TECHNICAL SPECIFICATION

ISO/TS 4869-5

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Acoustics — Hearing protectors —

Part 5: Method for estimation of noise reduction using fitting by inexperienced test subjects

Acoustique — Protecteurs individuels contre le bruit —

Partie 5: Méthode d'estimation de la réduction du bruit au moyen de réglages par des sujets d'essai non expérimentés

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Foreword

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

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.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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/TS 4869-5 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

ISO/TS 4869 consists of the following parts, under the general title *Acoustics — Hearing protectors*:

— *Part 1: Subjective method for the measurement of sound attenuation*

— *Part 2: Estimation of effective A-weighted sound pressure levels when hearing protectors are worn*

— *Part 3* [1]*: Measurement of insertion loss of ear-muff type protectors using an acoustic test fixture*

— *Part 4: Measurement of effective sound pressure levels for level-dependent sound-restoration ear-muffs (ISO/TR)*

— *Part 5: Method for estimation of noise reduction using fitting by inexperienced test subjects (ISO/TS)*

1) To be published.

The following part is under development:

— *Part 6: Active noise reduction of hearing protectors* [2)]

Annex A of this part of ISO 4869 is for information only.

2) Presently a preliminary work item.

Introduction

Hearing protectors are used to reduce the noise to which the ear is exposed. Hearing protectors are generally divided into ear-muffs and ear-plugs with a great variety of products within both categories. The measurement conditions given in this Technical Specification – making use of inexperienced hearing protector users – is believed to provide results that are representative for the noise reduction obtained by groups of typical users in real-world occupational settings.

The method described in ISO 4869-1 yields the sound attenuation of the hearing protector under test. The result of the measurement is a pure physical characteristic of the hearing protector.

The method described in this Technical Specification yields the performance of the system as a whole, i.e. hearing protector, test subjects, fitting and instruction.

Acoustics — Hearing protectors —

Part 5: Method for estimation of noise reduction using fitting by inexperienced test subjects

1 Scope

This Technical Specification specifies a method for measuring noise reduction of passive hearing protectors at the threshold of hearing. The method is designed to provide estimates of the noise reduction obtained by typical groups of users in real-world occupational settings, who may lack the training and motivation to wear hearing protectors in an optimum manner.

The principle of the test method is to measure the difference in hearing threshold with and without wearing a hearing protector. This difference between the thresholds constitutes the noise reduction. The measurement is done twice on a given number of test subjects.

NOTE 1 The principle of measuring the influence of a hearing protector on the hearing threshold is used in ISO 4869-1 and in this Technical Specification. The method described in ISO 4869-1 yields the sound attenuation of the hearing protector under test. The result of the measurement is a pure physical characteristic of the hearing protector. The method described in this Technical Specification yields the performance of the system as a whole, i.e. the influence of hearing protector, test subjects, fitting and instruction.

This test method yields data that are collected at low sound pressure levels (close to the threshold of hearing), but which are also representative of the noise reduction values of hearing protectors at higher sound pressure levels. This Technical Specification is inapplicable for level-dependent hearing protectors for sound pressure levels above the point at which their level-dependent characteristics become effective.

NOTE 2 At frequencies below 500 Hz, real-ear noise reduction data measured according to this Technical Specification may be spuriously high by a few decibels, with the error increasing as the frequency decreases. The error results from masking of the occluded-ear threshold by physiological noise during testing.

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.

IEC 60263, *Scales and sizes for plotting frequency characteristics and polar diagrams*

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

IEC 61260:1995, *Electroacoustics — Octave-band and fractional-octave-band filters*

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

Guide to the expression of uncertainty in measurement (GUM), BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML, ISBN 92-67-10188-9, 1993 [3)]

3) Corrected and reprinted in 1995.

3 Terms and definitions

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

3.1
hearing protector
device worn by a person to reduce unwanted effects of sound

NOTE Hearing protectors can include electronic devices for communication or devices designed to play an active role in the reduction of the noise level between the hearing protector and the eardrum.

3.2
ear-muff
hearing protector consisting of an ear-cup to be pressed against each pinna or of a circumaural ear-cup to be pressed against the head around the pinna

NOTE The ear-cups can be pressed against the head with a special headband or neck-band or by means of a device attached to a safety helmet or other equipment.

3.3
ear-plug
hearing protector that either is inserted into the external ear canal or covers the ear canal entrance

NOTE Some ear-plugs are held in place by a lightweight band. They are sometimes called canal caps, semi-aural inserts, or banded ear-plugs.

3.4
helmet
device which covers a substantial part of the head

3.5
hearing level
⟨of a pure tone⟩ at a specified frequency, for a specified type of earphone and for a specified manner of application, the sound pressure level of this pure tone produced by the earphone in a specified acoustic coupler or artificial ear minus the appropriate reference equivalent threshold sound pressure level

NOTE Values of reference equivalent threshold sound pressure levels are specified in ISO 389-1.

3.6
hearing threshold level
⟨of a given ear⟩ at a specified frequency and for a specified type of earphone, the threshold of hearing expressed as hearing level

NOTE For appropriate measurement procedures see, for example, ISO 6189 and ISO 8253-1.

3.7
threshold of hearing
lowest sound pressure level at which, under specified conditions, a person gives a predetermined percentage of correct detection responses on repeated trials

NOTE For the purpose of this Technical Specification, the threshold of hearing is measured with and without the hearing protector. For appropriate test conditions, see ISO 8253-2.

3.8
occluded-ear threshold of hearing
threshold of hearing when a hearing protector is worn

3.9
open-ear threshold of hearing
threshold of hearing when no hearing protector is worn

3.10
individual noise reduction
for a given test signal and a selected test subject, the difference between the occluded-ear threshold of hearing and the open-ear threshold of hearing, i.e. the threshold with and without the hearing protector

NOTE The individual noise reduction is expressed in decibels.

3.11
group noise reduction
for a given test signal, the mean of the individual noise reductions for a group of test subjects

3.12
pink noise
noise in which sound power spectral density is inversely proportional to frequency

3.13
reference point
fixed point within the test chamber; the test subject is positioned so that the mid-point of a line connecting the subjects' ear canal openings coincides with the reference point

NOTE All objective measurements of the sound field characteristics are referenced to the reference point.

3.14
reverberation time
time required for the sound pressure level to decrease by 60 dB after the sound source has stopped

NOTE See ISO 354.

4 Measurement of the noise reduction of hearing protectors

4.1 Test signals

The test signals shall consist of a signal from pink noise filtered through one-third-octave bands with centre frequencies in accordance with IEC 61260. At a minimum, the following centre frequencies shall be tested:

125 Hz, 250 Hz, 500 Hz, 1 000 Hz, 2 000 Hz, 4 000 Hz and 8 000 Hz

4.2 Test site

4.2.1 Conditions to be met for the test to be valid

a) With the test subject and the subject's chair absent, the sound pressure level measured with an omnidirectional microphone at positions 15 cm from the reference point on the front back, right-left and up-down axes shall deviate by no more than $\pm$ 2,5 dB from the sound pressure level at the reference point for any of the test signals. Further, the difference between the extreme right-left positions shall not exceed 3 dB. The orientation of the microphone shall be kept the same at each position.

b) At frequencies of 500 Hz and above, the sound pressure level at the reference point shall be within 5 dB for the two directions of measurement that give maximum and minimum readings of the incident sound energy when measured with a directional microphone with a front-to-random sensitivity index of 5 dB. For other directional microphones, the relationship between the front-to-random sensitivity index and the allowable field variation is given in Table 1.

Table 1 — Allowable field variation for different microphones

Front-to-random sensitivity index dB	Allowable field variation dB
$\geqslant 5$	5
4,5	4,5
4	4
< 4	Measurement not suitable
NOTE 1 The test should be carried out in a sufficient number of directions, which depend on the type of microphone and the characteristics of the loudspeaker arrangement and include at least the two directions where maximum and minimum sound pressure levels may be expected.	
NOTE 2 More than one loudspeaker is necessary to produce the desired sound field. The loudspeakers may require to be fed with non-coherent electrical signals to reduce the effects of standing waves.	

4.2.2 Reverberation time

The reverberation time in the test space (without subject) shall not exceed 1,6 s for each of the test bands.

4.2.3 Background noise

The background noise at the test site in the test room shall not exceed the values given in Table 2 with the test subject absent. The level of the background noise shall be determined by measuring the sound pressure level.

NOTE Background noise includes the ambient noise present in the room and the noise of the test equipment in the absence of the test signal.

Table 2 — Maximum permissible background sound pressure level

Centre frequency Hz	One-third-octave-band sound pressure level (ref. 20 µPa) dB
50	38
63	32
80	27
100	22
125	17
160	14
200	12
250	10
315	8
400	6
500	5
630	5
800	4
1 000	4
1 250	4
1 600	5
2 000	5
2 500	3
3 150	1
4 000	−1
5 000	1
6 300	6
8 000	12
10 000	14

With the background noise levels given in Table 2, it is possible to measure hearing threshold levels down to 0 dB. If test subjects' hearing threshold levels are better than 0 dB, the permissible background noise levels shall be lowered accordingly.

NOTE The values in Table 2 are from ISO 8253-2.

4.3 Test equipment

The test equipment shall be able to produce all test signals without distortion at the test subject's position.

For the test signals mentioned in 4.1, the frequency range shall be from 110 Hz (approximately, the lower limiting frequency of the 125 Hz one-third octave) to 9 000 Hz (approximately, the upper limiting frequency of the 8 000 Hz one-third-octave band).

The equipment, including the loudspeaker system, shall be able to produce the minimum and maximum test signal sound pressure levels given in Table 3 at the test subject’s position.

Table 3 — Minimum and maximum sound pressure levels for test signals

Centre frequency Hz	Minimum and maximum test signal sound pressure levels (ref. 20 µPa) dB
125	10 to 70
250	0 to 70
500	−5 to 80
1 000	−10 to 80
⩾ 2 000	−15 to 90

The equipment, including the loudspeaker system, shall secure the reproduction of the test signals without any audible crackle and rattle at each test band and each level as given in Table 3. At centre frequencies from one octave above the test band up to 16 kHz, and from one octave below the test band down to 63 Hz, all one-third-octave-band sound pressure levels shall remain at least 40 dB below the sound pressure level in the test band under all test conditions. The band levels shall be measured using filters complying with IEC 61260. The test band sound pressure levels shall be measured as average values (L_{eq} in IEC 61672-1) and the remaining band levels using time weighting F of IEC 61672-1.

NOTE The lower limits of the levels in Table 3 are set to allow open ear testing of subjects with better than average hearing.

Attenuator steps shall be 2,5 dB or smaller.

The error in the difference between the indications at any two positions of the attenuator with the complete test equipment including the loudspeaker shall not exceed 2 dB over the total range of the attenuator and 1 dB over any 80 dB range. Where possible, this test shall be performed acoustically. At low sound pressure levels, it is also permissible to check the test equipment by electrical measurement of the signal voltage at the terminals of the loudspeaker(s).

If it is not possible to achieve the desired accuracy in the attenuation system, the test equipment shall be calibrated and the corrections thus obtained shall be applied to the measurements.

The electrical signals applied to the loudspeakers shall comply with IEC 60645-1.

5 Test subjects

5.1 Conditions for subject acceptance/dismissal

5.1.1 General

No subject selection criteria shall exist besides those specified in this clause. It is not permitted to optimize a test panel based upon experience gained from subject participation in prior tests.

5.1.2 Age and sex

Subjects shall be at least 18 years of age.

Unless the hearing protector under test is designed to fit only males or only females, the balance of male to female subjects shall be 50/50 ± 10 %.

5.1.3 Previous experience with hearing protectors

Subjects shall not have had significant previous experience with hearing protectors. Potential subjects shall be questioned as follows:

a) Have you ever received one-to-one personal instruction in fitting of hearing protectors?

b) Within the past two years, have you attended a lecture on, or watched videotaped or computer-based instruction about how to fit hearing protectors?

c) Within the past two years, have you participated in an experiment designed to measure hearing protector noise reduction?

d) Within the past two years, on how many days have you worn any kind of hearing protector to protect yourself from noise, and for how many days have you worn ear-plugs while sleeping or swimming?

Potential subjects shall be rejected if they answer “yes” to questions (a), (b) or (c) or if in response to (d) they indicate use of any kind of ear-plugs for more than ten days or use of ear-muffs for more than two months.

5.1.4 Anatomical features

Subjects shall be selected without regard to sizes and shapes of heads, pinnae and ear canals. Subjects with features adversely affecting the fitting of hearing protectors, such as might arise from birth defects or ear surgery or personal adornment, shall be excluded.

5.1.5 Maximum hearing threshold levels

Subjects shall have pure-tone air-conduction hearing threshold levels no greater than 25 dB for all frequencies as measured separately in each ear by a Type 1 or Type 2 pure-tone audiometer complying with IEC 60645-1.

5.1.6 Minimum hearing threshold levels

Subjects should preferably have pure-tone air-conduction hearing threshold levels no less than 0 dB for all frequencies as measured separately in each ear by a Type 1 or Type 2 pure-tone audiometer complying with IEC 60645-1.

If test subjects' hearing threshold levels are better than 0 dB, the permissible background noise levels given in Table 2 shall be lowered accordingly.

5.1.7 Literacy

Subjects shall be able to demonstrate an understanding of the fitting instruction supplied with the hearing protector.

5.1.8 Threshold variability

Practice sessions of the audiometric procedure may be necessary for untrained subjects. Subjects shall provide three consecutive complete audiograms for the test signals given in 4.1. The difference between thresholds of hearing at corresponding centre frequencies shall not exceed 6 dB.

5.2 Number of subjects

At least sixteen subjects shall be used for each test on ear-muffs or ear-muffs attached to helmets. At least twenty subjects shall be used for each test on ear-plugs and on each test on a combination of an ear-plug and an ear-muff.

5.3 Otoscopic inspection

At the times of initial audiometric testing and subsequent noise reduction testing, the subject's ears, as determined by an otoscopic inspection, shall be free from impacted wax and there shall be no obvious signs of irritation or infection in areas of the head and ears that would be contacted by the hearing protector being tested.

5.4 Spectacles and jewellery

Spectacles, earrings or other devices likely to affect the ability of the hearing protector to make an acoustical seal shall not be worn during the test session.

5.5 Maximum number of tests per subject

Subjects who initially meet the requirements of 5.1.3 may participate in up to 30 separate subject-fit tests, each test consisting of two trials. Of those 30 tests, the total number permissible for ear-plugs and semi-aural inserts or both, shall not exceed 12, and there shall not be more than six tests on any one product.

As a condition of their participation in more than one noise reduction test, subjects shall receive no information about their performance on any test. If subjects inquire, they shall be reminded of the information statement in 7.2.

5.6 Exceptions

No subject who meets the requirements of 5.1 shall be excluded from tests unless

a) the subject’s ear canal will not accept a given ear-plug, or the ear-plug repeatedly falls out during testing [4)];

b) the subject is ill or physically unable to participate on the day of the test.

6 Product samples

6.1 General

A minimum of two samples of the hearing protector under test shall be used. The samples shall be evenly distributed among the subjects. For disposable ear-plugs, new protectors shall be provided for each test repetition and each subject shall wear a different pair.

6.2 Custom-moulded ear-plugs

A pair of ear-plugs shall be made in advance for each subject in accordance with the manufacturer’s instructions for the user normally accompanying the product.

NOTE Subjects who have participated in tests of custom-moulded ear-plugs should be regarded as having received one-to-one personal instruction in the fitting of hearing protectors and will be ineligible to participate in further tests (see 5.1.3).

6.3 Special requirements for product instruction

Products shall include complete on-package instructions in the same format as would be provided to a purchaser of the product. No additional instructions are permitted.

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4) If this occured in the workplace, it would be reasonable to expect that the devices would not be used for that particular individual. In the workplace, it would be considered a fitting difficulty and not an attenuation problem.

6.4 Variable position headbands

Some devices are intended for use with the headband in one of several positions such as under the chin, over the head or behind the neck. If it is intended to promote the use of such device through virtue of this feature of multi-position headband, noise reduction tests shall be carried out at all intended positions.

6.5 Variable band force

Hearing protectors with adjustments that allow the band force to be varied shall be set initially to the minimum of their adjustment range prior to being provided to each subject. The test subject will have to adjust it as per manufacturer's instruction.

7 Test procedure

7.1 Number of open-ear and occluded-ear threshold measurements

The individual noise reduction shall be measured on two trials during a single visit to the laboratory. Each trial shall consist of a paired open-ear and occluded-ear threshold. The order of the thresholds shall be counterbalanced across subjects. An example of the sequence of threshold testing is provided in Table 4.

Table 4 — Example of a counterbalanced threshold sequence

Trial no.	Half of the subjects	The other half of the subjects
1	*Fitting of the hearing protector* Occluded-ear threshold, then open-ear threshold	Open-ear threshold *Fitting of the hearing protector* then occluded-ear threshold
—	Rest period *without* hearing protection	Rest period *without* hearing protection
2	Open-ear threshold *Fitting of the hearing protector* then occluded-ear threshold	*Fitting of the hearing protector* Occluded-ear threshold, then open-ear threshold

The hearing protector shall be refitted for each trial. Although a rest period may be provided between trials, the subject shall not leave the chamber during a trial, i.e. between pairs of open-ear and occluded-ear thresholds.

Any recognized audiometric or psychophysical technique may be used to determine the threshold of hearing. The same technique shall be used to determine both the open-ear and the occluded-ear thresholds of hearing.

7.2 Information to subjects

The instructions given in the clauses below shall be followed in every detail. The *italicized passages* in quotation marks shall be read aloud in the appropriate language to the subject while he or she follows the text on a printed card. Subjects shall be informed about the test situation and procedure and told that they can withdraw from the test at any time for any reason.

The subjects shall be informed as follows:

> *"Because I do not want to influence the choices you will be making in the hearing protector evaluations, I cannot tell you any of your test results as long as you are a subject in this laboratory. After you complete your work as a participant on our panel, I will be pleased to share with you any of your results."*

7.3 Prior to entering the test room

The hearing protector, in the packaging in which it is intended to be sold, shall be placed on a table in front of the subject. If the hearing protector is supplied in several sizes, one pair of each size shall be placed on the table.

The subject shall be shown all available manufacturer's instructions on and inside the individual packaging or master dispenser. Whatever is necessary to follow the instructions shall be supplied.

If the hearing protector is a custom-moulded ear-plug and it is the manufacturer's condition of supply that a competent fitter must train the wearer to fit them, the fitter shall provide such training before the test is performed. However, the tester shall ensure that final pre-test fitting of the ear-plug is carried out by the subject without assistance of any kind from the fitter. If it is not the manufacturer's condition of supply that a competent fitter must train the wearer to fit them, fitting and testing of custom-moulded ear-plugs shall be carried out as for an ordinary ear-plug.

The subject shall be instructed as follows.

a) If the hearing protector is supplied in only one size or is a custom-moulded ear-plug:

   "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment.

   Please examine the manufacturer's instructions and fit and adjust the hearing protector to the best of your ability. I am not allowed to assist you in that process."

b) If the hearing protector is supplied in several sizes:

   "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment.

   Please examine the manufacturer's instructions, and then try these protectors on to find the size that is best for you. The size may be different for each of your ears.

   Please fit and adjust the hearing protector to the best of your ability. I am not allowed to assist you in that process."

The subject shall then fit and adjust the hearing protector without assistance of any kind from the experimenter or any other person.

When hearing protectors are tested that have headbands that can be worn in more than one position, such as over the head or behind the neck, the experimenter shall advise the subjects of the position to be utilized for the test being conducted.

Once the subject indicates that the fitting has been completed, he or she shall remove the hearing protector and enter the test room. The subject shall then be either seated for a quiet period (see 7.4.2) if the initial determination is the open-ear threshold, or instructed by the experimenter for the occluded-ear threshold determination (see 7.4.3).

7.4 Inside the test room

7.4.1 Positioning the subject

Throughout each threshold determination, the subject shall be seated so that his or her head is positioned correctly at the reference point (see 3.13). The subject shall be shown how to use any head-positioning device to maintain this position throughout the threshold determination.

7.4.2 Quiet period prior to first threshold determination

In order to allow for the accommodation to the test situation, the subject shall be seated in the test room, without talking to the experimenter and with no signals present, for a minimum of two minutes prior to the commencement of threshold determinations.

7.4.3 Fitting the hearing protector for test

7.4.3.1 Instruction

Immediately prior to determination of the occluded-ear threshold, the subject shall be instructed as follows:

> *"After I leave the room, please put on the hearing protector in the way you just practised. Refer to the manufacturer's instruction as needed.*
>
> *Let me know when you have the protector in place. I will then play noise through the loudspeaker(s) so that you can adjust the protector for good noise reduction.*
>
> *Once you indicate that you have completed fitting the protector, I will turn off the noise and there will be a one-minute quiet period to allow the protector to settle in place before the test begins. From the time the noise goes off, you must not touch or adjust the protector until you are asked to remove it at the end of the test.*
>
> *I will be able to visually observe you throughout the session. If the protector slips from your head or falls out of your ear or you feel it needs to be re-adjusted during the session, please signal me. Please also signal me if you hear any noise other than the signal sounds during the test.*
>
> *Please remember to maintain the same position throughout the test."*

If the manufacturers' instructions supplied with the hearing protector indicate that the device requires more than one minute to expand or conform to fit the test subject, the one-minute quiet period mentioned in the instruction above shall be adjusted accordingly (see also 7.4.3.2).

7.4.3.2 Fitting noise and final adjustment

When the subject indicates that the protectors are in place, the fitting noise shall be switched on to assist the subject to make final adjustments. The fitting noise shall consist of broadband noise with an overall A-weighted sound pressure level of about 65 dB.

When the subject has indicated that he or she has completed fitting the protector, the fitting noise shall be turned off and a quiet period (see 7.4.2) shall elapse before determination of the occluded-ear threshold begins. The duration of the quiet period shall be one minute unless the hearing protector under test incorporates 'slow release' material (e.g. slow recovery foam). In the latter case, occluded-ear threshold measurements shall begin a minimum of two and a maximum of four minutes after the hearing protector has been fitted, unless otherwise specified in the manufacturer's written instructions, in which case the time specified shall be followed.

7.4.4 Re-determination of thresholds

Re-determination of thresholds is permissible only in the abnormal situations defined below. Except in these situations, re-determination of thresholds shall not be made.

Defined abnormal situations are

a) the occurrence of distortion of the test signal or of extraneous noise at levels sufficient to cast doubt on the validity of the test result,

b) temporary indisposition of the test subject,

c) movement of the hearing protector to an extent that would, in ordinary circumstances of use, cause the wearer to readjust the position of the protector,

d) the subject, due to inattention or inability, provides a threshold which is clearly aberrant based upon the variability of a particular test at any given frequency.

If an abnormal situation occurs while a subject's threshold is being determined, the test shall be terminated and the threshold shall be re-determined after the abnormal situation has been rectified. Re-determination of thresholds shall not be made simply because the real-ear attenuation appears to be too high or too low.

If the re-determination is of the open-ear threshold of hearing, it shall commence from "Quiet period prior to first threshold determination", 7.4.2.

If the re-determination is of the occluded-ear threshold of hearing, it shall commence from "Fitting noise and final adjustment", 7.4.3.2.

8 Computation of noise reduction values

8.1 General

Experience shows that the individual noise reduction values often constitute a bimodal distribution, some values being small and other values being at their maximum. The validity of calculating statistical metrics that rely on a normal distribution, such as mean and standard deviation, may thus be doubtful. Nevertheless, the group noise reduction of the hearing protector is defined as the mean of the individual noise reductions.

In order to describe the data obtained with the present method, a histogram of the individual noise reductions shall be made. This histogram shall show individual data from both trials.

8.2 Calculation of the individual noise reductions

The individual noise reduction shall be computed at each test frequency by subtracting the open-ear threshold of hearing from the occluded-ear threshold of hearing. For each test subject, two individual noise reductions will be obtained, one from each of the two trials, i.e. the two open/occluded threshold differences.

8.3 Calculation of group noise reduction

The group noise reduction shall be computed at each test frequency as the mean of all the individual noise reductions from 8.2.

If the mean, $\bar{X}$, and standard deviation, s, of the individual noise reduction are calculated, the following formulae shall be used

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N} \qquad s = \sqrt{\frac{\sum_{i=1}^{N} d_i^2}{N-1}}$$

where

X_i is the individual noise reduction;

d_i is the difference between the mean and the individual noise reduction.

N is the number of measured individual noise reductions (typically two times the number of test subjects).

Additionally, the median value of the individual noise reductions from 8.2 shall be calculated at each test frequency.

8.4 Uncertainty of the noise reduction data

The uncertainty of results obtained from measurements according to this Technical Specification shall be evaluated in compliance with the BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML *Guide to the expression of uncertainty in measurement (GUM).* The expanded uncertainty together with the corresponding coverage factor for a stated coverage probability of 95 % as defined in the GUM shall be given. Guidance on the determination of the expanded uncertainty is given in Annex A.

9 Reporting of data

The test report shall include the following:

a) the type of hearing protector (replaceable parts of the hearing protector shall be described);

b) the individual noise reductions (see 8.2) and the group noise reduction according to 8.3;

c) the expanded uncertainty of the data;

d) statistical data that may be derived from the individual noise reductions, e.g. the mean and standard deviation, the median, appropriate centiles, and the range. Data on all subjects shall be incorporated in the calculations;

e) for each mode of testing (headband position, band force adjustment, see 6.4 and 6.5), the individual noise reductions (see 8.2) and the group noise reduction according to 8.3;

f) a reference to this Technical Specification (ISO/TS 4869-5);

g) the date(s) on which the tests were conducted;

h) the number of subjects used;

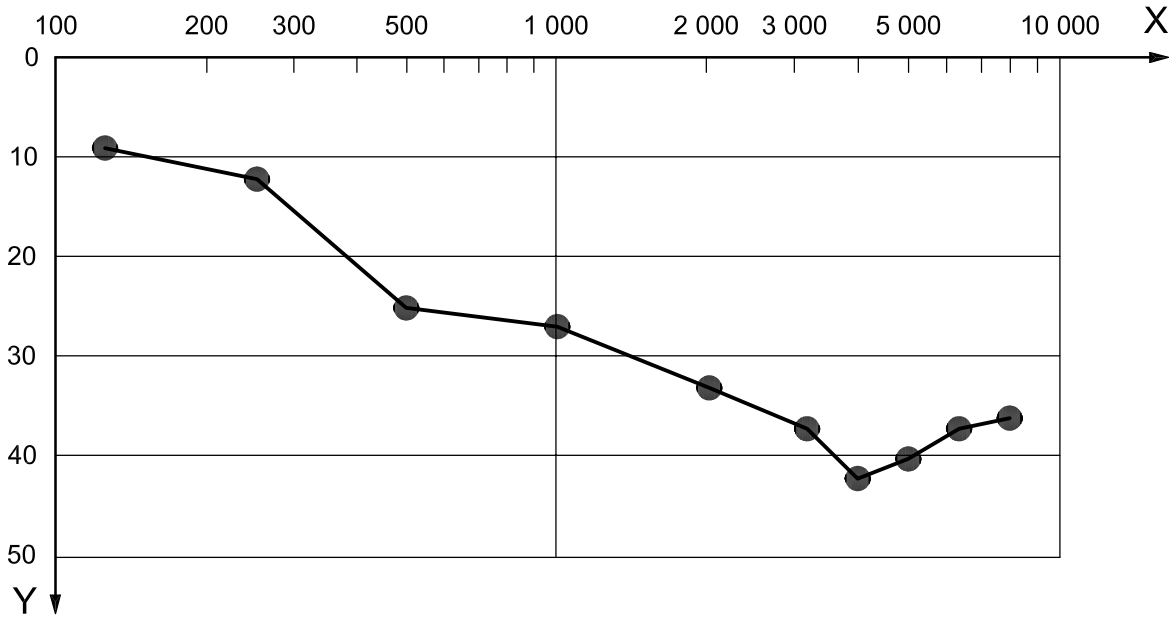
i) the number of samples of the hearing protector tested;

j) in the case of sized hearing protectors, the sizes that were tested and the number of subjects on which each size was tested;

k) a copy of the manufacturer's fitting instruction given to the subjects in the test;

l) the number of re-tests conducted, if any, and the reasons for each re-test (see 7.4.4).

When the noise reduction is presented in graphical form, the length of 50 dB shall equal the length of one decade according to IEC 60263. The noise reduction shall be plotted such that increasing values are directed downwards. An example is given in Figure 1.



Key

X frequency in hertz, Hz

Y noise reduction in decibels, dB

Figure 1 — Example of the group noise reduction for a hearing protector

Annex A
(informative)

Uncertainty of hearing protector noise reduction measurements

A.1 General

Uncertainties in the measurement of the noise reduction of a hearing protector according to this Technical Specification may arise from various sources, such as selection of the test subject group, fitting of the hearing protector on the test subjects, threshold determination of the subjects, the uncertainty in the measurement of the sound level measurements, the uncertainty in the test signal generators, etc.

A.2 Model

A general expression for the calculation of the group noise reduction, Y, is given by the following equation

$$Y = L_{\text{occ}} - L_{\text{open}} + \sum_{i=1}^{3} \delta_i \tag{A.1}$$

where

Y is the real group noise reduction;

L_{occ} is the mean hearing threshold level (from all subjects/trials) determined *with* the hearing protector; L_{occ} is subject to variations from the fitting of the protector, from the instruction given to the test subject, from the type of protector and from variability in the test subject:

L_{open} is the mean hearing threshold level (from all subjects/trials) determined *without* the hearing protector, i.e. the open ear threshold; L_{open} is subject to variability in the test subject;

δ_1 is an input quantity due to variability in the test subject group selection;

δ_2 is an input quantity due to deviations from an ideal random incidence sound field;

δ_3 is an input quantity due to uncertainties in the measurement equipment.

A probability function (normal, rectangular, etc.) is associated with each of the input terms on the right hand side of the equation. The mean value (= expectation value) of each of the terms on the right hand side is the best estimate of that term. The standard deviation of each of the terms is a measure of the dispersion of values, termed uncertainty. The mean value of each of the δ-terms is assumed to be zero. However, in any particular determination of a noise reduction, the uncertainties do not vanish and they contribute to the combined uncertainty associated with noise reduction determinations.

A.3 Uncertainty budget

The contributions to the combined uncertainty associated with noise reduction determinations, depend on each of the input quantities, their respective probability distributions and sensitivity coefficients, c_i. The sensitivity coefficients are a measure of how the values of individual noise reductions are affected by the changes in the values of the respective input quantities. In the model above, Equation (A.1), all sensitivity coefficients have a value of 1. The contribution of the respective input quantities to the overall uncertainty are then given by the products of the standard uncertainties and their associated sensitivity coefficients. Thus, the information needed to derive the overall uncertainty is illustrated in Table A.1.

Table A.1 — Uncertainty budget

Quantity	Estimate in dB	Standard uncertainty u_i in dB	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i c_i$ in dB
L_{open} (mean hearing threshold level without the hearing protector present)	$\overline{L_{open}}$	2	Normal	1	2
L_{occ} (mean hearing threshold level with the hearing protector present), muff	$\overline{L_{occ}}$	3	Normal	1	3
L_{occ} (mean hearing threshold level with the hearing protector present), plug	$\overline{L_{occ}}$	5	Normal	1	5
δ_1 (subject selection)	0	4	Normal	1	4
δ_2 (sound field)	0	0,5	Normal	1	0,5
δ_3 (equipment)	0	0,2	Normal	1	0,2

The standard uncertainty of the occluded hearing threshold is different for ear-muffs and for ear-plugs (rows 2 and 3 in Table A.1). The uncertainty figures supplied for ear-muffs and ear-plugs are estimated from measurements at the National Acoustic Laboratories, Australia, and from measurements at the National Institute for Occupational Safety and Health, USA. The standard uncertainty of the open-ear threshold is estimated from considerable experience at various test laboratories.

The standard uncertainty of the δ-terms remains to be established by research. Ongoing research will make an estimate of δ_1 available in the near future. The values of δ_2 and δ_3 are based on the experience obtained at various test laboratories around the world. The standard uncertainty figures supplied in Table A.1 are considered being representative of the measurements and equipment that would normally be used in hearing protector testing.

A.4 Expanded uncertainty

The combined standard uncertainty, u, of the determination of the noise reduction of a hearing protector is given by the equation:

$$u = \sqrt{\sum_i (u_i c_i)^2}$$

where

u_i is the standard uncertainty;

c_i is the sensitivity coefficient.

Thus, for the values in Table A.1, the combined standard uncertainty, u, is calculated to be

	Muffs	Plugs
Combined uncertainty	5,4 dB	6,7 dB

The *Guide to the expression of uncertainty in measurements (GUM)* requires an *expanded* uncertainty, U, to be specified, such that the interval [$Y - U$, $Y + U$] covers, e.g. 95 % of the values of Y that might reasonably be attributed to the noise reduction, Y. For this purpose, a coverage factor, k, is used, such that $U = k \cdot u$. For a confidence level of approximately 95 % and for normal probability distributions, the coverage factor k has a value of 2. Thus U will be two times u.

The expanded uncertainty of noise reduction measurements according to this Technical Specification is thus

	Muffs	**Plugs**
Expanded uncertainty, rounded to the nearest whole number	11 dB	13 dB

NOTE Some standard uncertainties can be obtained as statistical estimated standard deviations from the statistical analysis of a series of observations (referred to as type A evaluation of standard uncertainty in the *GUM*). Such estimations may be included in this Technical Specification at a later stage.

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