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Acoustics — Soundscape —

Part 3: **Data analysis**

Acoustique — Paysage sonore —

Partie 3: Analyse de données

Reference number
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Foreword

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This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise.*

A list of all parts in the ISO 12913 series can be found on the ISO website.

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

Introduction

The ISO 12913 series on soundscape was developed in order to enable a broad international consensus and to provide a foundation for communication across disciplines and professions with an interest in soundscape. ISO 12913-1 provides the definition of and a conceptual framework for the term 'soundscape'. ISO/TS 12913-2 provides requirements and supporting information on data collection and reporting for soundscape studies, investigations and applications. This document provides guidance on how to analyse data collected in agreement with ISO/TS 12913-2.

Acoustics — Soundscape —

Part 3:
Data analysis

1 Scope

This document provides requirements and supporting information on analysis of data collected in-situ through methods as specified in ISO/TS 12913-2.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 12913-1, *Acoustics — Soundscape — Part 1: Definition and conceptual framework*

ISO/TS 12913-2:2018, *Acoustics — Soundscape — Part 2: Data collection and reporting requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12913-1 and ISO/TS 12913-2 and the following apply.

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

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

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

3.1
confounder
factor influencing the collected responses that is not controlled or systematically considered

EXAMPLE Sequential effect, certain scaling effects like the range effect, or demand characteristics.

4 General

As mentioned in the Introduction of ISO/TS 12913-2:2018, "*The concept of soundscape was adopted to provide a holistic approach to the acoustic environment, beyond noise, and its effect on the quality of life. Soundscape investigations intend to assess all sounds perceived in an environment in all its complexity. To do this, soundscape studies use a variety of data collection methods related to human perception, the acoustic environment and the context. Importantly, the study of soundscape relies primarily upon human perception, and only then turns to physical measurement.*" Data collection is based on this focus and requires a respective analysis (see References [1],[2]).

For the analysis of qualitative and quantitative data through methods specified in ISO/TS 12913-2, methods and tools shall be applied as provided in this document. Given the diversity of the data collected (qualitative and quantitative), corresponding analysis methods could take precedence depending on the needs of the project or the research question, and should be integrated for a holistic understanding of the soundscape. In general, descriptive statistics are used to describe and summarize the collected perceptual data, such as measures of central tendency, measures of dispersion (see Reference [3]).

For quantitative measures of dependence, inferential statistics using parametric and non-parametric tests shall be applied depending on the respective data. Fulfilment of model assumptions (e.g. normality distribution) shall be carefully assessed, especially in the case of small numbers of participants. If needed, appropriate remedial measures shall be applied. However, as soundscape investigations are intended to be "holistic in covering all auditory sensations as well as all other context variables such as visual stimuli and personal expectations" [ISO/TS 12913-2], the use of statistical analysis methods (e.g. statistical hypothesis testing) is recommended, but may be less important in case of qualitative or explorative methods. For qualitative data, a variety of approaches are available to systematically analyse qualitative data using some kind of step by step coding principles to generalize the observations. In addition, soundwalks are a method for bringing diverse parties together and provide a common basis for communication.

Because of factors that could influence results, a thorough discussion of potential confounders (i.e. bias effects) shall complete the general data analysis. Confounders are, for example, the sequential effect (a previous site influences the assessments of the following site) (see Reference [4]) certain scaling effects, like the range effect (tendency to use full range of a scale independent from stimuli set) (see Reference [5]), or demand characteristics (cues, like the instruction text or the behaviour of the person leading the soundwalk, that signal the research goal and influence assessments) (see Reference [6]).

NOTE Based on the collected data, it is possible to study classification of sites. For the study of classification of sites, different statistical clustering methods are available, which allows for identifying relevant variables for clustering and determining the similarity or dissimilarity of sites.

5 Analysis of quantitative data

The quantitative data obtained by means of questionnaires in soundscape investigations shall be analysed depending on the respective level of measurement (i.e. nominal, ordinal, interval, and ratio). Any correlation analysis shall be chosen in accordance with the level of measurement of the questionnaire data. Inferential statistical tests regarding the level of significance of differences in evaluation between sites and/or correlations shall be carried out and probability values reported. Any chosen method (e.g. measure of central tendency, measure of dispersion, correlation analysis, and statistical hypothesis testing method) shall be reported. For more information, see Annex A (Method A) and Annex B (Method B).

6 Analysis of qualitative data

Data from qualitative interviews shall be transcribed for reporting and further analysis. The style of transcription, whether clean read, verbatim or strict verbatim transcription, depends on the object of the investigation. For the analysis via the Grounded Theory, the clean read transcription style is sufficient. Violations of common rules for conducting interviews (ethical rules, being suggestive, being prejudiced) shall be reported, and the related data excluded from further analysis.

Qualitative data shall be analysed by scientifically proven systematic text analysis methods, such as the Grounded Theory (see Reference [7]), Qualitative Content Analysis (see Reference [8]) or Social Network Analysis as part of mixed-methods design (see Reference [9]). The process of analysis shall follow these methods and be described. For more information, see Annex C.

In addition to established text analysis methods, other methods to gather and analyse qualitative data (such as behavioral mapping, observational analyses, analysis of social interaction, walking patterns; see examples in References [61], [62], [63], [64]) are available and, if determined appropriate in certain cases, shall be applied.

7 Analysis of binaural data

The binaural recordings are the basis for characterizing the acoustic environment at the receiver as the sound from all sound sources modified by the environment [ISO 12913-1]. The measurements and their psychoacoustic analyses enable the determination of the (basic) auditory sensations evoked by the sound. Any binaural recording shall be equalized for the analysis as specified in ISO/TS 12913-2, approximating a monaural microphone measurement.

After applying the recording equalization, the remaining signals of the left and right channels are separately processed to determine (psycho-)acoustic metrics.

The different metrics used (e.g. $L_{\text{Aeq},T}$, $L_{\text{Ceq},T}$, $L_{\text{AF5},T}$, $L_{\text{AF95},T}$, N_5, N_{95}, N_{rmc}, S_{50}, IACC) shall be linked to the perception and the assessment of the concerned people [ISO/TS 12913-2]. In general, the consideration of acoustic analysis results shall provide a basis for the evaluation and classification of soundscapes by complementing the perceptual data. Moreover, based on the results of the binaural data analysis, given sufficient position data, maps based on psychoacoustic and other data can be determined. For more information, see Annex D.

8 Triangulation

The general idea of triangulation is to achieve a higher level of validity if different methods applied lead to the same result and hierarchical agglomerative clustering complement each other. Triangulation for soundscape measurement is a technique that facilitates validation of data through cross verification of three components: people, context and acoustic environment. In particular, it refers to the application and combination of several research methods in the study of the same phenomenon. For more information, see Annex E.

Annex A
(informative)

Analysis of data related to Method A

A.1 General

Method A, described in C.3.1 of ISO/TS 12913-2:2018, consists of category scales containing five response categories.

A.2 Determination of central tendencies of responses

For the analysis of the collected responses by means of Method A as described in C.3.1 of ISO/TS 12913-2:2018, numbers shall be assigned to the response categories of the category scales as follows.

The five response categories of questionnaire part 1 (see Figures C.2 and C.3 of Annex C of ISO/TS 12913-2:2018) from left ('not at all') to right ('dominates completely') are assigned scale values from 1 to 5.

The five response categories of questionnaire part 2 (see Figure C.4 of Annex C of ISO/TS 12913-2:2018) from left ('strongly agree') to right ('strongly disagree') are assigned scale values from 5 to 1.

The five response categories of questionnaire part 3 (see Figure C.5 of Annex C of ISO/TS 12913-2:2018) from left ('very good') to right ('very bad') are assigned scale values from 5 to 1.

The five response categories of questionnaire part 4 (see Figure C.6 of Annex C of ISO/TS 12913-2:2018) from left ('not at all') to right ('perfectly') are assigned scale values from 1 to 5.

For all category scales, the level of measurement is ordinal, which means that the median values should be reported as the measure of central tendency, and the range as the measure of dispersion. See Table A.1.

Table A.1 — Assigned scale values to rating scales of Method A and statistical measures

Part (see ISO/TS 12913-2)	Scale values to be assigned	Measure of central tendency	Measure of dispersion
1 (sound source identification)	1 ,2 ,3, 4, 5	median	range
2 (perceived affective quality)	5, 4, 3, 2, 1	median	range
3 (assessment of surrounding sound environment)	5, 4, 3, 2, 1	median	range
4 (assessment of the appropriateness)	1, 2, 3, 4, 5	median	range

A.3 Determination of two soundscape dimensions based on perceived affective quality responses

Environmental psychologists have repeatedly demonstrated that when people are asked to freely describe how they perceive environments they respond affectively (see Reference [10]).

These affective responses can be represented in a two-dimensional model where the main dimension is related to how pleasant or unpleasant the environment was judged, and therefore noted as pleasantness. The second dimension is related to the amount of human and other activity (see

Reference [11]). For soundscape, this second dimension is represented by how eventful or uneventful the acoustic environment is perceived to be, and therefore noted as eventfulness (see Reference [12]). An eventful environment is busy with human activity, for example a city centre or other sound events produced by non-human agents, whereas an uneventful environment is completely devoid of human activity, for example a wilderness area or during late evening hours in a residential area without social, commercial and industrial activity. If the previously mentioned pleasantness and eventfulness axes are taken as perpendicular, further labelling corresponding to human judgments can be prescribed to two additional axes rotated 45°on the same plane. At a rotation of 45° from the two main dimensions, are two alternative dimensions representing environments that are chaotic and stressful versus calm, and environments that are monotonous and dull versus vibrant and exciting (see References [12] and [13]). According to the two-dimensional model, vibrant soundscapes are both pleasant and eventful, chaotic soundscapes are both eventful and unpleasant, monotonous soundscape are both unpleasant and uneventful, and finally calm soundscapes are both uneventful and pleasant.

NOTE Based on the tradition in environmental noise research, the term 'annoying' is used instead of 'unpleasant' in the model used in this document. However, some sociological models ascribe a stronger sense of intentionality to sounds that are annoying compared to those that are unpleasant.

The results from part 3 (see A.1) are further processed to derive the values on two dimensions (pleasantness and eventfulness) for each site. Results can be reported in a two-dimensional scatter plot with coordinates for the two dimensions 'pleasantness' and 'eventfulness' (see Figure A.1). The coordinates for 'pleasantness' are plotted on the X-axis, and the coordinates for 'eventfulness' on the Y-axis. Every data point in the scatter plot represents one investigated site.

The coordinate for pleasantness P is calculated by means of Formula (A.1):

$$P = (p - a) + \cos 45° \cdot (ca - ch) + \cos 45° \cdot (v - m) \quad \text{(A.1)}$$

The coordinate for eventfulness E is calculated by means of Formula (A.2):

$$E = (e - u) + \cos 45° \cdot (ch - ca) + \cos 45° \cdot (v - m) \quad \text{(A.2)}$$

where

a is annoying;

ca is calm;

ch is chaotic;

e is eventful;

m is monotonous;

p is pleasant;

u is uneventful;

v is vibrant.

In Formulas (A.1) and (A.2), cos45° is used as a weighting function to adjust for the 45° rotation in the two-dimensional model (Figure A.1). The range of the coordinates that results from the formulas is $\pm\left(4+\sqrt{32}\right)=\pm 9{,}66$. To change the range to ±1, divide the coordinates by $\left(4+\sqrt{32}\right)$.

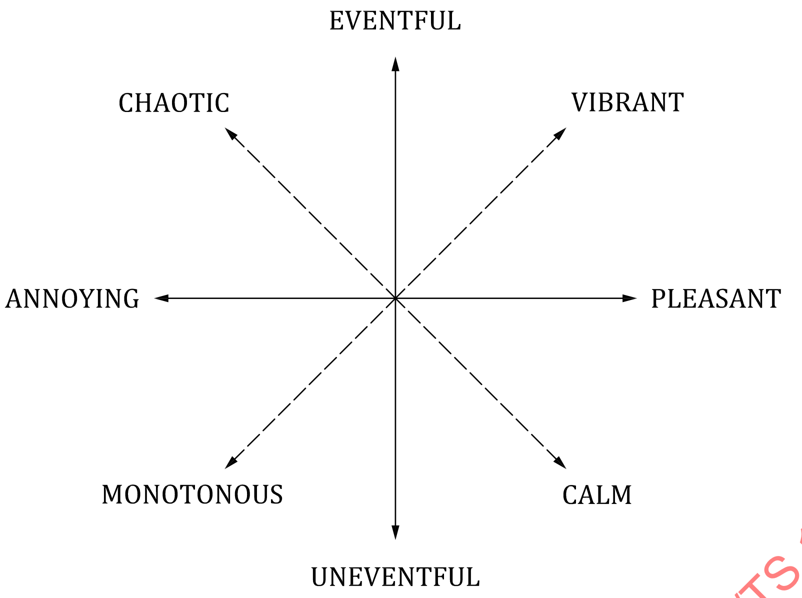


Figure A.1 — Graphical representation of Formulas (A.1) and (A.2)

NOTE The generality of the two-dimensional model is still under examination (see for example Reference [65]) and it is noted that the two-dimensional model requires further validation across languages and sites.

A.4 Link of Method A results to acoustic data

Rating data collected via questionnaires should be linked to the results of the acoustic data analyses in order to identify potential relationships (see References [14] and [15]). These relationships may be investigated by means of statistical analyses, such as correlation analyses, linear regression or ANOVA (see References [47]). The adequate correlation analysis depends on the level of the measurement scale (e.g. ordinal vs. interval). For ordinal data, the Spearman's rank correlation coefficient, r_{spearman}, should be calculated (see Reference [16], [46], and [60]) using Formulas (A.3) and (A.4).

$$r_{\text{spearman}} = 1 - \frac{6 \cdot \sum_{i=1}^{n} d_i^2}{n \cdot \left(n^2 - 1\right)} \quad \text{for untied ranks} \tag{A.3}$$

$$r_{\text{spearman}} = \frac{2 \cdot \left(\frac{n^3 - n}{12}\right) - T - U - \sum_{i=1}^{n} d_i^2}{2 \cdot \sqrt{\left(\frac{n^3 - n}{12} - T\right) \cdot \left(\frac{n^3 - n}{12} - U\right)}} \quad \text{for tied ranks} \tag{A.4}$$

where

d_i is the difference in paired ranks;

n is the number of cases;

$$T = \frac{\sum_{j=1}^{k(x)} \left(t_j^3 - t_j\right)}{12};$$

$$U = \frac{\sum_{j=1}^{k(y)} \left(u_j^3 - u_j\right)}{12};$$

t_j is the number of in t_j tied ranks of the variable x;

u_j is the number of in u_j tied ranks of the variable y;

$k(x)$ and $k(y)$ are the numbers of tied ranks of the variables x and y.

The determined correlation coefficient should be reported as a numerical measure of statistical relationship between two variables. In addition, the statistical significance of the correlation should be determined, and the probability value reported.

Annex B
(informative)

Analysis of data related to Method B

B.1 General

Method B, described in C.3.2 of ISO/TS 12913-2:2018, consists of five-point unipolar continuous-category scales, a ranking test and free words data, which should be separately analysed. The free words data refer to method B as described in C.3.2 of ISO/TS 12913-2:2018 where, after listening, the soundwalk participants are requested to write down their thoughts and feelings while still at the specific location.

B.2 Determination of central tendencies of responses

Part 1 (assessment of the sound environment — ISO/TS 12913-2:2018, Figure C.7)

The responses on the five-point unipolar continuous-category scales are assigned the scale values from 1 to 5 in dependence of the marked point on the scale (see Table B.1). The values used for analysis shall be determined at least with one decimal place. This shall be done by using a ruler and measuring the position of the marked point on the scale with the accuracy of one decimal point or, in case of assessments digitally collected on a computer screen, by determining the marked point on the scale with the accuracy of one decimal point (rounded). The level of measurement is interval (see Reference [17]), which means that the arithmetic mean value for each site should be reported as the measure of central tendency. For each determined arithmetic mean value, the standard deviation and the 95 % confidence interval should be calculated. However, the ratings may not represent an interval scale, and statistics for an ordinal scale level may be additionally applied.

NOTE If considered to provide further information, other measures of central tendency can be determined.

Part 2 (sound source recognition, including ranking — ISO/TS 12913-2:2018, Figure C.8)

The ranking responses are assigned the values starting with 1 (natural numbers) up to 8 (if 8 different sources are listed), indicating the most noticeable sound sources at a site (see Table B.1). The level of measurement is ordinal, which means that the median value for all recognized sound source at each site should be reported as the measure of central tendency.

The indication of certain sound sources, assessed as most noticeable by the different soundwalk participants, can be related to the collected ratings of part 1. A specific focus on a sound source or on a set of sources might influence the assessment of the sound environment in its entirety, and thus should be explored. The data might allow studying the relevance of sound source focus to the perception and assessment of multi-sound source scenarios as acoustic environments usually are.

Table B.1 — Assigned scale values to rating scales of Method B and statistical measures

Part (see ISO/TS 12913-2)	Scale values to be assigned	Measure of central tendency	Measure of dispersion
1 (assessment of the sound environment)	1 - 5	arithmetic mean	standard deviation
2 (sound source recognition)	1 ,2 ,3, 4, 5, 6, 7, 8	median	range

Part 3 (subsequent comments — ISO/TS 12913-2:2018, Figure C.9)

For analyses, the responses related to part 3 (subsequent comments) gained by a soundwalk should be systematically analysed. For it, the provided comments are clustered by increasing the level of abstraction of the used word to identify meaningful categories. This analysis process can be realized according to established methods of empirical social research, such as the Grounded Theory (see Reference [7]) or Qualitative Content Analysis (see Reference [8]). By means of categories identified and the frequency of occurrence of certain categories at each site, standard statistical analysis can be performed (e.g. in terms of histograms). This analysis is performed per site and per condition (e.g. time of the day), where applicable.

The analysis can be additionally performed for all sites together investigating the general character of the investigated area covered by the soundwalk and for later comparison to other investigated areas.

NOTE Free response data are needed to understand the meaning of scaling or responses to structured questionnaires. People involved can use their own words to describe their perception and feelings.

B.3 Link of Method B results to acoustic data

The analysis of the link between results and acoustic data should be determined according to A.4. For interval data, the Pearson correlation coefficient, *r*, should be calculated (see Reference [48]) according to the Formulas (B.1) and (B.2).

$$r = \frac{\operatorname{cov}(x, y)}{\sigma_x \cdot \sigma_y} \quad \text{(B.1)}$$

where

σ_x is the standard deviation of the array x_i;

σ_y is the standard deviation of the array y_i;

$$\operatorname{cov}(x, y) = \frac{\sum_{i=1}^{n} (x_i - \bar{x}) \cdot (y_i - \bar{y})}{n} \quad \text{(B.2)}$$

where

$\bar{x}$ is the arithmetic mean value of the array x_I;

$\bar{y}$ is the arithmetic mean value of the array y_i;

n is the number of cases.

Annex C
(informative)

Analysis of data related to Method C

Method C, described in C.3.3 of ISO/TS 12913-2:2018, provides a guideline for a narrative interview consisting of several open questions that allow for deepening the understanding of the effects of soundscape.

The guideline referring to satisfaction with the living space, residential experience, experiences with/relation to sounds in life, daily routines, co-inhabitants, neighbours, spatial identification of sound effects should be systematically analysed according to an established interview analysis using explicit systematic procedures.

An established analysis method is the Grounded Theory, which enables the development of integrative diagrams leading to a systematic model of categories that give access to main strategies of habits with regard to living in an acoustic environment (see References [18] to [23]). The Grounded Theory is simply the discovery of emerging patterns in data. The Grounded Theory generates theories from data (see Reference [24]). The procedure of the Grounded Theory is explicitly systematic and based on defined rules and guidelines. The general demand is that the results are constantly "grounded" in the data to guarantee that validity and intersubjective traceability are given. The systematic analysis approach requires starting with open coding, in which the analyst enhances the level of abstraction step by step in order to improve its generalization. The data is divided into discrete incidents, ideas, events, acts, feelings and reactions and described with general, abstract notations. These notations can describe different objects, events, actions, interactions, feelings or psychological states (see Reference [25]).

The purpose behind categorizing phenomena is to be able to group similar events, sensations, reactions or objects under more common heading or classification, if these events share common characteristics or related meanings. The data is elaborately coded word by word, line by line and sentence by sentence. When the first notations begin to accumulate, the process of grouping the categories under more abstract terms starts. With the help of the clustered categories, core categories can be detected, which subsume and cluster the diverse categories and codes under broader terms. That procedure enables the analyst to discover the ties and dependencies between the generated categories (see Reference [26]). After the initial and unfocused coding, the phase of selective and axial coding follows, in which the conceptualization of the data is more target-directed because of the analyst's increased theoretical sensitivity. In addition, integrative diagrams are developed to explore the missing links and connections between the different categories and core categories (see Reference [27]). By means of such diagrams, a concept of dependencies and deeper understanding of the object of investigation arises. After creating integrative diagrams, the data is analysed again based on the derived understanding. Thus, the analysis process is circular (see Figure C.1). The circular analysis process is continued until the process is "saturated", which means that new aspects cannot be detected anymore by re-analysing the data again. Thus, the Grounded Theory is not only an exploratory tool for a quantitative study, but it permits the development of a theory and the identification of relevant moderators for perception (see References [28] and [29]).

The data should be analysed through correlation and triangulation; sound and psycho-acoustic parameters should be collected and they should be analysed with regards to their synergetic effects.

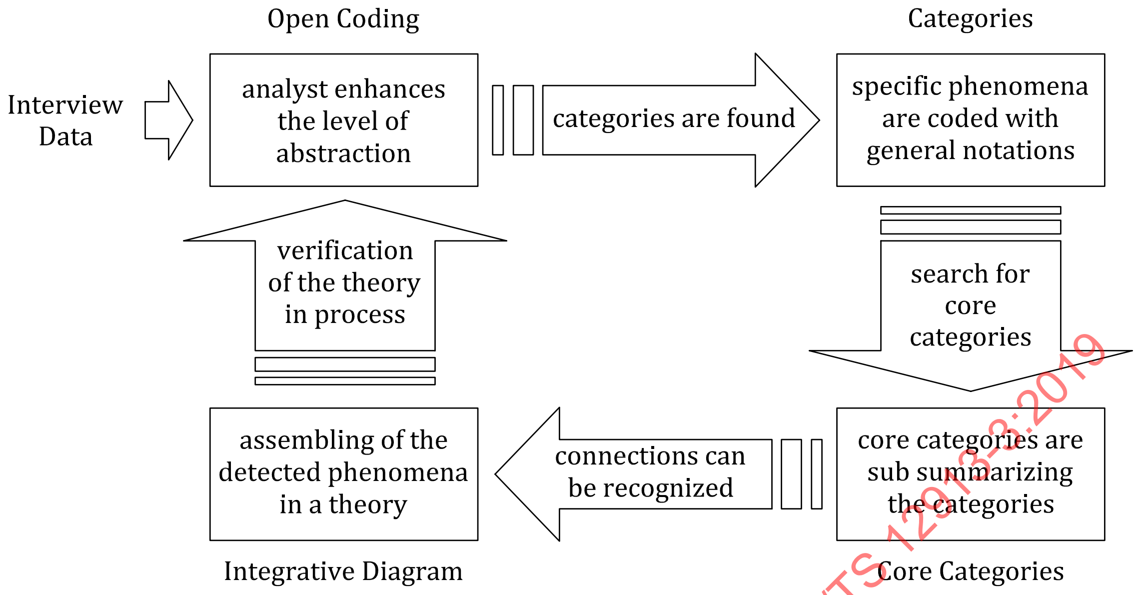


Figure C.1 — Circular systematic analysis approach according to the Grounded Theory (see Reference [27])

Annex D
(informative)

Analysis of binaural data

D.1 General

The analysis of the binaural data enables the characterization of the acoustic environment and the identification of auditory sensations. The results of the binaural data analysis, including psychoacoustic indicators, enable the quantification of the acoustical impact on the listener, and the exploration of relationships between physical properties of the environments and human response behaviour (see Reference [30]). Also, the amount of unexplained variance of the soundscape related responses should be determined and reported.

NOTE The amount of unexplained (residual) variance indicates the proportion to which the results from the binaural data analysis do not account for the variation of the human response data set. In simple words, it is the amount of error made by predicting the human responses by means of the results of the binaural data analysis only.

The intended purpose of psychoacoustic indicators is not to explain the level of pleasantness or appropriateness of sound in its entirety [ISO/TS 12913-2]. Binaural recordings enable the aurally-accurate reproduction of the sound measured in-situ, which allows listening to the acoustic environment with all spatial information retained. For example, the opportunity to identify the distribution of sound sources in the analysis process may be helpful to relate this information to the human responses.

D.2 Determination of metrics

Because binaural measurements provide two signals representing the left and right ear of a human listener, any acoustic parameter is calculated for both ears separately. For all metrics considered, the highest value of both channels of a binaural recording is used as the single representative value indicating the overall experience. The arithmetic mean value of the values determined for the left and right channel may be determined additionally. The consideration of ratios between different percentile values of psychoacoustic analysis results can be used to quantify the amount of variation of a certain metric over time (see Reference [31]). For example, the quotient of the loudness N_5 (loudness exceeded in 5 % of the time interval) and loudness N_{95} (loudness exceeded in 95 % of the time interval) may be an indicator of the level of loudness variability. Such metrics intending to describe the variation over time should also be considered for other psychoacoustic metrics. See Table D.1.

NOTE The use of binaural technology allows for capturing the spatial auditory impression in an aurally accurate way. The gained signals resemble the signals a listener would experience with both ears at the measured situation, i.e. the signals contain all changes of sound due to the presence of a human in the measured acoustic environment differing from the measuring result of a monaural microphone recording. Because humans do not explicitly perceive separately a left ear and a right ear sound, but combine cognitively both inputs to one perception, the derivation of a single representative value based on the two input channels from the binaural measurement system resembles the way humans perceive sound.

In order to determine the reliability of determined acoustic values representing certain sites, repeated measurements should be analysed. Reliability considers the aspect whether the same results are obtained if the same measurement is repeated (see Reference [33]). A high reliability is a prerequisite condition for validity (see Reference [34]). The variation per site of acoustic data analysis results should be investigated and reported. For larger data sets of repeated measurements, the measure coefficient of variation can be considered.

Table D.1 — Metrics and representative single values

Parameter	Metrics to be determined for each channel separately	Determination of representative single value	Reference
Sound pressure level	$L_{\text{Aeq},T}$, $L_{\text{Ceq},T}$, $L_{\text{AF5},T}$, $L_{\text{AF95},T}$	higher value of left and right metric values	ISO 1996-1
Loudness (time-variant loudness)	N_5, N_{average}, N_{rmc}, N_{95}, $\frac{N_5}{N_{95}}$	higher value of left and right metric values (or the average of left and right metric values)	ISO 532-1
Sharpness	S_5, S_{average}, S_{95}	higher value of left and right metric values (or the average of left and right metric values)	DIN 45692
Psychoacoustic tonality	T	higher value of left and right metric values (or the average of left and right metric values)	ECMA 74
Roughness	R_{10}, R_{50}	higher value of left and right metric values (or the average of left and right metric values)	[32]
Fluctuation strength	F_{10}, F_{50}	higher value of left and right metric values (or the average of left and right metric values)	[32]

The acoustic data can be subject to clustering analyses. This can be done in terms of psychoacoustic metrics that are related to the different sites combined with data collected from questionnaires. A multitude of clustering analyses is available (such as hierarchical agglomerative clustering, k-means clustering, multidimensional scaling, see References [49] and [50]), which allows for the discrimination of relevant factors influencing the perception of acoustic environment (see References [35] and [36]) and to cluster sites grounded on perceptual and psychoacoustic data obtained in-situ (see Reference [37]).

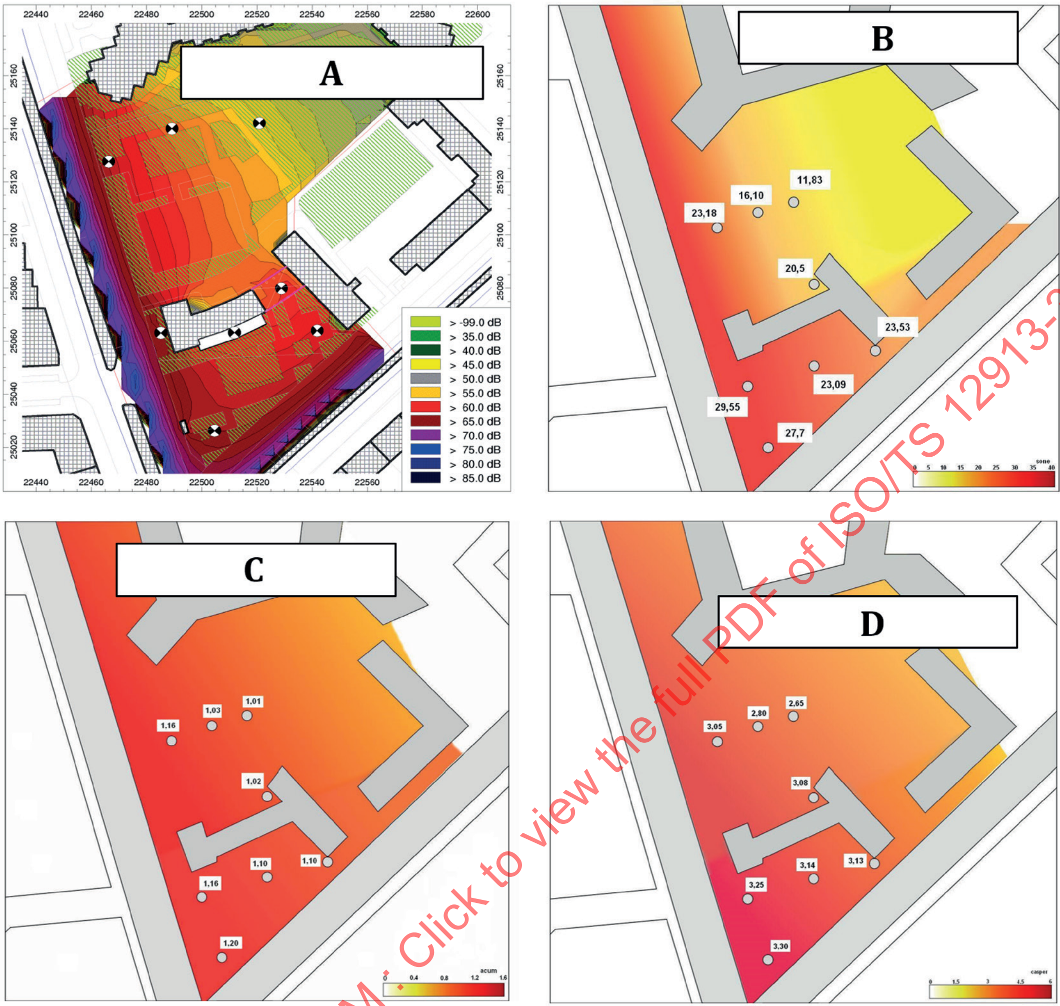
D.3 Psychoacoustic mapping

In the context of environmental noise assessment, noise mapping in terms of sound pressure level maps is usually applied in order to estimate the impact of noise on human beings. Since the sound pressure level is related only to a limited degree to the perception of environmental noise and acoustic environments respectively, the creation of psychoacoustic maps is recommended in order to have available more information for the description of the acoustic environment (see Reference [38]).

While it is possible to predict precisely the sound pressure level depending on the distance to a sound source or to calculate the resulting sound pressure level of superposed sound sources, such methods of calculation are not applicable for psychoacoustic parameters such as loudness, sharpness, roughness, or fluctuation strength (see Reference [39]). The principle of the sound pressure dependency of distance in free field is known: doubling the distance to point-source yields half the sound pressure.

In contrast, the behaviour of psychoacoustic parameters with distance is often non-linear and more complex. For example, the change in loudness due to a distance change differs from the behaviour of the sound pressure level (Figure D.1). A depiction of this phenomenon is displayed in Figure D.2, which indicates the general behaviour of psychoacoustic parameters on the basis of one vehicle pass-by event recorded at different distances. The parameter 'sharpness' shows only minor changes due to the relative constant spectral shape and is only influenced by the frequency-dependent absorption in air during propagation within greater distances. The perceived 'roughness' displays only small changes as well, since the modulation frequency and the degree of modulation are almost constant and are not dependent on absolute sound pressure levels. Similar psychoacoustic maps can provide more information compared to maps exclusively depicting sound pressure levels (see Reference [40]).

Generally, in contrast to sound pressure level maps, which can be calculated by the sound pressure levels of the sources alone, it is not possible to create psychoacoustic maps without time signals. In particular, if several sources are superposed, the single values of psychoacoustic parameters of the sources alone are not sufficient to predict the single value of the resulting overall noise. The new time signal should be measured or simulated to determine the single value of the overall noise. For the creation of a psychoacoustic map, the specifications and recommendations given in the D.2 concerning “psychoacoustic indicators” should be considered.



Key

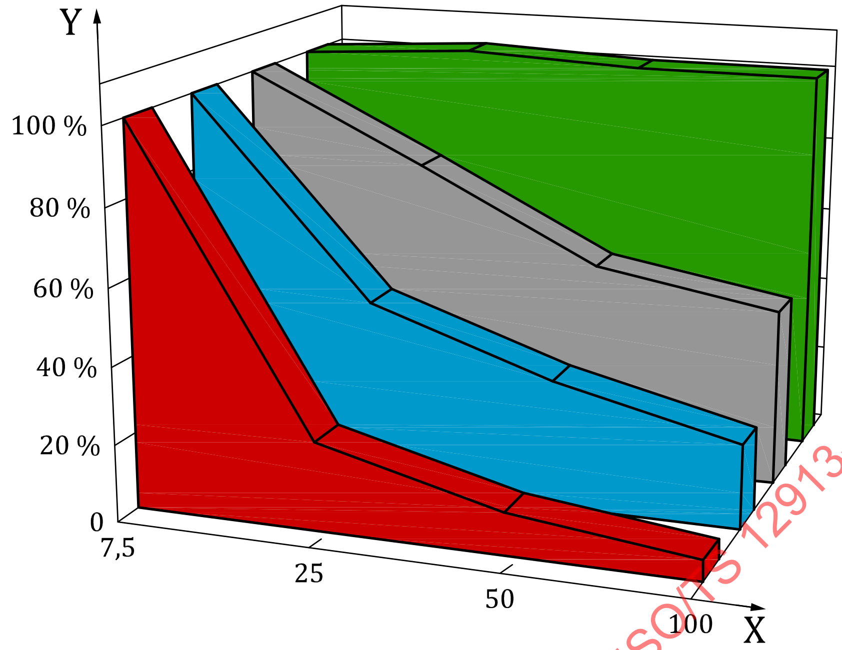
A conventional noise map

B schematic distribution of loudness

C schematic distribution of sharpness

D schematic distribution of roughness

Figure D.1 — Conventional noise map and psychoacoustic noise maps of the public space “Nauener Platz” in Berlin (see Reference [41])



Key

X	distance, in meters
Y	relative change of acoustic parameters, in %
red	sound pressure level (A-weighted)
blue	loudness (ISO 532-1)
grey	roughness
green	sharpness (DIN 45692)

Figure D.2 — Relative change of acoustic parameters in % of a pass-by event of a passenger car recorded at the distances 7,5 m, 25 m, 50 m and 100 m

Annex E
(informative)

Triangulation

Soundscape studies use a variety of data collection and measurement methods related to human perception, the acoustic environment and the context. The use of different measurement methods is known as triangulation. The term triangulation is borrowed from surveying or navigation, where it refers to the practice of establishing the exact position of a given object by taking readings or measurement from multiple viewpoints. Using more than one reference point enables greater accuracy of measurement (see Reference [51]). In the context of social sciences, it means a process by which the same problem or phenomenon is investigated from different perspectives (see Reference [52]).

In general, it is possible to identify four different types of triangulation (see Reference [53]) which are data, investigator, theory, and methodological. All of the four types can be principally applied in soundscape investigations and research.

1. Data triangulation: creation of multiple data sets by collecting data in a variety of contexts and settings at different points in time. This may involve using the same method on more than one occasion or using different methods or different times.

2. Methodological triangulation distinguishes between two broad subtypes: the 'within-method' and the 'between-methods' or 'across-methods' approach. The former entails applying the same method on different occasions or using multiple techniques within a given method. But when using 'between methods', triangulation refers to the actual mixing in a single research design.

3. Investigator triangulation occurs when more than one researcher or evaluator investigates the situation. Using multiple investigators ensures that a number of viewpoints are represented. It is noted that individual evaluators are largely influenced by their disciplinary roots, and therefore multidisciplinary evaluation teams are required for specialist knowledge in addition to the technical expertise.

4. Theory triangulation, which entails making use of a number of alternative or competing theories in examining the data.

In most cases, the first two types (data and methodological triangulation) are applied in soundscape investigations (see References [58] and [59]). For example, to use a questionnaire at the soundwalk and to perform narrative interviews with further groups to look at different problems in the same study using different approaches calls for triangulation. Due to the variety of methods and tools for data collection described in ISO/TS 12913-2, the use of triangulation is required. Triangulation increases the validity and reduces the uncertainty of the measurements, compared to relying on a single method or a single data set.

Annex F
(informative)

Laboratory studies

In order to analyse the data further, it can be relevant to perform laboratory studies. The performance of a laboratory study can deepen basic knowledge and assist in detailed analyses of specific phenomena related to soundscape. Any performance and analysis of laboratory studies include a discussion about the limitations of the results in terms of ecological validity. For example, one's assessment of sounds is influenced by memory effects. The auditory system is capable of detecting small differences based on short-term memory; however, such discrimination cannot be made based on the long-term memory, causing individuals to depend more on characteristic noise features and patterns. Such memory effects influence the results of laboratory studies and shall be discussed with respect to their meaning for the overall results. The duration of presented sounds may play a role as well. It is recommended to choose specific durations of sounds presented in laboratory studies, which are long enough to immerse a participant sufficiently into the acoustic situation. The presentation of sounds of only few seconds might be misleading in the context of soundscape investigations. The main advantage of soundscape laboratory studies is the greater control of several variables such as ensuring that all participants are exposed to exactly the same acoustic environment (see Reference [42]).

The design of experiment aspects including instruction, scale, and context should be selected according to the object of investigation. In principle, methods like paired comparison, ranking, category scaling, semantic differential, magnitude estimation and interview methods can be used.

In case of a category (partition) scaling method, participants are requested to rate sounds on a scale that is divided into a finite number of categories. The distances between the categories are supposed to be equidistant and the categories are thought to represent equal sections leading to interval scaled data. Bipolar and unipolar category scales can be used; the bipolar scale uses two opposing attributes, whereas on a unipolar scale only one-dimensional categories are provided. Established verbal labelling of categories of unipolar and bipolar scales for intensity, quality, frequency of occurrence, and agreement were introduced (5-point scales: not, a little, moderately, quite a bit, very / bad, inadequate, fair, good, excellent / never, seldom, sometimes, often, always / fully agree, mainly agree, neutral, mainly disagree, fully disagree, see References [17] and [43]).

The semantic differential method typically comprises a set of bipolar rating scales, which cover multiple dimensions. In most cases, 7-point category scales are used. A semantic differential can provide a detailed semantic profile of a sound. Usually, the data obtained by a semantic differential method is analysed based on principal component analysis or factor analysis, and the large quantity of data obtained by a semantic differential test is reduced to a set of unobserved, latent variables describing most of the variance in the data.

Absolute, relative magnitude estimation and magnitude production are the most known magnitude estimations methods. Absolute and relative magnitude estimations operate without and with a standard stimulus. These methods are rarely used in the context of soundscape investigations and they are not recommended.

Another method is the free sorting task, which allows for researching aspects of categorical perception of complex auditory situations. It is often used, followed by a free-format verbal description task of categories created in order to avoid confining responses to verbal descriptors predefined by the experimenter (see Reference [44]).

It allows for identifying "natural" verbal descriptors that are meaningful for participants. Free categorisation experiments might allow recognizing how human beings process sounds based on the linguistic exploration of verbal data (see Reference [45]). Methods, like Intermittent Thinking Aloud (ITA) or Subsequent Thinking Aloud (STA), are another way to collect data without predefined questions guiding an interview and can be subject to explorative analysis and to determine personal meaning as well (see Reference [23]).

By means of interview methods, information can be collected on the one hand to explore relevant factors for the assessment of sounds, and on the other hand to estimate the explanatory power and validity of the collected scaling data and to evaluate the adequacy of test method and evaluation task. The application of interview methods, in combination with other scaling methods like category scaling methods, is highly recommended.

In general, the data collection methods described in ISO/TS 12913-2 can be used in laboratory studies.