INTERNATIONAL STANDARD

ISO 8253-1

Second edition
2010-11-01

Acoustics — Audiometric test methods —

Part 1: Pure-tone air and bone conduction audiometry

Acoustique — Méthodes d'essais audiométriques —

Partie 1: Audiométrie à sons purs en conduction aérienne et en conduction osseuse

Reference number
ISO 8253-1:2010(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8253-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

This second edition cancels and replaces the first edition (ISO 8253-1:1989) and ISO 6189:1983, which have been technically revised.

ISO 8253 consists of the following parts, under the general title *Acoustics — Audiometric test methods*:

— *Part 1: Pure-tone air and bone conduction audiometry*

— *Part 2: Sound field audiometry with pure-tone and narrow-band test signals*

— *Part 3: Speech audiometry*

Introduction

This International Standard specifies requirements and procedures for carrying out basic audiometric tests in which pure tones are presented to the test subject using earphones or bone vibrators. Electrophysiological test methods are not included.

In order to obtain a reliable measure of hearing ability, many factors are involved. IEC 60645-1 specifies requirements for audiometers. It is essential that audiometric equipment, when in service, be checked and the calibration maintained. This part of ISO 8253 outlines a calibration scheme. To avoid masking of the test signal by ambient noise in the audiometric test room, the levels of the ambient noise shall not exceed certain values, depending upon the method of signal presentation to the test subject, i.e. by different earphones or by bone vibrator. This part of ISO 8253 gives maximum permissible ambient sound pressure levels which shall not be exceeded when hearing threshold levels down to 0 dB have to be measured. It indicates the maximum ambient sound pressure levels which are permissible when other minimum hearing threshold levels require measurement. It sets out procedures for determining hearing threshold levels by pure-tone air conduction and bone conduction audiometry. For screening purposes, only methods for air conduction audiometry are outlined.

Audiometry can be performed by using:

a) a manual audiometer;

b) an automatic recording audiometer;

c) computer-controlled audiometric equipment.

Methods for threshold audiometry are given for these three types of signal presentation. For screening purposes, only methods using a manual or a computer-controlled audiometer are set out. The procedures are applicable to the majority of adults and children. Other procedures may yield results equivalent to those derived by the procedures specified in this part of ISO 8253. For very young, aged or sick people, some modification of the recommended procedures is likely to be required. This may result in a less accurate measurement of hearing.

Acoustics — Audiometric test methods —

Part 1: Pure-tone air and bone conduction audiometry

1 Scope

This part of ISO 8253 specifies procedures and requirements for pure-tone air conduction and bone conduction threshold audiometry. For screening purposes, only pure-tone air conduction audiometric test methods are specified. It is possible that the procedures are not appropriate for special populations, e.g. very young children.

This part of ISO 8253 does not cover audiometric procedures to be carried out at levels above the hearing threshold levels of the subjects.

Procedures and requirements for speech audiometry, electrophysiological audiometry, and where loudspeakers are used as a sound source are not specified.

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 389-1, *Acoustics — Reference zero for the calibration of audiometric equipment — Part 1: Reference equivalent threshold sound pressure levels for pure tones and supra-aural earphones*

ISO 389-2, *Acoustics — Reference zero for the calibration of audiometric equipment — Part 2: Reference equivalent threshold sound pressure levels for pure tones and insert earphones*

ISO 389-3:1994, *Acoustics — Reference zero for the calibration of audiometric equipment — Part 3: Reference equivalent threshold force levels for pure tones and bone vibrators*

ISO 389-5, *Acoustics — Reference zero for the calibration of audiometric equipment — Part 5: Reference equivalent threshold sound pressure levels for pure tones in the frequency range 8 kHz to 16 kHz*

ISO 389-8, *Acoustics — Reference zero for the calibration of audiometric equipment — Part 8: Reference equivalent threshold sound pressure levels for pure tones and circumaural earphones*

IEC 60645-1:2001, *Electroacoustics — Audiological equipment — Part 1: Pure-tone audiometers*

IEC 61260, *Electroacoustics — Octave-band and fractional-octave-band filters*

IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement* (*GUM:1995*)

3 Terms and definitions

For the purposes of this part of ISO 8253, the following definitions apply.

3.1
air conduction
transmission of sound through the external and middle ear to the inner ear

3.2
ear simulator
device for measuring the acoustic output of sound sources where the sound pressure is measured by a calibrated microphone coupled to the source so that the overall acoustic impedance of the device approximates that of the normal human ear at a given location and in a given frequency band

NOTE An ear simulator is specified in IEC 60318-1[4] and IEC 60318-4[6].

3.3
acoustic coupler
device for measuring the acoustic output of sound sources where the sound pressure is measured by a calibrated microphone coupled to the source by a cavity of predetermined shape and volume which does not necessarily approximate the acoustic impedance of the normal human ear

NOTE An acoustic coupler is specified in IEC 60318-3[5] and IEC 60318-5[7].

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

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

3.6
mechanical coupler
device designed to present a specified mechanical impedance to a vibrator applied with a specified static force and equipped with a mechano-electrical 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 60318-6[8].

3.7
otologically normal person
person in a normal state of health who is free from all signs and symptoms of ear disease and from obstructing wax in the ear canal and who has no history of undue exposure to noise, exposure to potentially ototoxic drugs, or familial hearing loss

3.8
hearing threshold
lowest sound pressure level or vibratory force level at which, under specified conditions, a person gives a predetermined percentage of correct detection responses on repeated trials

3.9
equivalent threshold sound pressure level
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 ear simulator when the earphone is actuated by that voltage which, with the earphone applied to the ear concerned, would correspond to the hearing threshold

3.10
reference equivalent threshold sound pressure level
RETSPL
at a specified frequency, the median value of the equivalent threshold sound pressure levels of a sufficiently large number of ears of otologically normal persons of both sexes aged from 18 years to 25 years inclusive, expressing the hearing threshold in a specified acoustic coupler or ear simulator for a specified type of earphone

NOTE ISO 389-1 refers to an age range of 18 years to 30 years inclusive, and specifies modal values.

3.11
equivalent threshold vibratory force level
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 or forehead, 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 or forehead concerned, would correspond to the hearing threshold

3.12
reference equivalent threshold vibratory force level
RETVFL
at a specified frequency, the median value of the equivalent threshold vibratory force levels of a sufficiently large number of ears of otologically normal persons of both sexes aged from 18 years to 25 years inclusive, expressing the hearing threshold in a specified mechanical coupler for a specified type of bone vibrator

NOTE ISO 389-3 refers to an age range of 18 years to 30 years inclusive, and specifies an arithmetic mean.

3.13
hearing level of a pure tone
HL of a pure tone
at a specified frequency, for a specific type of transducer and for a specified manner of application, sound pressure level or vibratory force level of a pure tone, produced by a transducer in a specific ear simulator or mechanical coupler, minus the appropriate reference equivalent threshold sound pressure level or reference equivalent threshold vibratory force level

3.14
hearing threshold level of a given ear
at a specified frequency and for a specific type of transducer, hearing threshold at that frequency, expressed as hearing level

3.15
occlusion effect
change (usually an increase) in level of a bone-conducted signal reaching the inner ear when an earphone or an earplug is placed over or at the entrance of the ear canal, thereby forming an enclosed air volume in the external ear

NOTE The effect is greatest at low frequencies.

3.16
masking
process by which the hearing threshold of a given ear for a particular sound is raised by the presence of another (masking) sound

3.17
effective masking level of a noise band
level equal to that hearing level of a pure tone, the frequency of which coincides with the geometric centre frequency of the noise band, to which the threshold of hearing of the pure tone is raised by the presence of the masking noise band

NOTE IEC 60645-1:2001, 8.5.2 a), specifies that masking levels for narrow-band noise be calibrated in terms of effective masking level.

3.18
vibrotactile threshold level
level of the vibratory force or sound pressure at which a person gives 50 % of correct detection responses on repeated trials due to the sensation of vibration on the skin

3.19
pure-tone audiometer
electroacoustic instrument, equipped with earphone(s), that provides pure tones of specified frequencies at known sound pressure levels

NOTE In addition, it may be equipped with bone vibrator(s) and/or masking facilities.

3.20
manual audiometer
audiometer in which the signal presentations, frequency and hearing level selection and recording of the results are performed manually

3.21
automatic-recording audiometer
audiometer in which signal presentations, hearing level variation, frequency selection or frequency variation, and recording of the responses of the test subject are implemented automatically

NOTE Hearing level change is under the control of the test subject and is recorded automatically.

3.22
automatic fixed-frequency audiometry
audiometry in which hearing level variations are under the control of the test subject and are recorded automatically for specific frequencies

3.23
automatic sweep-frequency audiometry
audiometry in which hearing level variations are under the control of the test subject and where the frequency is varied continuously or in steps much smaller than one-third octave

3.24
screening audiometry
pass-fail procedure where pure tones of a fixed level, the screening level, are presented

3.25
audiogram
presentation, in graphical or tabular form, of the hearing threshold levels of the ears of the test subject, determined under specified conditions and by a specified method, as a function of frequency

4 General aspects of audiometric measurements

4.1 General

Hearing threshold levels can be determined by air conduction and bone conduction audiometry. In air conduction audiometry, the test signal is presented to the test subject by earphones. In bone conduction audiometry, the test signal is presented by a bone vibrator placed on the mastoid or forehead of the test subject. It is recommended that threshold level determinations be started with air conduction measurements followed by bone conduction measurements. Hearing threshold levels can be determined using test tones with fixed frequencies (fixed-frequency audiometry) or a test signal with frequency varying with time according to a predetermined rate of change (sweep-frequency audiometry). Methods for fixed-frequency audiometry are given in Clause 6 and sweep-frequency audiometry is described in Clause 7. In air and bone conduction measurements, the hearing threshold levels of both ears shall be determined separately. Under specified conditions, masking noise shall be applied to the ear not under test (contralateral ear). The masking noise is presented to that ear through a supra-aural, circumaural or insert-type earphone.

4.2 Standard reference zero for the calibration of audiometric equipment

The standard reference zero for air conduction audiometers is given in ISO 389-1, ISO 389-2, ISO 389-5, and ISO 389-8 and for bone conduction audiometers in ISO 389-3 in terms of reference equivalent threshold sound pressure levels or vibratory force levels (RETSPL or RETVFL, respectively) at specified frequencies. Different RETVFL values are valid for different locations of the vibrator, i.e. at the mastoid or forehead. ISO 389-3:1994 presents values for mastoid location and its Annex C gives corresponding difference values for forehead location of the vibrator.

4.3 Requirements on audiometric equipment

Audiometers shall be constructed in accordance with IEC 60645-1 and calibrated in accordance with the requirements of the relevant part of ISO 389. In occupational audiometry and for testing of schoolchildren, a type 4 audiometer (IEC 60645-1:2001) may be used and the frequency range sometimes limited to 500 Hz and upwards.

4.4 Qualified tester

A qualified tester is understood to be someone who has followed an appropriate course of instruction in the theory and practice of audiometric testing. This qualification may be specified by national authorities or other suitable organizations. Throughout this part of ISO 8253, it is assumed that tests are carried out only by, or under the supervision of, a qualified tester.

The tester should make decisions on the following aspects of the audiometric test which are not specified in detail in this part of ISO 8253, namely whether:

a) the left or the right ear is tested first (usually the ear considered to be more sensitive is chosen);

b) masking is required;

c) responses of the test subject correspond to the test signals;

d) there is any external noise event or any behaviour response of the test subject that might invalidate the test;

e) to interrupt, terminate or repeat all or part of the test.

4.5 Test time

Care shall be taken not to fatigue the test subject unduly since reliable results may be progressively difficult to obtain if the test subject is not given a rest from testing after about 20 min.

4.6 Conditions for audiometric test environments

Ambient sound pressure levels in an audiometric test room shall not exceed the values specified in Clause 11.

The test subject and the tester shall be comfortably seated during audiometric testing and shall be neither disturbed nor distracted by unrelated events nor by people in the vicinity.

Air temperature in the audiometric test room should be in the range permitted for offices by local authorities. The audiometric test room should allow for sufficient exchange of air.

If the audiometer is operated manually, the test subject shall be clearly visible to the tester who shall, however, not be able to see the audiometer settings change nor the test tone being switched on or interrupted. When using an automatic recording audiometer, the recording mechanism shall not be visible to the test subject.

When the test is carried out from outside the audiometric test room, the test subject shall be visually monitored through a window or by a closed-circuit TV system. Acoustic monitoring of the subject should be undertaken.

4.7 Measurement uncertainty

The uncertainty of hearing threshold levels determined in accordance with any of the procedures specified in this part of ISO 8253 depends on a variety of parameters, such as:

a) the performance of the audiometric equipment used;

b) the type of transducers used and their fitting by the tester;

c) the frequency of test tones;

d) the conditions of the test environment, especially the ambient noise;

e) the qualification and experience of the tester;

f) the cooperation of the test subject and the reliability of responses;

g) the use of non-optimized masking noise.

Due to the complexity of the measurement process, including the personal behaviour of both the test subject and the tester, it is difficult to express the measurement uncertainty in a single generally valid figure. However, a detailed evaluation of measurement uncertainty provides useful information on the reliability of audiometric test results and provides a sufficient estimate of the uncertainty in most applications.

The uncertainty of results of measurements according to this part of ISO 8253 shall be evaluated in accordance with ISO/IEC Guide 98-3. If reported, the expanded uncertainty together with the corresponding coverage factor for a stated coverage probability, as defined in ISO/IEC Guide 98-3, shall be given. Guidance on the determination of the expanded uncertainty is given in Annex A.

5 Preparation and instruction of test subjects before audiometric testing and positioning of transducers

5.1 Preparation of test subjects

Recent exposure to noise may cause a temporary elevation of the hearing threshold levels. Therefore, significant noise exposure should be avoided before audiometric testing or it shall be noted. In order to avoid errors due to excessive physical exertion, test subjects should be present at least 5 min prior to testing.

Normally, the audiometric test is preceded by an otoscopic examination carried out by a qualified person. If obstructing wax is found in the canal(s) of the outer ear it shall be removed and audiometry may be delayed for a suitable period. The ear should also be checked for the possibility of collapsing ear canals and appropriate action taken, if necessary.

NOTE 1 Preliminary information about the type of hearing loss and masking requirements can be obtained by performing tuning fork tests.

NOTE 2 The qualifications of a person can be specified by national authorities or other suitable organizations. The qualified person need not be the same person as the qualified tester mentioned in 4.4.

5.2 Instruction of test subjects

In order to achieve reliable test results, it is essential that relevant instruction in the test procedure be given unambiguously and that it is fully understood by the test subject.

The instructions shall be phrased in language appropriate to the listener and shall normally indicate:

a) the response task;

b) the need to respond whenever the tone is heard in either ear, no matter how faint it may be;

c) the need to respond as soon as the tone is heard and to stop responding immediately once the tone is no longer heard;

d) the general pitch sequence of the tones;

e) the ear to be tested first.

The response from the test subject indicating when the tone is heard and when it is no longer heard shall be clearly observable. Examples of commonly used responses are:

— pressing and releasing a signal switch;

— raising and lowering the finger or hand.

Test subjects shall also be instructed to avoid unnecessary movements so as to obviate extraneous noise. After the instructions have been given, the test subject shall be asked if he or she has understood. The test subject shall be informed that he or she may interrupt the test in the case of discomfort. If there is any doubt, the instructions should be repeated.

5.3 Placement of transducers

In advance of testing, the following actions should be undertaken: spectacles and head ornaments, when necessary, and hearing aids shall be removed. Hair shall be moved from between the head and the sound transducers, i.e. earphones and bone vibrators, if possible. The transducers shall be fitted by the tester to ensure that they are properly positioned and subjects shall be instructed not to touch the transducers thereafter. The sound opening of an earphone shall face the ear canal entrance. The bone vibrator shall be positioned so that the largest possible area of the tip is in contact with the skull. If placed on the mastoid, the vibrator shall be positioned behind and as near as possible to the pinna, without touching it.

6 Air conduction hearing threshold level determinations using fixed-frequency audiometry

6.1 General

The audiometric test may be carried out using a manual audiometer or an automatic-recording audiometer. The procedures are specified in 6.2, 6.3, and 6.4.

The order of presentation of test tones when the audiometer settings are performed manually shall be from 1 000 Hz upwards, followed by the lower frequency range, in descending order. A repeat test shall be carried out at 1 000 Hz on the ear tested first.

Vibrotactile sensations may occur at low frequencies and high hearing levels; care, therefore, shall be taken that such sensations are not misinterpreted as hearing sensations.

Preferably, automatic-recording audiometers should present test tones in the same sequence as in manual audiometry.

6.2 Manually controlled threshold determination

6.2.1 Presentation and interruption of test tones

The test tone shall be continuous and presented for a duration of 1 s to 2 s. When a response occurs, the interval between tone presentations shall be varied but shall not be shorter than the test tone duration. Unless otherwise stated, reference to tone presentation throughout this part of ISO 8253 refers to this method.

Automatically pulsed tones are sometimes used as an alternative stimulus. However, correlative data are not currently available. The use of such stimuli should be noted on the audiogram.

6.2.2 Initial familiarization

The test subject shall be familiarized with the task prior to threshold determination by presenting a signal of sufficient intensity to evoke a definite response. By using the familiarization step, the tester can be sure that the test subject understands and can perform the response task.

EXAMPLE The following method of familiarization can be used:

a) present a tone of 1 000 Hz at a hearing level which is clearly audible, e.g. 40 dB for a normal hearing test subject;

b) reduce the level of the tone in steps of 20 dB until no response occurs;

c) increase the level of the tone in steps of 10 dB until a response occurs;

d) present the tone again at the same level.

If the responses are consistent with the tone presentation, the familiarization is complete. If not, it should be repeated. After a second failure, the instructions should be repeated.

In cases of profound deafness, these procedures may not be applicable.

6.2.3 Hearing threshold measurements with and without masking

6.2.3.1 General

In 6.2.3.2, test procedures are outlined for those tests in which masking noise is not applied to the non-test ear. In 6.2.3.3, procedures are outlined for tests with masking. The method for calculating hearing threshold level is given in 6.2.4.

6.2.3.2 Procedures for testing without masking

Two audiometric test procedures with a manual audiometer are specified: a bracketing method and an ascending method. These methods differ only in the sequence of the levels of the test tones presented to the test subject.

In the ascending method, consecutive test tones having ascending levels are presented until a response occurs.

In the bracketing method, consecutive test tones having ascending levels are presented until a response occurs, after which test tones having levels in a descending sequence are presented.

When properly carried out, both methods result in substantially the same hearing threshold levels.

Measurements using the ascending method differ from those of the bracketing method only in step 2 of the measurements presented below.

If the hearing threshold level measurements result in a hearing level of 40 dB or more in either ear at any frequency, these results should be interpreted with caution due to the phenomenon of cross-hearing. Contralateral masking can then be necessary.

Step 1

Present the first test tone at a level which is 10 dB below the lowest level of the response of the test subject during the familiarization session. After each failure to respond to a test tone, increase the level of the test tone in steps of 5 dB until a response occurs.

Step 2

Ascending method

After the response, decrease the level in steps of 10 dB until no response occurs. Then begin another ascent with 5 dB steps. Continue until three responses occur at the same level out of a maximum of five ascents. This level is then defined as the hearing threshold level (see 6.2.4.2).

If less than three responses out of five ascents have been obtained at the same level, present a test tone at a level 10 dB higher than the level of the last response. Then repeat the general test procedure: 10 dB down after a response, 5 dB up until a response occurs.

A shortened version of the ascending method has been shown to yield nearly equivalent results and may be appropriate in some cases. In this shortened version, continue the testing until at least two responses occur at the same level out of three ascents.

Bracketing method

After the response, increase the level of the test tone by 5 dB and begin a descent in which the level of the tone is decreased in steps of 5 dB until no response occurs. Then decrease the level of the test tone another 5 dB and begin the next ascent at this level. This should be continued until three ascents and three descents have been completed.

Shortened versions of the bracketing method may be appropriate in some cases. Shortening consists of omitting the further descent of 5 dB after no response occurs or requiring only two ascents and two descents in series provided that the four minimal response levels differ by no more than 5 dB.

Step 3

Proceed to the next test frequency at an estimated audible level, as indicated by the previous responses, and repeat step 2. Finish all test frequencies on one ear.

NOTE For any frequency, the familiarization, or an abbreviated form of it, can be repeated.

Finally, repeat the measurement at 1 000 Hz. If the results at 1 000 Hz of the repeat measurement for that ear agree to 5 dB or less with those of the first measurements for the same ear, proceed to the other ear. If 10 dB or more improvement or worsening in hearing threshold level is discernible, retest at further frequencies in the same order until agreement to 5 dB or less has been obtained.

Step 4

Proceed until both ears have been tested.

6.2.3.3 Procedures for testing with masking

To avoid the test tone being heard in the non-test ear, it may be necessary to apply masking noise to that ear. For the procedure described below, the masking noise signal is delivered by means of an earphone.

Although experience, to a large extent, dictates the procedures used and the choice of the masking noise level, the following procedure is recommended to determine the hearing threshold level with masking.

Step 1

Present a test tone to the ear being tested at a level equal to the hearing threshold level without masking. Present masking noise to the non-test ear with an effective masking level equal to the hearing threshold level of the non-test ear. Increase the noise level until the test tone is inaudible or until the noise level exceeds the test tone level.

Step 2

If the tone is still audible when the noise level equals the test tone level, assume this to be the hearing threshold level. If the tone is masked, increase its level until it becomes audible again.

Step 3

Increase the noise level by 5 dB. If the test tone is inaudible, increase the test tone level until the tone becomes audible again. Repeat this procedure until the test tone remains audible although the level of the masking noise has been increased by more than 10 dB. This masking level, i.e. the level above which no further increase in the tone level is required for its audibility, is the correct masking level and this procedure should have produced the correct hearing threshold level for that test frequency. Note the correct masking level.

NOTE 1 This is the plateau-seeking method. In some cases where the plateau is short, the above procedure can give false results.

NOTE 2 The masking noise can also mask the test tone in the ear being tested. This phenomenon, called overmasking, can be reduced by presenting the masking noise using an appropriate insert earphone.

6.2.4 Calculation of hearing threshold level

6.2.4.1 General

The hearing threshold levels for each frequency and ear shall be determined in accordance with the following procedures, dependent upon the measurement method used.

6.2.4.2 Determination when the ascending method has been used

For each frequency and ear, determine the lowest level at which responses occur in more than half of the ascents. This level is defined as the hearing threshold level.

If the lowest response levels span more than 10 dB at a given frequency, the test should be considered of doubtful reliability and should be repeated. This should be noted on the audiogram.

6.2.4.3 Determination when the bracketing method has been used

For each frequency and ear, average the lowest levels at which responses occur in the ascents. Again, for each frequency and ear, average the lowest levels at which responses occur in the descents. Determine the mean value of the two averages obtained in this way for each frequency and ear. This mean value, rounded to the nearest 5 dB step, is taken as the hearing threshold level for that frequency and ear.

If the lowest response levels in the ascents deviate by more than 10 dB among themselves or if the lowest response levels in the descents deviate by more than 10 dB among themselves, the test should be repeated.

6.3 Hearing threshold determination with an automatic recording audiometer

6.3.1 General

Automatic-recording audiometers often have no masking facilities and this procedure is therefore limited to air-conduction audiometry and to cases where no masking is required.

6.3.2 Presentation of test tone

The test tone may be presented either pulsed or continuously. Pulsed tones are preferred for threshold determination. When both pulsed and continuous tones are used, pulsed tones shall be presented first.

The temporal characteristics of the pulsed tone are specified in IEC 60645-1.

NOTE 1 Continuous tones are used only for some specialized audiological purposes.

NOTE 2 The increment in level can vary between instruments but is typically less than 1 dB. The attenuation rate is often 2,5 dB/s (IEC 60645-1:2001, 8.4.2).

6.3.3 Familiarization

Prior to the hearing threshold level measurements, the following familiarization of the test subject with the test tones and response tasks shall be carried out:

a) start the attenuation system, but not necessarily the recording mechanism, at the first test frequency (1 000 Hz);

b) observe the performance of the test subject — practice for 20 s to 30 s indicates whether the test subject has understood the instructions; if so, start the recorder mechanism, if not, repeat the instructions.

6.3.4 Hearing threshold level measurements

After the recorder mechanism has been started, the test shall be continued until both ears have been tested once.

6.3.5 Calculation of hearing threshold level

The following procedure shall be applied to the results of the test:

a) ignore the first reversal following a change of frequency and any reversals associated with a trace excursion of 3 dB or less;

b) average the peaks and average the valleys of the tracing for a given frequency and ear;

c) determine the mean of the two averages obtained in b) — this mean value, rounded up to the nearest whole number in decibels, is the hearing threshold level for that frequency and ear.

An audiometric recording should be considered of doubtful reliability and should be repeated if either of the following conditions apply:

— the peaks deviate by more than 10 dB from each other and/or the valleys deviate by more than 10 dB from each other;

— less than six reversals remain after a).

NOTE 1 When the trace excursions are regular, results very close to those obtained by the procedure given above can be obtained more simply by "visual averaging".

NOTE 2 On average, a difference exists between hearing threshold levels determined by manual audiometry and those recorded by automatic audiometers. This difference is assumed in this part of ISO 8253 to be 3 dB, the hearing threshold level values determined by automatic audiometers being lower than those determined by manual audiometry using 5 dB steps.

6.4 Computer-controlled threshold determination

The programming and operation of computer-controlled audiometric equipment shall be done in such a way that results are equivalent to those obtained by the methods described in this part of ISO 8253.

7 Air conduction hearing threshold level determinations using sweep-frequency audiometry

7.1 General

In sweep-frequency audiometry, the frequency range is swept automatically at a given rate of change (normally in the range of 0,5 octave/min to 2,0 octave/min). The normal sweep direction is from low to high, but the reverse direction may also apply.

Sweep-frequency audiometers often have no masking facilities and this procedure is therefore limited to air-conduction audiometry and to cases where no masking is required.

7.2 Presentation of test tone

The test tone may be presented either pulsed or continuously. Pulsed tones are preferred for threshold determination. When both pulsed and continuous tones are used, pulsed tones shall be presented first.

7.3 Familiarization

Prior to hearing threshold level measurements, the following familiarization of the subject with the test tones and response tasks shall be carried out by:

a) starting the attenuation system, but not the recording mechanism, at the lowest frequency required;

b) observing the performance of the test subject — practice for 20 s to 30 s indicates whether the subject has understood the instructions; if so, start the recorder mechanism, if not, repeat the instructions.

7.4 Hearing threshold level measurement

After the recording mechanism has been started, the test shall be continued until both ears have been tested.

7.5 Calculation of hearing threshold level at a specified frequency

For a specified frequency, the hearing threshold level is determined by averaging from tracing the three peaks and averaging the three valleys closest to the frequency in question.

The mean of these two averages, rounded to the nearest whole number in decibels, is the hearing threshold level for that frequency and ear.

The hearing threshold level may be determined as a semicontinuous function of frequency by forming a running average of three consecutive pairs of peaks and valleys. The arithmetic mean of these six level values is the hearing threshold level for a frequency equal to the geometric mean value for the six frequencies at which these peaks and valleys occur.

NOTE 1 If the three peaks or valleys used to obtain an average deviate by more than 10 dB from each other, the threshold determination is less reliable.

NOTE 2 When trace excursions are regular, results very close to those produced by the method above can be obtained by forming the simple average of each peak-valley pair and each valley-peak pair, or simply by "visual averaging".

8 Bone conduction hearing threshold audiometry

8.1 Method of audiometry

Hearing threshold levels for air conduction depend to a certain extent on the audiometric test method. This aspect has not been systematically investigated for bone conduction audiometry. Therefore, no quantitative adjustments for different techniques (manual or automatic recording) are recommended at this time for bone conduction audiometry. The same procedures for air and bone conduction audiometry shall be used.

For precise monaural hearing threshold level determination, bone conduction audiometry requires masking of the non-test ear at all levels.

NOTE Where a precise monaural bone conduction hearing threshold is not required, bone conduction audiometry may be undertaken without masking.

8.2 Occlusion

The ear being tested by bone conduction should be unoccluded. If the ear is occluded (see Note 1 to 8.3), it shall be noted on the audiogram.

8.3 Airborne sound radiation from the bone vibrator

Any airborne sound which the bone vibrator radiates when in contact with the head of a test person having unimpaired outer- and middle-ear function should be low enough in level to provide a sufficient margin between the true bone conduction hearing threshold level and a false air conduction hearing threshold level evoked by the bone vibrator.

If this condition is not met directly at frequencies above 2 000 Hz, the effect of unwanted sound radiation can be eliminated by inserting an ear plug into the outer ear canal of the test subject. However, consideration should be given to the possibility of the occlusion effect also occurring at frequencies above 2 000 Hz.

NOTE A detailed test procedure is described in IEC 60645-1.

8.4 Vibrotactile sensation

For mastoid location of the bone vibrator, the vibrotactile threshold coincides on average with a hearing level of approximately 40 dB at 250 Hz, 60 dB at 500 Hz and 70 dB at 1 000 Hz. However, large individual variations may occur. Therefore, care shall be taken that vibrotactile sensations are not misinterpreted as hearing sensations.

NOTE If the audiometer is calibrated for forehead placement of the vibrator, the values quoted above are approximately 10 dB lower.

8.5 Procedures for testing with masking in bone conduction audiometry

Although experience, to a large extent, dictates the procedure used and the choice of the masking level, the following procedure is recommended.

Step 1

After positioning the bone vibrator on the subject, place the masking earphone on the non-test ear. Care shall be taken that the headbands of the two transducers do not interfere with each other. Measure the hearing threshold level in the absence of masking noise in accordance with one of the shortened procedures described in 6.2.3.2.

NOTE It is possible that the result of this measurement does not represent a true estimate of the non-masked bone conduction threshold because of the possible presence of occlusion effect in the non-test ear.

Step 2

Repeat the test tone at this level while presenting masking noise to the non-test ear with an effective masking level equal to the air conduction hearing threshold of the non-test ear. Increase the noise level until the test tone is inaudible or until the noise level exceeds the test tone level by 40 dB.

Step 3

If the tone is still audible when the noise level is 40 dB above the test tone level, assume this to be the hearing threshold level. If the tone is masked, increase its level until it becomes audible again.

Step 4

Increase the noise level by 5 dB. If the test tone is inaudible, increase the test tone level until the tone becomes audible again. Repeat this procedure until the test tone remains audible although the level of the masking noise has been increased by more than 10 dB. This masking level, i.e. the level above which no further increase in the tone level is required for its audibility, is the correct masking level and this procedure should have produced the correct hearing threshold level for that test frequency. Note the correct masking level.

NOTE 1 This is the plateau-seeking method. In some cases where the plateau is short, the above procedure can give false results.

NOTE 2 The masking noise can also mask the test tone in the ear being tested. This phenomenon, called overmasking, can be reduced by presenting the masking noise using an appropriate insert earphone.

NOTE 3 The masking plateau can have a slope greater than zero due to central masking.

NOTE 4 In certain cases, it is appropriate to increase the noise level in steps of 10 dB.

9 Screening audiometry

9.1 General

In screening audiometry, the test tones at the screening level are either audible or inaudible to the subject. The test result shows whether hearing threshold levels are lower (better), or the same, or higher (worse) than the screening level used.

Screening audiometry may be combined with hearing threshold measurements at those frequencies where the test subject fails the screening test. A procedure in accordance with Clause 6 should then be used.

For the preparation and instruction of the test subjects before audiometric testing, see Clause 5.

9.2 Procedure for the screening test

9.2.1 General

Procedures for manual audiometry are specified in 9.2.2 and for computer-controlled audiometry in 9.2.3.

9.2.2 Manually controlled screening test

The test involves presenting one or more test tones of preset frequencies and levels, and recording the responses of the test subject.

Present the test frequencies in increasing sequence from 1 000 Hz, followed by the range below 1 000 Hz in decreasing sequence.

First, present a tone at 1 000 Hz and a hearing level of 40 dB to the right ear of the test subject to check that the test subject has understood the instructions. If not, re-instruct and repeat the tone. If the test subject does not respond again, increase the level until a response occurs.

Adjust the signal level to the required screening level and present two tones lasting 1 s to 2 s with an intervening interval of 3 s to 5 s. If both are perceived, the test subject has passed the screening test at this frequency. If only one was heard, present a third tone. If this third tone is heard, the test subject has passed the screening test. If it is not heard or if neither of the first two tones was heard, the test subject has failed the screening test at 1 000 Hz at the screening level chosen. Continue with other test frequencies as required and then proceed to the left ear.

9.2.3 Computer-controlled screening test

The programming and operation of computer-controlled audiometric equipment shall be such that the results are consistent with those obtained by the methods specified in 9.2.2.

10 Audiograms

Hearing threshold levels may be presented in tabular form or graphically as an audiogram. For audiograms, one octave on the frequency axis shall correspond to 20 dB on the hearing level axis. Where a graphical presentation of hearing threshold levels is required, the symbols given in Table 1 shall be used. Continuous straight lines shall be used to connect the adjacent points for air conduction. Broken lines may be used for bone conduction.

Table 1 — Symbols for the graphical presentation of hearing threshold levels

Test type	Right	Left
Air conduction — Unmasked	○	×
Example of no-response symbols Air conduction — Unmasked	↙○	×↘
Air conduction — Masked	△	□
Bone conduction — Unmasked, mastoid	<	>
Bone conduction — Masked, mastoid	[	]
Bone conduction — Masked, forehead	┐	┌
Bone conduction — Unmasked, forehead	∨	
NOTE Where symbols (○, ×) are used for masked air conduction as well, the use of masking should be noted in the audiogram.		

If no response occurs at the maximum output level of the audiometer, an arrow should be drawn pointing vertically or be attached to the lower outside corner of the appropriate symbol (i.e. to the right for left-ear symbols and to the left for right-ear symbols) and drawn downwards at an angle of about 45° from the vertical. The no-response symbol shall be placed on the audiogram at the hearing level representing the maximum output of the audiometer.

If colour is used, red shall be used for the right-ear symbol and connecting lines, and blue for the left-ear symbol and connecting lines.

Results obtained from screening audiometry shall be clearly indicated as such.

11 Permissible ambient noise

11.1 Permissible ambient noise for threshold determinations

Ambient sound pressure levels in an audiometric test room shall not exceed certain values to avoid masking of the test tones. These values are specified as maximum permissible ambient sound pressure levels, $L_{S,\text{max}}$, in one-third octave bands for:

a) a lowest hearing threshold level of 0 dB;

b) a maximum amount of allowable threshold shift (uncertainty) of +2 dB and of +5 dB at the lowest test tone level;

c) two presentations of test tones — through an earphone for air conduction measurements and by means of a bone vibrator for bone conduction measurements;

d) three test tone frequency ranges for air conduction — from 125 Hz to 8 000 Hz, from 250 Hz to 8 000 Hz and from 500 Hz to 8 000 Hz;

e) two test tone frequency ranges for bone conduction — from 125 Hz to 8 000 Hz and from 250 Hz to 8 000 Hz.

Table 2 specifies values for $L_{S,\text{max}}$ for air conduction audiometry when typical current supra-aural earphones are used. The average sound attenuation of these earphones is given in Table 3. These values are based on experimental data for two commercially available earphone types. If other types of earphones are used, the difference in the sound attenuation of those earphones and the values in Table 3 shall be added to the values for $L_{S,\text{max}}$ specified in Table 2. The values for $L_{S,\text{max}}$ for pure-tone bone conduction audiometry are specified in Table 4.

If it is necessary to measure minimum hearing threshold levels other than 0 dB, other values for $L_{S,\text{max}}$ are appropriate. These sound pressure levels are calculated by adding to the values given in Table 2 and Table 4, as appropriate, the minimum hearing threshold level to be measured.

The ambient noise level measurements shall be made at a time when conditions are representative of those existing when audiometric tests are carried out. If a ventilation system is usually operating during testing, noise measurements shall be made with that system operating. The measurements shall be made at the position at which the head of the test subject would be in the test room, but with the subject not present. The measurements shall meet the requirements for class 1 sound level meters of IEC 61672-1 and IEC 61620 and have a noise floor at least 6 dB below the sound pressure level being measured.

11.2 Psycho-acoustic check on ambient noise

If sound pressure level measurements cannot be carried out, a psycho-acoustic check of the ambient noise may be carried out by conducting an audiometric test on at least two test subjects who are known to have stable audiograms and, at all frequencies, lower (better) hearing thresholds levels than the lowest hearing levels to be used during regular testing. Hearing threshold levels obtained in this way, which are higher by 5 dB or more, indicate a requirement for reduction of the noise in the room. If bone conduction audiometry is performed in the room, the check shall be carried out by means of bone conduction. The audiometric test shall be carried out during the time in which the audiometry would normally be conducted.

Table 2 — Maximum permissible ambient sound pressure levels in one-third-octave bands, $L_{S,\mathrm{max}}$, for air conduction audiometry for hearing threshold level measurements down to 0 dB when typical current supra-aural earphones are used

Mid-frequency of one-third-octave band Hz	Maximum permissible ambient sound pressure levels[a] $L_{S,\mathrm{max}}$ (Reference: 20 µPa) dB		
	Test tone frequency range		
	125 Hz to 8 000 Hz	250 Hz to 8 000 Hz	500 Hz to 8 000 Hz
31,5	56	66	78
40	52	62	73
50	47	57	68
63	42	52	64
80	38	48	59
100	33	43	55
125	28	39	51
160	23	30	47
200	20	20	42
250	19	19	37
315	18	18	33
400	18	18	24
500	18	18	18
630	18	18	18
800	20	20	20
1 000	23	23	23
1 250	25	25	25
1 600	27	27	27
2 000	30	30	30
2 500	32	32	32
3 150	34	34	34
4 000	36	36	36
5 000	35	35	35
6 300	34	34	34
8 000	33	33	33

NOTE Using the values given, the lowest hearing threshold level to be measured is 0 dB, with a maximum uncertainty of +2 dB due to ambient noise. If a maximum uncertainty of +5 dB due to ambient noise is permitted, the values may be increased by 8 dB.

a Sources: ISO 389-4[1], ISO 389-7[2].

Table 3 — Average sound attenuation, in decibels, for different earphones

Frequency Hz	Typical current supra-aural earphone[abc] dB	Etymotic ER-3A[def] dB	Sennheiser HDA 200[deg] dB
31,5	0	33	—
40	0	33	—
50	0	33	—
63	1	33	17
80	1	33	16
100	2	33	15
125	3	33	15
160	4	34	15
200	5	35	16
250	5	36	16
315	5	37	18
400	6	37	20
500	7	38	23
630	9	37	25
800	11	37	27
1 000	15	37	29
1 250	18	35	30
1 600	21	34	31
2 000	26	33	32
2 500	28	35	37
3 150	31	37	41
4 000	32	40	46
5 000	29	41	45
6 300	26	42	45
8 000	24	43	44

[a] The values given are based on measurements using pure tones in a free sound field and using Telephonics TDH39[d] with MX 41/AR cushions[d] and Beyer DT48[d] earphones.

[b] Attenuation data based on narrow-band noise in a diffuse sound field are assumed to provide a more realistic measure of attenuation properties. Somewhat lower values than those given can be expected with noise bands in a diffuse field; however, insufficient data are available at the present time.

[c] Sources: References [10], [11], [16].

[d] Data are valid for an artificial diffuse field according to ISO 4869-1[3].

[e] This is a product available commercially. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of this product.

[f] Source: Reference [17].

[g] Source: Reference [18].

Table 4 — Maximum permissible ambient sound pressure levels in one-third-octave bands, $L_{S,\max}$, for bone conduction audiometry for hearing threshold level measurements down to 0 dB[a]

Mid-frequency of one-third octave band Hz	Maximum permissible ambient sound pressure levels $L_{S,\max}$ (Reference: 20 µPa) dB Test tone frequency range 125 Hz to 8 000 Hz	 250 Hz to 8 000 Hz
31,5	55	63
40	47	56
50	41	49
63	35	44
80	30	39
100	25	35
125	20	28
160	17	21
200	15	15
250	13	13
315	11	11
400	9	9
500	8	8
630	8	8
800	7	7
1 000	7	7
1 250	7	7
1 600	8	8
2 000	8	8
2 500	6	6
3 150	4	4
4 000	2	2
5 000	4	4
6 300	9	9
8 000	15	15

NOTE 1 Using the values given, the lowest hearing threshold level to be measured is 0 dB, with a maximum uncertainty of +2 dB due to ambient noise. If a maximum uncertainty of +5 dB due to ambient noise is permitted, the values may be increased by 8 dB.

NOTE 2 With most of the current sound level meters, it is difficult to measure sound pressure levels below 5 dB.

[a] Sources: ISO 389-4[1], ISO 389-7[2].

12 Maintenance and calibration of audiometric equipment

12.1 General

Correct calibration of audiometers and related equipment is highly important for reliable test results. It is essential that audiometric equipment, when in service, be calibrated in accordance with the relevant part of ISO 389 and complies with the requirements of IEC 60645-1.

In order to ensure this, the following scheme, consisting of three stages of checks and calibration procedures, should be followed:

a) stage A — routine checking and subjective tests;

b) stage B — periodic objective checks;

c) stage C — basic calibration tests.

It is recommended that stages A and B be performed on the equipment in its normal working position.

12.2 Intervals between checks

The recommended intervals at which the various checks are to be carried out are by necessity only a guide. They should be adhered to unless and until there is evidence that a different interval would be appropriate.

It is recommended that stage A check procedures be carried out weekly in full on all equipment in use. The checks outlined in 12.3.2.2 to 12.3.2.6 should be followed on the equipment on each day of use.

Periodic objective checks, stage B, should preferably be performed at intervals of three months, although different intervals between checks may be acceptable, in the light of experience, with particular equipment in known conditions of use, provided that the stage A checks are regularly and carefully applied. The maximum interval between such checks should not exceed 12 months.

Basic calibration tests, stage C, need not be employed on a routine basis if stage A and stage B checks are regularly performed. Stage C procedures are required only when a serious equipment fault or error occurs or when, after a long period of time, it is suspected that the equipment may no longer be performing fully to specifications. It may, however, be advisable to submit equipment to a stage C test after, for example, five years' use if it has not received such a test during that time in the course of repair.

12.3 Stage A — Routine checking and subjective tests

12.3.1 General

The purpose of routine checking is to ensure, as far as possible, that the equipment is working properly, that its calibration has not noticeably altered and that its attachments, leads and accessories are free from any defect that might adversely affect the test result. The procedures involve simple tests (see 12.3.2) throughout, i.e. measuring instruments are not necessary.

The most important elements in stage A are the subjective tests and these tests can only be successfully carried out by an operator with unimpaired and preferably very good hearing.

The ambient noise conditions during the tests should not be substantially worse than those encountered when the equipment is in use.

12.3.2 Tests and checking procedures

12.3.2.1 The following tests and checks should be carried out to fulfil the requirements of stage A.

It is recommended that the tests given in 12.3.2.2 to 12.3.2.6 tests be carried out on the equipment on each day of use.

The checking procedures described in 12.3.2.2 to 12.3.2.10 should be carried out with the audiometer set up in its usual working situation. If a booth or separate test room is used, the equipment should be checked as installed; an assistant may be required in order to carry out the procedures. The checks then cover the interconnections between the audiometer and the equipment in the booth, but the additional connecting leads and any plug and socket connections at the junction box should be examined as well as potential sources of intermittency or incorrect connection.

NOTE When subjective checks of bone conduction threshold levels are being performed by an operator with normal hearing, air-conducted sound radiated from the bone vibrator can be heard at a high enough level to invalidate this test, especially at frequencies above 2 000 Hz. Sufficient attenuation of this air-conducted sound can be achieved by wearing the air conduction headphones (disconnected) or earplugs during the test at frequencies of 2 000 Hz and above.

12.3.2.2 Clean and examine the audiometer and all accessories. Check earphone cushions, plugs, main leads and accessory leads for signs of wear or damage. Damaged or badly worn parts should be replaced.

12.3.2.3 Switch on equipment and leave for the recommended warm-up time. If no warm-up period is quoted by the manufacturer, allow 5 min for circuits to stabilize. Carry out any setting-up adjustments as specified by the manufacturer. On battery-powered equipment, check battery state using the specified method. Check that earphone and bone vibrator serial numbers tally with the instrument serial number, if possible.

12.3.2.4 Check that audiometer output is approximately correct on both air and bone conduction by sweeping through at a hearing level of, for example, 10 dB or 15 dB and listening for “just audible” tones. This test shall be performed at all appropriate frequencies and for both earphones as well as the bone vibrator.

12.3.2.5 Check at high level (e.g. hearing levels of 60 dB on air conduction and 40 dB on bone conduction) on all appropriate functions (and on both earphones) at all frequencies used; listen for proper functioning, absence of distortion, freedom from interruptor clicks, etc. Check all earphones (including masking transducer) and the bone vibrator for absence of distortion and intermittency; check plugs and leads for intermittency. Check that all switch knobs are secure and that lamps and indicators work correctly.

12.3.2.6 Check that the signal system of the test subject operates correctly.

12.3.2.7 Listen at low levels for any sign of noise or hum, for unwanted sounds (break-through arising when a signal is introduced in another channel) or for any change in tone quality as masking is introduced. Check that attenuators do attenuate the signals over their full range and that attenuators intended to be operated while a tone is being delivered are free from electrical or mechanical noise. Check that interruptor keys operate silently and that no noise radiated from the instrument is audible at the position of the test subject.

12.3.2.8 Check subject communication speech circuits, if appropriate, applying procedures similar to those used for pure-tone function.

12.3.2.9 Check tension of headset headband and bone vibrator headband. Ensure that swivel joints are free to return without being excessively slack. Check headbands and swivel joints on noise-excluding headsets for signs of wear strain or metal fatigue.

12.3.2.10 On automatic recording audiometers, check the marking pen and mechanical operation and function of limit switches and frequency switches. Check that no extraneous instrument noise is audible at the position of the test subject.

12.4 Stage B — Periodic objective checks

Periodic objective checks consist of measuring and comparing results with appropriate standards (see Clause 2) for:

a) the frequencies of test signals;

b) the sound pressure levels from earphones in an acoustic coupler or ear simulator;

c) the vibratory force levels from the bone vibrator on a mechanical coupler;

d) the levels of masking noise;

e) the attenuator steps (over a significant part of the range, especially below 60 dB);

f) the harmonic distortion.

NOTE 1 Complete checks of attenuator range and levels of masking noise are not possible with the equipment recommended below.

NOTE 2 With sweep frequency audiometers, standardized calibration data are available only at discrete frequencies specified in ISO 389-1, ISO 389-2, ISO 389-3, ISO 389-5, and ISO 389-8.

The following equipment is recommended as a minimum for periodic objective checks:

— class 1 sound level meter, comprising a pressure-calibrated condenser microphone of a type suitable for the ear simulator, designated as being in compliance with IEC 61672-1;

— one-third-octave-band filter set, complying with IEC 61260;

— ear simulators or acoustic couplers, designated as being in compliance with IEC 60318-1[4], IEC 60318-3[5], IEC 60318-4[6], and IEC 60318-5[7];

— mechanical coupler, designated as being in compliance with IEC 60318-6[8];

— digital frequency counter;

— oscilloscope;

— contact thermometer for checking the operating temperature (23 °C) of the mechanical coupler.

If frequencies or test tone levels are found to be out of calibration, it is normally possible to adjust them. If not, refer the equipment for a basic calibration. When calibration adjustments are made, both sets of measurements (i.e. before and after the adjustment) should be recorded.

When the results of the measurements on the equipment are recorded, information on calibration drift may be obtained. The interval between objective tests may need to be determined by observations on the trends which such drifting may follow.

It is recommended that a calibration check label be attached to the equipment, giving the date on which the next objective test is due.

12.5 Stage C — Basic calibration tests

A basic calibration shall be performed by a competent laboratory. The procedure shall be such that, after the audiometric equipment has been submitted for a basic calibration, it shall meet the relevant requirements given in IEC 60645-1.

When the instrument is returned after basic calibration, it should be checked in accordance with procedures outlined in 12.3 or 12.4 before being put back into service.

Annex A
(informative)

Measurement uncertainty

A.1 General

The generally accepted format for the expression of uncertainties associated with results of measurements is that given in ISO/IEC Guide 98-3. This format requires a functional relationship (model function) to be established between the measurand, which in the context of this part of ISO 8253 is the frequency-dependent hearing threshold level of a test subject, and several input quantities describing effects that may influence the measurement result. Each of these input quantities is characterized by its estimate, its probability distribution, and its standard uncertainty. The existing knowledge on these input quantities is to be compiled in an uncertainty budget from which the combined standard uncertainty and the expanded uncertainty of the measurement result can be derived.

Scientifically verified data necessary to establish a sound uncertainty budget for each measurement performed using any of the procedures specified in this part of ISO 8253 are not available at the time of publication. However, an indication of the relevant sources of uncertainty and their characteristics can be given, mostly based on empirical knowledge. The general approach to the calculation of uncertainties in accordance with ISO/IEC Guide 98-3 is illustrated in this annex. It allows an approximate determination of uncertainties under special assumptions.

A.2 Model function

The expression for the determination of the hearing threshold level, L_{HT}, at a certain frequency is given by Equation (A.1):

$$L_{\text{HT}} = L'_{\text{HT}} + \delta_{\text{eq}} + \delta_{\text{tr}} + \delta_{\text{n}} + \delta_{\text{m}} + \delta_{\text{te}} + \delta_{\text{su}} + \delta_{\text{pr}} \quad \text{(A.1)}$$

where

L'_{HT} is the outcome of a hearing threshold level determination in accordance with any of the procedures specified in this part of ISO 8253 (see A.3.2);

δ_{eq} is an input quantity to allow for any deviation from nominal performance of the audiometric equipment used (A.3.3);

δ_{tr} is an input quantity to allow for uncertainties due to the use of a certain type of transducer and its fitting (A.3.4);

δ_{n} is an input quantity to allow for the influence of non-ideal environmental conditions, especially ambient noise (A.3.5);

δ_{m} is an input quantity to allow for any uncertainties due to a non-optimized masking noise (A.3.6);

δ_{te} is an input quantity to allow for any uncertainties due to lacking qualification and experience of the tester (A.3.7);

δ_{su} is an input quantity to allow for any uncertainties due to lack of cooperation and non-reliable responses of the test subject (A.3.8);

δ_{pr} is an input quantity to allow for any uncertainties due to special problems arising from an unusually difficult measurement situation (A.3.9).

Usually, each of the δ input quantities is considered to have an estimate of 0 dB, i.e. no correction is applied to the determined hearing threshold level. However, each of these quantities is associated with an uncertainty as explained in A.3. None of the input quantities is correlated to another to any significant extent.

A.3 Input quantities

A.3.1 General

Input quantities described in A.3.2 to A.3.6 have to be considered in nearly all audiometric applications while those described in A.3.7 to A.3.9 are to be taken into account only in exceptional situations subject to the personal judgement of the tester.

A.3.2 Determined hearing threshold level, L'_{HT}

During routine audiometry, the hearing threshold level of a test subject at a certain frequency is usually determined just once for each ear. However, based on empirical knowledge, the following standard uncertainties for repeated measurements under identical test conditions can be assumed:

a) for air conduction audiometry (Clauses 6 and 7): 2,5 dB at frequencies up to 4 kHz and 4 dB at frequencies above 4 kHz;

b) for bone conduction audiometry (Clause 8): 3 dB at frequencies up to 4 kHz and 5 dB at frequencies above 4 kHz.

The probability distribution of probable values of L'_{HT} can be assumed to be normal; its estimate is designated $L'_{HT,est}$ (see Table A.1).

A.3.3 Audiometric equipment, δ_{eq}

Assuming that the audiometric equipment meets the requirements of IEC 60645-1 for a type 1 or type 2 audiometer, its dominant contribution to the measurement uncertainty is probably given by the deviation of the output levels provided from nominal values. IEC 60645-1 specifies the following maximum deviations:

a) air conduction: ±3 dB at frequencies up to 4 kHz and ±5 dB at frequencies above 4 kHz;

b) bone conduction: ±4 dB at frequencies up to 4 kHz and ±5 dB at frequencies above 4 kHz.

Unless any more specific information on the performance of the equipment is available, the probability distribution of the output levels can be assumed to be rectangular, resulting in standard uncertainties that are equal to half the maximum spread of possible values, divided by $\sqrt{3}$.

If the step size of the hearing level control is 5 dB, this introduces another non-negligible uncertainty contribution with a rectangular probability distribution and a standard uncertainty of $2{,}5/\sqrt{3}$ dB.

The two contributions result in an approximate overall standard uncertainty, e.g. for air conduction and frequencies up to 4 kHz of $\sqrt{[(3/\sqrt{3})^2 + (2{,}5/\sqrt{3})^2]}$ dB = 2,3 dB.

In special test situations, for example if the hearing threshold level of a test subject varies heavily with frequency, deviations of the test tone frequency from nominal values and the harmonic distortion of the test tones may also contribute to the overall uncertainty of results due to equipment performance.

A.3.4 Transducers and their fitting, δ_{tr}

The RETSPL and RETVFL values for different types of transducers such as supra-aural, circumaural or insert earphones and bone vibrators, as specified in the relevant part of ISO 389, are not completely equivalent, though the differences between them are not exactly known. It seems, however, realistic to assume a standard uncertainty due to these differences of 1,5 dB at frequencies up to 4 kHz and 2,5 dB at frequencies above 4 kHz.

Moreover, the sound pressure levels or vibratory force levels provided by different types of transducers to the ear or bone of a test subject may be differently sensitive to anatomic and physiological characteristics of the test subject, to their placement at the ear or bone and to deviations of the headband forces from nominal values. For bone vibrators, further uncertainties may arise from radiated airborne sound and vibrotactile sensation. Generally valid figures on the uncertainty contribution from these effects cannot be stated at present. However, unless more detailed knowledge is available, a standard uncertainty of 2,5 dB at frequencies up to 4 kHz and of 3 dB at frequencies above 4 kHz may be assumed.

The two effects together result in an approximate standard uncertainty of $\sqrt{(1,5^2 + 2,5^2)}$ dB = 2,9 dB at frequencies up to 4 kHz and $\sqrt{(2,5^2 + 3^2)}$ dB = 3,9 dB at frequencies above 4 kHz.

A.3.5 Environmental conditions, δ_n

If the requirements on ambient noise (see Clause 11) are fully met, the standard uncertainty of δ_n may be assumed to be 2 dB with a normal probability distribution, considering test subjects with a hearing threshold level close to 0 dB. For test subjects with hearing threshold levels significantly above 0 dB, the uncertainty contribution due to ambient noise may be negligible.

On the other hand, the maximum permissible ambient sound pressure levels might often be exceeded during routine testing, resulting in a considerably larger uncertainty contribution.

A.3.6 Masking noise, δ_m

Measured hearing threshold levels may be affected by the use of non-optimized masking noise (see 6.2.3.3 and 8.5). No generally valid figures on the contribution of this effect to the measurement uncertainty can be given. However, a standard uncertainty of 2 dB may provisionably be attributed to δ_m with a normal probability distribution if masking noise is applied.

A.3.7 Experience of the tester, δ_{te}

For a qualified tester (see 4.4) with sufficient experience, the contribution to uncertainty due to personal judgements may be considered to be included in the standard uncertainty for repeated measurements (see A.3.2) for usual test situations. Under special circumstances, it may however be appropriate to attribute an additional uncertainty to δ_{te}.

A.3.8 Responses of the test subject, δ_{su}

Under normal circumstances, uncertainties due to minor inconsistencies in the responses of a test subject are included in the standard uncertainty for repeated measurements (see A.3.2). There may, however, be reasons to attribute an additional standard uncertainty to δ_{su} in exceptional situations.

A.3.9 Special measurement situations, δ_{pr}

There may be exceptional cases in which it is extremely difficult to determine the hearing threshold level of a test subject. In such cases, an additional standard uncertainty may be attributed to δ_{pr}.

A.4 Uncertainty budget

The contributions to the combined uncertainty associated with the value of the determined hearing threshold level depend on the standard uncertainties, u_i, as described in A.3 and the related sensitivity coefficients, c_i. The sensitivity coefficients are a measure of how the values of the hearing threshold level are affected by changes in the values of the respective input quantities. Mathematically, they are equal to the partial derivative of the model function with respect to the relevant input quantity. The contributions of the respective input quantities are then given by the products of the standard uncertainties and their associated sensitivity coefficients.

The uncertainty budget compiles the available information on the various uncertainty contributions in tabular form, as in Table A.1.

Table A.1 — General form of an uncertainty budget for hearing threshold level determinations

Quantity	Estimate dB	Standard uncertainty u_i dB	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $c_i u_i$ dB
L'_{HT}	$L'_{HT,est}$	u_1	normal	1	u_1
δ_{eq}	0	u_2	rectangular	1	u_2
δ_{tr}	0	u_3	normal	1	u_3
δ_{n}	0	u_4	normal	1	u_4
δ_{m}	0	u_5	normal	1	u_5
δ_{te}	0	u_6	normal	1	u_6
δ_{su}	0	u_7	normal	1	u_7
δ_{pr}	0	u_8	normal	1	u_8

A Gaussian probability distribution of values related to any of the input quantities (except that described in A.3.3) can be assumed unless more specific knowledge is available.

A.5 Combined and expanded uncertainty

The combined uncertainty for the hearing threshold level is given by Equation (A.2).

$$u = \sqrt{\sum_{i=1}^{8} u_i^2} \quad \text{(A.2)}$$

ISO/IEC Guide 98-3 requires an expanded uncertainty, U, to be specified such that the interval [$L_{HT} - U$, $L_{HT} + U$] covers, for example, 95 % of the values of L_{HT} that might reasonably be attributed to L_{HT}. To that end, a coverage factor, k, is used such that $U = k\,u$. For a coverage probability of 95 % and a normal distribution, $k = 2$.

A.6 Example

The expanded measurement uncertainty is evaluated for the determination of the hearing threshold level of a test subject using air conduction audiometry at a frequency below 4 kHz without masking and assuming that the requirements on ambient noise are met and that no further uncertainty contribution arises from any other sources. The uncertainty budget then has a form as presented in Table A.2.

Table A.2 — Example of an uncertainty budget for the measurement conditions stated above

Quantity	Estimate dB	Standard uncertainty dB	Probability distribution	Sensitivity coefficient	Uncertainty contribution dB
L'_{HT}	$L'_{HT,est}$	2,5	normal	1	2,5
δ_{eq}	0	2,3	rectangular	1	2,3
δ_{tr}	0	2,9	normal	1	2,9
δ_{n}	0	2,0	normal	1	2,0

Combined standard uncertainty: u = 4,9 dB.

Expanded measurement uncertainty for 95 % coverage probability, rounded to the nearest full decibel: U = 10 dB.

Bibliography

[1] ISO 389-4, *Acoustics — Reference zero for the calibration of audiometric equipment — Part 4: Reference levels for narrow-band masking noise*

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

[3] ISO 4869-1, *Acoustics — Hearing protectors — Part 1: Subjective methods for the measurement of sound attenuation*

[4] IEC 60318-1, *Electroacoustics — Simulators of human head and ear — Part 1: Ear simulator for the measurement of supra-aural and circumaural earphones*

[5] IEC 60318-3, *Electroacoustics — Simulators of human head and ear — Part 3: Acoustic coupler for the calibration of supra-aural earphones used in audiometry*

[6] IEC 60318-4, *Electroacoustics — Simulators of human head and ear — Part 4: Occluded-ear simulator for the measurement of earphones coupled to the ear by means of ear inserts*

[7] IEC 60318-5, *Electroacoustics — Simulators of human head and ear — Part 5: 2 cm^3 coupler for the measurement of hearing aids and earphones coupled to the ear by means of ear inserts*

[8] IEC 60318-6, *Electroacoustics — Simulators of human head and ear — Part 6: Mechanical coupler for the measurement of bone vibrators*

[9] ARLINGER, S.D. Comparison of ascending and bracketing methods in pure-tone audiometry: A multi-laboratory study. *Scand. Audiol*. 1979, **8**, pp. 247-251

[10] BRINKMANN, K., RICHTER, U. Kopfhörer DT 48: Schalldämmung und Ohrverschluss-Effekt [Headphone DT 48: Sound absorption and occlusion effect]. *Acustica* 1980, **47**, pp. 53-54

[11] COPELAND, A.B., MOWRY, H.J., III. Real-ear attenuation characteristics of selected noise-excluding audiometric receiver enclosures. *J. Acoust. Soc. Am*. 1971, **49**, pp. 1757-1761

[12] HOOD, J.D. Principles and practice of bone-conduction audiometry. *Laryngoscope* 1960, **70**, pp. 1211-1228

[13] ROBINSON, D.W., WHITTLE, L.S. A comparison of self-recording and manual audiometry: Some systematic effects shown by unpractised subjects. *J. Sound Vibration* 1973, **26**, pp. 41-62

[14] SANDERS, J.W. Masking. In: KATZ, J., editor. *Handbook of clinical audiology*, 2nd edition, pp. 124-140. Baltimore, MD: Williams and Wilkins, 1978

[15] STUDEBAKER, G.A. Clinical masking. In: RINTELMANN, W.F., editor. *Hearing assessment*, pp. 51-100. Baltimore, MD: University Park Press, 1979

[16] TYLER, R.S., WOOD, E.J. A comparison of manual methods for measuring hearing levels. *Audiology* 1980, **19**, pp. 316-329

[17] BERGER, E.H., KILLION, M.C. Comparison of the noise attenuation of three audiometric earphones, with additional data on masking near threshold. *J. Acoust. Soc. Am*. 1989, **86**, pp. 1392-1403

[18] GÖSSING, P., RICHTER, U. Characteristic data of the circumaural earphone Sennheiser HDA 200 in the conventional and the extended high frequency range. In: RICHTER, U., editor. *Characteristic data of different kinds of earphones used in the extended high frequency range for pure-tone audiometry.* PTB report PTB-MA-72, Braunschweig, 2003

[19] LAUKLI, E., MAIR, I.W.S. High-frequency audiometry: Normative studies and preliminary experiences. *Scand. Audiol*. 1985, **14**, pp. 151-158

[20] LAUKLI, E., FJERMEDAL, O. Reproducibility of hearing threshold measurements: Supplementary data on bone-conduction and speech audiometry. *Scand. Audiol*. 1990, **19**, pp. 187-190

ICS 13.140

Price based on 29 pages