for frequencies below 250 Hz are not specified in this International Standard. Results from one laboratory are given for information in annex D.

Table 1 — Reference equivalent threshold force levels (RETFLs) for location of the vibrator on the mastoid bone

Frequency Hz	RETFL* (reference : 1 μN) dB
250	67,0
315**	64,0
400**	61,0
500	58,0
630**	52,5
750***	48,5
800**	47,0
1 000	42,5
1 250**	39,0
1 500***	36,5
1 600**	35,5
2 000	31,0
2 500**	29,5
3 000	30,0
3 150**	31,0
4 000	35,5
5 000***	40,0
6 000***	40,0
6 300***	40,0
8 000***	40,0

* Values rounded to the nearest 0,5 dB.

** Values for these frequencies are derived by interpolation.

*** Values for these frequencies are derived from the results in one laboratory only.

5 Test conditions and requirements

The reference equivalent threshold force levels apply when the conditions and requirements specified in this clause are met.

5.1 Bone vibrator

The vibrator shall have a plane, circular tip, of nominal area 175 mm^2. Any airborne sound which it radiates when in contact with the head of a test subject having unimpaired external and middle ear function shall be low enough in level to provide a margin of 10 dB or more between the true bone conduction hearing threshold level and a false air conduction hearing threshold level evoked by the bone vibrator.

NOTE — If this condition is not met directly at all frequencies, the unwanted sound radiation is excluded by inserting an ear plug into the external canal of the ear under test at the frequencies which are affected. Due to the occlusion effect, use of the ear plug is confined to frequencies above 2 000 Hz.

5.2 Fitting of the bone vibrator

A headband shall be used to hold the vibrator on the mastoid bone with a nominal static force of 5,4 N. The vibrator shall be placed on the mastoid prominence, not touching the pinna, and adjusted so as to remain in a stable position.

5.3 Mechanical coupler

The mechanical coupler shall comply with the specification in IEC Publication 373 (see annex B, in particular clause B.3).

NOTE — The mechanical coupler specified in the first edition (1971) of IEC Publication 373 differs in material respects and is not applicable to this International Standard.

5.4 Test signal

The vibratory force signal produced by the bone vibrator at the excitation level corresponding to table 1, as measured on the mechanical coupler, shall exhibit total harmonic distortion not exceeding 1 % for fundamental frequencies from 500 Hz to 1 000 Hz, and 2 % for frequencies from 250 Hz to 400 Hz inclusive and from 1250 Hz upwards.

5.5 Masking noise

The masking noise signal shall be generated by passing random white noise, defined as a noise the power spectral density of which is essentially independent of frequency, through a band-pass filter one-third octave wide, centred logarithmically on the test-tone frequencies given in table 1.

5.6 Masking transducer

The masking noise signal shall be delivered to the ear not under test by means of a supra-aural earphone of a pattern conforming to one of the specifications in ISO 389.

5.7 Fitting of masking transducer

The earphone delivering the masking noise shall be applied to the ear not under test of the test subject by means of a headband exerting a nominal force of 4,5 N, and designed not to interfere with the headband holding the bone vibrator which is worn simultaneously.

5.8 Datum level of masking noise

The masking noise, applicable to the mean otologically normal young person (see 3.9), shall be presented at the datum level specified in 3.18.

NOTES

1 A constant hearing level of 40 dB in each one-third octave band is approximately equal to the datum level as defined, although, in principle, the value depends slightly on the band centre frequency (due to the variable width of critical bandwidths). The difference between the hearing level of the noise band and that of the pure tone referred to in 3.18 is approximately 5 dB; it represents the amount by which masking noise in a critical bandwidth may exceed a pure tone at the 50 % correct detection level of the pure tone (see ISO 8798).

2 The datum level may be expressed as sound pressure level in decibels relative to 20 µPa by adding 40 dB to the RETSPL values specified in ISO 389 for the pattern of earphone used as the masking transducer.

Annex A

Note on the derivation of RETFL values

(This annex does not form an integral part of this standard.)

A.1 Source of data

The RETFL values specified in this International Standard are obtained from the results of three independent experimental investigations communicated to ISO/TC 43, *Acoustics*. Brief particulars of the tests are given in table 2.

Table 2 — Investigations on RETFL values

Test data	Investigation [A]	[B]	[C]
Type of vibrator	B-71[1]	B-71[1]	KH-70[2]
Type of masking earphone	TDH39[3]	TDH39[3]	DT48[4]
Level of masking noise	30 dB effective[5]	25 dB and 40 dB sensation level	40 dB effective[5] at 125 Hz, 250 Hz; 30 dB effective[5] at higher frequencies
Number of ears tested	60	136	50
Number of subjects	60	68	25
Frequencies tested, Hz	250, 500, 1 000, 2 000, 3 000, 4 000	250, 500, 1 000, 2 000, 3 000, 4 000	125, 250, 500, 750, 1 000, 1 500, 2 000, 3 000, 4 000, 5 000, 6 000, 6 300, 8 000

1) Manufactured by Radioear Corporation, USA.

2) Manufactured by VEB Präcitronic, DDR.

3) Manufactured by Telephonics Corporation, USA.

4) Manufactured by Beyer AG, FRG.

5) "Effective masking level" as defined in American National Standards Institute publication S3.13-1972 (R 1977), appendix A4.

The bone conduction hearing threshold values used in the development of this International Standard were not corrected for deviations of the test subject's air conduction hearing threshold levels from 0 dB. Further details of the derivation of RETFL values are given in [B].

A.2 Bibliography

[A] DIRKS, D.D., LYBARGER, S.F., OLSEN, W.O. and BILLINGS, B.L., Bone conduction calibration — present status, *Journ. Speech Hearing Disorders*, **44** (2), 1979 : pp. 143-155.

[B] ROBINSON, D.W. and SHIPTON, M.S., A standard determination of paired air and bone conduction thresholds under different masking noise conditions, *Audiology*, **21**, 1981 : pp. 61-82.

[C] RICHTER, U. and BRINKMANN, K., Threshold of hearing by bone-conduction — a contribution to international standardization, *Scand. Audiol.*, **10**, 1981 : pp. 235-237.

Annex B

Guidance on the application of the standard reference zero to the calibration of bone conduction audiometers

(This annex does not form an integral part of this standard.)

B.1 General

When a bone conduction audiometer is calibrated in accordance with this International Standard and used under the conditions stipulated in clauses 4 and 5, where applicable, to measure the hearing of young otologically normal subjects, a mean hearing threshold level of 0 dB should be obtained if the ambient noise levels in the test room and the procedures used for the threshold determination comply with ISO 8253.

B.2 Choice and fitting of bone vibrator

The plane, circular contact area should be 175 ± 25 mm^2 as specified in IEC Publication 645. The addition of a slightly rounded edge (for example, of radius 0,5 mm) to the vibrator tip prevents discomfort. In general, the inertia-reaction types of vibrator derived from hearing aid designs have only limited output for acceptable distortion at low frequencies, and are not usually suitable for audiometry below 250 Hz; the larger button-type vibrators tend to be superior in this respect, but may produce more unwanted sound radiation at high frequencies due to their larger size.

The headband used should provide a static force of 5,4 ± 0,5 N.

NOTE — A headband providing a force of 5,4 N for a mean head width of 145 mm (for mastoid application) or 190 mm (for forehead application) will usually comply within the above tolerance for adult test populations.

B.3 Calibration of the bone vibrator

The vibrator should be attached to the mechanical coupler with a static force of 5,4 ± 0,5 N, as specified in IEC Publication 645. The bone vibrator and mechanical coupler should both be brought to the proper operating temperature of 23 ± 1 °C as specified in IEC Publication 373. Because of the high thermal capacity of the mechanical coupler, a period of several hours may be required to bring the system to thermal equilibrium before calibration. Any deviation from this temperature can only be allowed for if data for the temperature dependence of the performance of the specific type of bone vibrator on the mechanical coupler are available.

B.4 Choice and fitting of masking transducer

It is convenient to use the same earphone for delivering the masking noise as is used to determine the subject's air conduction threshold in the ear not under test. The headband force should be 4,5 ± 0,5 N. These procedures enable the hearing level of the masking noise to be set correctly using the pure-tone air conduction calibration of the earphone in accordance with ISO 389.

B.5 Masking noise source

The datum conditions of this International Standard specify noise with a one-third octave bandwidth derived from random noise having uniform spectral density (white noise). Tolerance on the bandwidth (defined by the 3 dB-down points of the spectral density) of + 1/6, − 0 octave is recommended. For generating one-third octave band masking noise from wide-band white noise, the filter characteristics should conform to the specifications of IEC Publication 225.

Annex C

Interim differences in reference equivalent threshold force levels between forehead and mastoid location of vibrator

(This annex does not form an integral part of this standard.)

Interim differences in reference equivalent threshold force levels between forehead and mastoid locations of the vibrator are given in table 3. They are derived from determinations of the hearing threshold by bone conduction on otologically normal persons in the conditions described in clause 5.

NOTE — The values given in table 3 are obtained from the results of four experimental investigations communicated to ISO/TC 43. Brief particulars of these tests are given in table 4.

Table 3 — Interim differences in reference equivalent threshold force levels between forehead and mastoid location of vibrator

Frequency Hz	RETFL (forehead) minus RETFL (mastoid)* dB
250	12,0
315**	12,5
400**	13,5
500	14,0
630**	13,5
750***	13,0
800**	12,0
1 000	8,5
1 250**	10,0
1 500***	11,0
1 600**	11,0
2 000	11,5
2 500**	12,0
3 000	12,0
3 150**	11,5
4 000	8,0
5 000***	11,0
6 000***	11,0
6 300***	10,0
8 000***	10,0

* Values rounded to the nearest 0,5 dB.

** Values for these frequencies are interpolated.

*** Values for these frequencies are derived from the results in one laboratory only.