INTERNATIONAL STANDARD

ISO 16832

First edition
2006-08-01

Acoustics — Loudness scaling by means of categories

Acoustique — Mesurage de la sonie par échelles de catégories

Reference number
ISO 16832:2006(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 16832 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

Introduction

The assessment of loudness function based on category loudness scaling is used when the evaluation of hearing is not only necessary at the boundaries of the auditory sensation area (threshold of hearing, uncomfortable level), but for a knowledge over the entire individual auditory sensation area.

Important fields of use are diagnostic evaluations, especially the evaluation of recruitment and fitting of hearing instruments.

Since the results of loudness scaling can markedly depend on the exact procedure used, this International Standard sets the conditions for reliable measurement methods.

Acoustics — Loudness scaling by means of categories

1 Scope

This International Standard specifies basic methods for scaling loudness into categories for audiological applications.

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 8253-1:1989, *Acoustics — Audiometric test methods — Part 1: Basic pure tone air and bone conduction threshold audiometry*

ISO 8253-2:1992, *Acoustics — Audiometric test methods — Part 2: Sound field audiometry with pure tone and narrow-band test signals*

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

3 Terms and definitions

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

3.1
loudness
auditory sensation in terms of which sounds can be ordered on a scale extending from soft to loud

NOTE Loudness depends primarily upon the sound pressure of the stimulus, but also depends upon its frequency, bandwidth, waveform and duration; see IEC 60050[4].

3.2
category
one of an exhaustive set of classes among which loudness sensations can be distributed

3.3
category scale
ordering of a loudness sensation by means of categories

NOTE 1 The scale should contain a middle category and an equal number of categories above and below the middle category.

NOTE 2 Perceptively equidistant categories should be used (for an example, see Annex A).

3.4
category loudness scaling
method whereby the test subject judges the loudness of a presented stimulus on a category scale

NOTE Verbal categories only describe loudness (for an example, see Annex A).

3.5

response alternatives

choices available to the test subject in the rating scale

NOTE 1 The number of response alternatives may be larger than the number of categories on the category scale.

NOTE 2 If verbal categories are used, the number of response alternatives should be larger than the number of categories.

3.6

presentation level

sound pressure level at which the signal is presented

NOTE The number of presentation levels can be different from the number of categories and the number of response alternatives.

3.7

dynamic range of hearing

difference between the highest stimulus level that is judged by the category “not heard” and the lowest stimulus level that is judged by the category “extremely loud” for a specific auditory stimulus

3.8

auditory sensation field

region defined by the dynamic range of hearing across the audible frequency range

NOTE Because the auditory sensation area, according to IEC 60050[4], is enclosed by the threshold of pain, the necessity for the additional definition of the auditory sensation field was seen in order to define the actual measurement range.

3.9

loudness function

function describing the relation between the signal level and the corresponding loudness

3.10

familiarization

process of orienting the subject with the range of possible loudness magnitudes, the response alternatives and the procedure

NOTE Within this range, stimuli are perceived absolutely with respect to their magnitude, i.e. without any perceived relation, e.g. very loud or soft. The state of being familiarized may have its origin by past experience or actual presentation of the range of loudness magnitudes.

4 Category loudness scaling procedure

4.1 General

The purpose of the category loudness scaling is to evaluate the loudness function of a test subject. Therefore, signals with different levels are presented to the test subject who shall judge the loudness on a category scale. The description of the scale can be verbal, numerical or symbolic. When verbal descriptions are used, preferably, the name of the middle category is “medium”, the names of the boundary categories are “not heard” and “extremely loud”. These categories can be transformed to a scale ranging, for example, from 0 to 50. In this case, “0” on the scale corresponds to “not heard”, “25” corresponds to “medium” and “50” corresponds to “extremely loud” (see Annex A).

4.2 Procedure for assessment

4.2.1 Preparation and instruction of test subject

In the preparation and instruction of test subjects the requirements given in ISO 8253-1:1989, 5.1 and 5.2 apply. For other conditions for the audiometric tests, follow the procedures given in ISO 8253-1:1989, Clause 4, as applicable.

NOTE An example of the instruction is: “During the following examination you will hear signals (e.g. sounds, tones) that differ in loudness (and pitch). Following each presentation, please indicate how loud the signal (the sound, the tone) is.”

In addition, the loudness categories shall be explained. The rating scale consisting of the response alternatives shall be presented to the test subject during the test. The response alternatives shall contain at least all used verbal or numerical categories. It should have provisions to make finer judgements between verbal categories. Statistical analysis has shown that a minimum of 11 response alternatives is recommended.

4.2.2 Training and familiarization

The preparation and instruction is followed by a training and familiarization phase, in which the test subject should hear levels over the whole dynamic range. This phase trains the subject and confirms the expectations induced by the scale (between “not heard” and “extremely loud”). This phase avoids biases caused by the first trials that do not cover the whole dynamic range. The phase ends when the test subject is judged to be ready for a valid test.

4.2.3 Test

During the test, signals are presented to the test subject at all presentation levels. The range of presentation levels should cover the individual dynamic range of hearing. An estimation of the dynamic range can be derived from the results of the training phase (for an example, see Annex A).

After the presentation of a stimulus, the test subject shall indicate the loudness of the signal.

Each test signal shall be presented at at least five levels. These presentation levels shall be distinguishable and should cover the whole dynamic range.

NOTE 1 In reasonable cases, exceptions can be made. Examples are tests with children or with test subjects with extremely narrow residual dynamic range.

The presentation levels should be sequenced in a non-systematic way (pseudo-randomized). To avoid obtaining judgements biased by the previous signal, two subsequent signals should be clearly different. These signals should be as different as possible without confusing the test subjects (e.g. by variation of presentation level and/or frequency). To ensure that the test subject stays familiarized during the whole test, the dynamic range of hearing should be covered fully during short groups of subsequent presentations.

When the whole auditory sensation field is to be tested with narrow band signals, tests at at least four different centre frequencies are required.

NOTE 2 Preferred standard centre frequencies are 500 Hz, 1 kHz, 2 kHz and 4 kHz.

4.3 Test signal characteristics

The duration of the test signals shall be at least 1 s. However, the signal may be switched off immediately if the response of the test subject is “extremely loud”. The rise and fall times of the signal must comply with IEC 60645-1:2001, 8.6.3.

In loudness scaling, narrow band signals shall be used. This includes filtered noise and warble tones. The bandwidth of the signals shall not exceed one-third octave. To measure frequency-dependent effects, the filter slope of the narrow band signals shall exceed 36 dB per octave. The filter slope of the test signals limits the

application of the method. For subjects with steeply sloping hearing losses, a filter slope of at least 80 dB per octave is recommended.

Whenever other signals are used, e.g. in cochlear-implant patients, they shall be specified in detail.

4.4 Test room and equipment

4.4.1 Transducers

Signal presentation may be via a loudspeaker, an earphone or, if neccessary, a cochlear implant.

4.4.2 Test room

For sound field audiometry, the ambient noise levels in the test room must comply with ISO 8253-2:1992, Clause 6.

Sound field conditions shall be in accordance with ISO 8253-2:1992, Clause 5.

If pure tones are used in a free sound field, that sound field shall be in accordance with the specifications given in ISO 8253-2:1992, 5.1.

For signal presentation via earphone, the test room shall comply with the requirements given in ISO 8253-1:1989, 4.6.

4.4.3 Equipment

The test equipment shall comply with the general requirements given in IEC 60645-1:2001, Clause 5.

5 Evaluation of the category loudness scaling

5.1 Determination of reference values

To estimate a reference loudness function for each method, loudness scaling tests must be performed for a sufficiently large group of normal hearing subjects (number of subjects > 20). For each response alternative, median values of the corresponding levels shall be calculated. These points reflect the form of the loudness function. Then a loudness function is fitted to these points giving a reference loudness function (for an example, see Clause A.6). The interquartile range of the levels used to calculate the median value is given as the reference range. The reproducibility of the test method may be checked by conducting the tests at least two times with a time gap of at least one week with a control group of normal hearing test subjects (number of subjects > 20).

5.2 Numerical and graphical presentation of the results

The rating scale should be transformed into a numerical scale by an appropriate monotonically increasing function. A 51-point scale is recommended. The relation between the scales should be given.

To provide a comparable aspect ratio in the graphical presentation of the results, the full loudness scale should be the same length as that of a 50 dB-range on the level axis (for examples, see Clause A.6).

The function related to loudness should be approximated with a straight line, lines or a curve that best fits the measured data points in order to interpret the results.

For the interpretation of the function related to loudness, all data points should be given. Levels should be given as sound pressure levels in decibels. Alternatively, the results of the loudness scaling can be presented as equal loudness level contours.

6 Test report

The test report shall contain identifying information including date of birth of the tested subject, sex, date of the test, identification of the examiner, information about the test signals and the number and manner of presentations, and a description of the scale.

The test report shall contain the location of the test, the type of test room, and a list of the presented signal sequence containing information about the presentation level and the responses of the test subject to the respective signal.

Graphical presentations should comply with 5.2.

Annex A
(informative)

Example of a reference method

A.1 General

NOTE See Reference [7].

In the standard loudness scaling procedure, one-third-octave narrow band noises with a duration of 1 s are presented. After signal presentation, loudness judgement is given on the scale shown in Table A.1. The next presentation is given only after a judgement by the subject has been made.

A.2 Description of the adaptive level adjustment

In order to achieve a fast and reliable estimation of the loudness function of a signal, presentation levels should be distributed such that the subject's judgements equally cover the whole category scale. This can be achieved by a two-phase adaptive level adjustment procedure. In the first phase, the subject's individual dynamic range is estimated coarsely by a few signal presentations. This phase should also provide the subject's familiarization. Starting with medium levels, the dynamic range is "stretched" to lower and higher levels, respectively.

In the second phase of the adaptive procedure, at least five levels are equally distributed over the estimated hearing range based on the estimations of the threshold of hearing and the level that is judged by the category "extremely loud" from phase I (see Clause A.3). In contrast to any "constant" procedures, the dynamic range of the presentation levels is not fixed during the test, but the five levels are constantly being re-distributed based on the actual estimation of the loudness function. This procedure helps to avoid any negative impact on the course of the test from the initial estimation of the function related to loudness.

A.3 Phase I — Estimation of the dynamic range

The first presentation is usually at a sound pressure level of 65 dB, which can be heard by most subjects without being perceived as "extremely loud". If this presentation level is judged as "not heard", the level is raised in 15 dB-steps until the sound is perceived. If the first presentation is judged "extremely loud", the level shall be lowered in an analogous manner. If a level within the dynamic range is found with this method, then present the following two level sequences alternately.

Within the first sequence, the level is raised until the presentation is judged with the highest category ("extremely loud") or equipment limitations preclude higher presentation levels. The step size is 10 dB below a sound pressure level of 90 dB and 5 dB above 90 dB. The final level of this sequence is taken as preliminary estimation of the level corresponding to "extremely loud" for the second part of the procedure.

Within the second sequence, the level is lowered by 15 dB-steps until the signal is judged as "not heard". Then the level is raised by 5 dB-steps until the signal becomes audible again. The final level of this sequence is used as a preliminary estimation of the threshold of hearing for the second part of the procedure.

Phase I may be skipped if the dynamic range of the test subject is known from previous tests.

A.4 Phase II — Calculation of levels

After the coarse estimation of the threshold of hearing and the level corresponding to "extremely loud" during the first phase, at least five levels are calculated that should lead to loudness ratings of 5 ("very soft"), 15 ("soft"), 25 ("medium"), 35 ("loud") and 45 ("very loud") based on the preliminary estimation of the loudness function. These levels are presented in a pseudo-randomized sequence. In the randomization, level differences that exceed half of the actual estimated dynamic range shall be avoided. Following this, a new estimation of the

loudness function is calculated based on all subject's responses so far, including the responses in phase I of the procedure, thus giving five new presentation levels. This procedure is repeated several times depending on the test accuracy to be yielded. In the standard procedure, three iterations are performed.

There are a few exceptions to the procedure described for phase II, e.g. the lowest level in the first group of five may be left out since a level just above the threshold of hearing was presented shortly before in phase I. Further, there are means to prevent uncomfortably loud presentation levels: if a level is judged “extremely loud”, the maximum presentation level, L_{max}, should be set to that level. Even if the actual estimation of the level corresponding to “extremely loud” is higher, subsequent presentations should be at levels below L_{max}. Since the relatively modest levels that the subjects quite often judge as “extremely loud” in the beginning might not seem so uncomfortably loud later on in that test, L_{max} should not be kept constant during the entire test. Therefore, the maximum presentation level should be raised by 5 dB if a presentation at L_{max} is not judged as “extremely loud” again.

A.5 Example of a rating scale

The rating scale as shown in Table A.1 consists of 11 response alternatives, including seven verbal categories and four additional response alternatives marked by lines. The verbal categories are named “very soft”, “soft”, “medium”, “loud” and “very loud”. The boundaries of the scale are formed by the categories “not heard” and “extremely loud”. The response alternatives are equally spaced and are transformed into the 51-point numerical scale.

Table A.1 — Representation of the categories and response alternatives relative to the 51-point numerical scale[a]

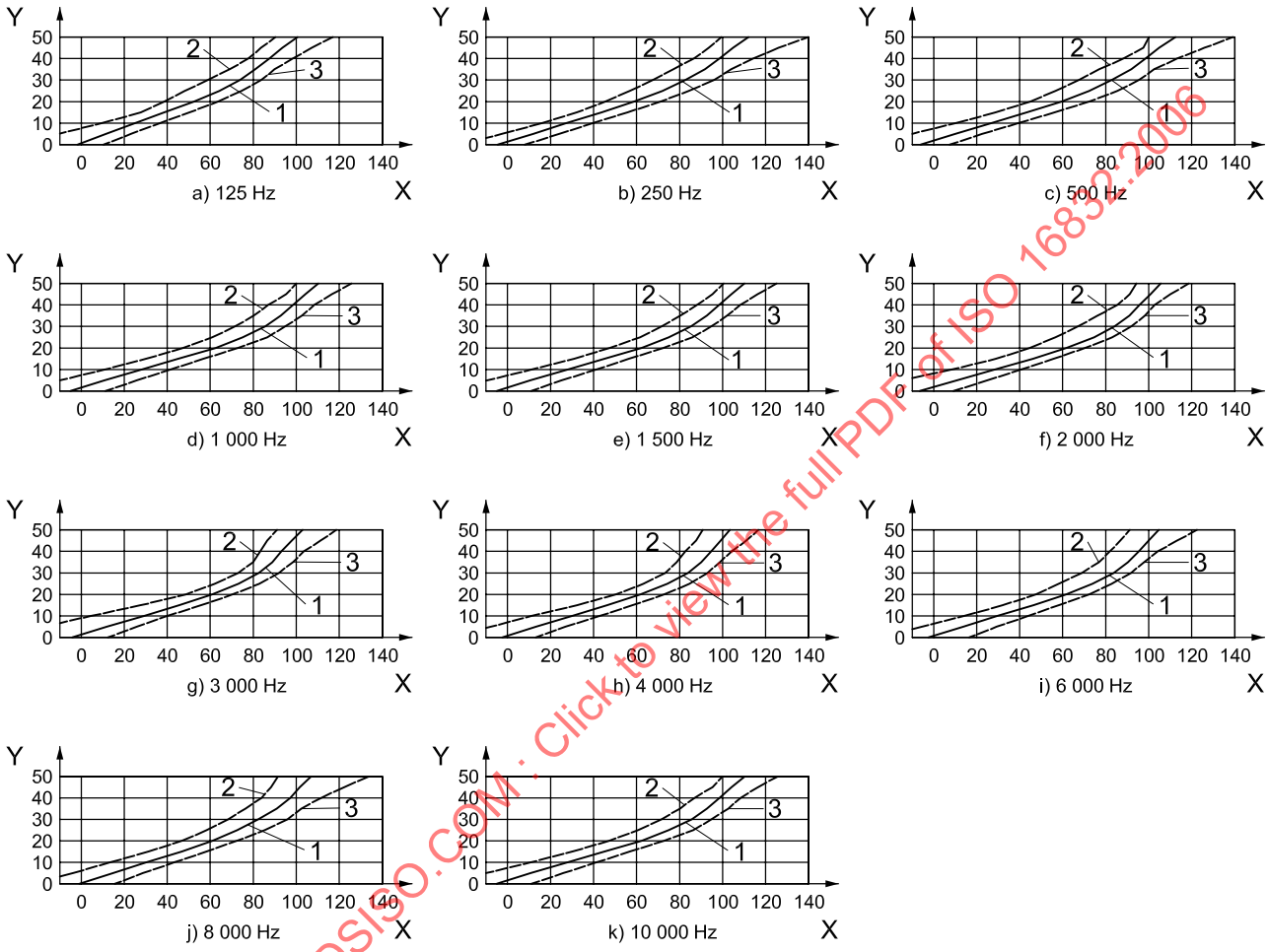
Categories	Response alternatives	Numerical scale value
Extremely loud	extremely loud	50
Very loud	very loud	45
	------ [b]	40
Loud	loud	35
	----- [b]	30
Medium	medium	25
	--- [b]	20
Soft	soft	15
	- [b]	10
Very soft	very soft	5
Not heard	not heard	0

[a] Adopted from Reference [7] by permission of the author.

[b] Intermediate response alternatives.

A.6 Typical results

Figure A.1 shows typical results yielded with the method given in this Annex for 22 normal-hearing listeners (aged 16 years to 42 years, median age 25 years). Both ears of each subject were tested monaurally. Signals were one- third-octave noises centred around 125 Hz, 250 Hz, 500 Hz, 1 kHz, 1,5 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 10 kHz, respectively. Signals had a duration of 1 000 ms and were presented monaurally via Sennheiser HDA 200 headphones[1)].



Key

X hearing level, expressed in decibels
Y loudness
1 mean
2 5th percentile
3 95th percentile

Figure A.1 — Typical loudness functions yielded with the measurement method given in this Annex

1) Sennheiser HDA 200 headphones is an example of a suitable 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.

Annex B
(informative)

Sample level sequences

Although the randomization of levels is an important issue in order to avoid bias in the results, test of loudness scaling shall be possible without computer-controlled equipment. Therefore, this annex gives several non-monotonous level sequences for different dynamic ranges. The individual dynamic range can be estimated, e.g. from pure tone audiograms.

Table B.1 — Sample level sequences for different dynamic ranges

Dynamic range dB	Sound pressure levels dB				
	Level 1	Level 2	Level 3	Level 4	Level 5
20-90	40	20	55	90	70
20-90	20	55	40	70	90
30-90	30	45	90	60	75
30-90	45	30	75	60	90
40-90	55	75	40	90	65
40-90	40	65	55	75	90
50-90	70	50	80	60	90
50-90	60	80	50	90	70
60-90	70	80	75	90	60
60-90	75	60	80	70	90

Annex C
(informative)

Illustration of loudness scales

Figure C.1 illustrates how a stimulus with specific characteristics including a specific sound pressure level causes a “loudness” sensation on an internal continuous “loudness” scale. This continuous sensation is then divided internally into categories, which build up a category scale. The sensation is judged by selecting one of the categories. The response is given by selecting one of the response alternatives. Seven of the response categories are verbally named, four are represented by lines of different lengths. The subjects select the response alternative that corresponds to their loudness category. This response alternative is transformed to a numerical representation.

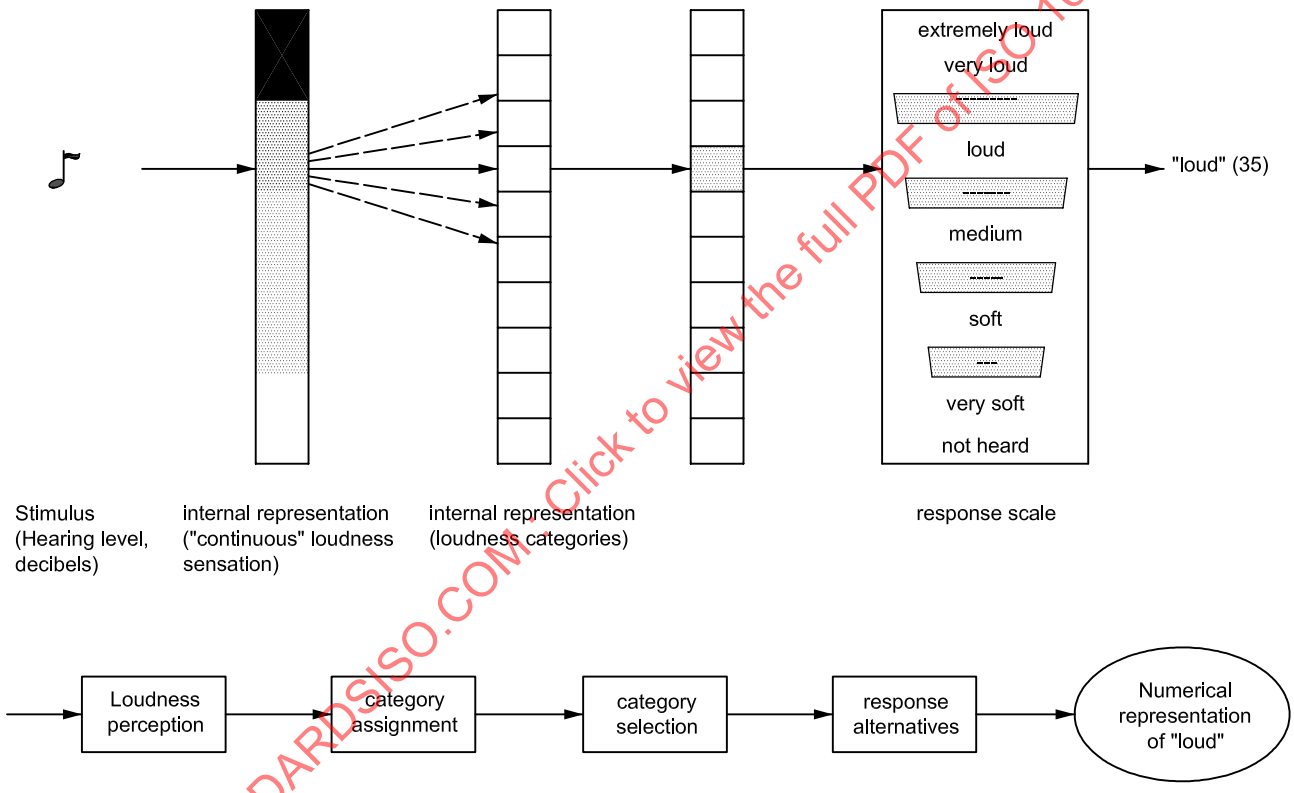


Figure C.1 — Relation between the “internal” loudness scales and the “external” response scales and their representations