



Review

Acoustic Quality of the External Environment: Indications on Questionnaire Structure for Investigating Subjective Perception

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Abstract: The subjective judgment on the annoyance produced by noise is always an important tool to complete an investigation, and to find the best way for its reduction. Therefore, acoustic analyses for environmental improvement frequently combine objective measures with subjective surveys to gain a comprehensive understanding of the problem. The technical specification, concerning the “Assessment of noise annoyance by means of social and socio-acoustic surveys”, ISO/TS 15666 (revised in 2021), has represented a basis for these activities since 2003, when it aimed to obtain information about noise annoyance “at home”. The more recent ISO/TS 12913-2 (2018), aimed at soundscape studies, investigations and applications, provides guidelines for conducting social and socio-acoustic surveys to assess noise annoyance and, in particular, it gives detailed indications on data collection and reporting. The indications provided by the technical specifications represent a common guideline for addressing the implementation of a subjective survey in the acoustic field, and to make investigations as comparable as possible. However, they do not cover all the fields of acoustic subjective investigations. Therefore, to make the collection of information from questionnaires more effective, it is useful to have a broader review of the issues that need to be addressed. To support this type of activity, this paper collects and presents relevant observations for the design of subjective survey questionnaires focused on outdoor acoustic quality. Drawing on previous research studies and experiences, it provides a series of observations on the main aspects to be considered in order to structure multipurpose acoustic evaluation questionnaires, including discussion of the general considerations for questionnaire structure, administration methods, population sample characterization, question formulation, and classification. It also deals with specific indications related to acoustic evaluations, such as the characteristics of annoying noise, boundary conditions, subjective feelings, and source features.

Keywords: acoustic survey; questionnaire structure; subjective assessment



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1. Introduction

Noise pollution is one of the major environmental problems, particularly prevalent in urban areas where it often becomes the subject of thorough investigation [1]. The health, comfort, and productivity of individuals both outdoors and indoors [2] are strongly influenced by environmental quality.

Negative effects associated with noise annoyance include difficulties in verbal communication, sleep disturbance, altered behaviours and psychological conditions [3,4]. Moreover, the resulting stress may contribute to the onset of serious diseases, mostly related to the cardiovascular, respiratory, and nervous systems [5,6].

In the strategies for evaluating acoustic quality, both in internal and external environments, two main aspects can be emphasized: quantifying physical parameters using measurements and simulations, and assessing individual perception through subjective investigations [7,8].

The collection of data on noise levels, the analysis of their characteristics, and of the results is generally performed using technological tools (measurement and data-processing tools). The methods for measuring and processing data are usually defined by regulatory indications aimed at protecting potentially exposed individuals.

However, often the thresholds do not match actual individual perception and do not correspond to a judgment on the acoustic quality of the environment. Therefore, it can be concluded that technical investigations alone are not exhaustive and do not adequately represent individual perception in a satisfactory manner [9].

The opinions expressed by the population constitute a valuable source of information on the environmental quality in which we live and work. They allow identifying and characterizing the relationships between environment, comfort, and productivity in a better way [10].

Based on this, it is evident that there is a need for subjective investigations to support the usual methods of technical-scientific analysis, in order to improve the overall evaluation.

Some regulations already acknowledge the importance of citizen participation in addressing environmental noise [11,12]. However, they often limit citizen involvement to information dissemination rather than active engagement in social investigations that provide a more complete understanding of the issue.

As a result, the population's role is passive as they are only provided with information after technical decisions have been made, without being asked for their opinions beforehand.

An active survey system, on the other hand, enables the collection of data in a standardized manner on extensive samples, allowing for mathematical and statistical analyses that can provide useful insights and support decision-making processes decisions based on individual satisfaction.

Human perception involves both a cognitive dimension, where individuals retrospectively evaluate their personal standards (expectations, desires, previous experiences, etc.), and an affective dimension, where present experiences influence retrospective reflections. These two processes influence the correlation between objective and subjective data, making the association between the investigated event and the opinion expressed on it dynamic.

The interpretive process of the results is influenced by hysteresis, and thus it is essential to rely on a robust statistical analysis to minimize uncertainties. When the statistical analysis confirms a non-objective but shared situation, this reveals that individual judgment has such a high weight, to be held in high consideration, as it tends to prevail over the objectivity of the phenomenon being studied.

The objective of this work is to provide reflections and guidelines to support the development of questionnaires based on previous experiences and information collection. Some considerations pertain to the overall structure of a questionnaire, while subsequent ones specifically address questionnaires related to aspects of environmental acoustics. The aspects covered encompass a wide range of contexts, extending beyond the soundscape, and are applicable to any situation where the use of subjective survey instruments is valuable for analysing the impact of external environmental acoustic issues on the population. In this phase of the project, the focus was not on analysing the relationship between questionnaire results and quantitative acoustic measurements. Instead, attention is directed towards factors that can influence the user's judgment beyond the confines of quantitative parameters that characterize the phenomenon. The study complements an extensive and specific literature review [13] on surveys in the acoustics field, which has considerably different investigation methods such as soundwalks, interviews, listening tests, and focus groups. It provides additional insights for the formulation of questionnaires, both in general terms and within the specific field of application.

The analysis focuses on formulating indications to be included in guidelines for creating subjective survey questionnaires, specifically for the acoustic field. General notes on specific acoustic investigations developed through subjective perception questionnaires demonstrate the usefulness of this tool. The benefits of indications shared through guide-

lines and regulatory indications, which promote greater replicability of the models and comparison of surveys, are outlined (par. 2). The article first discusses general considerations that apply to questionnaires in various fields of investigation (par. 3). It then outlines the main steps involved in creating an effective questionnaire, starting with the overall structure, primary questions, and population sample considerations. The section focuses on the peculiarities of the questions that should be anticipated for different purposes of the questionnaire, as well as some characteristics of the administration methods. It serves as a necessary foundation for acoustic surveys. The subsequent section (par. 4) highlights several salient aspects that are specific to acoustic surveys, including the type of noise being studied, the characteristics of the questions and their evaluation scales, the administration methods, and the types of sound sources being examined to collect information related to subjective perception.

2. State of the Art: Questionnaire Approach for Outdoor Noise Investigations

The results of some previous experiences [14,15] have supported the notes presented here. Some general premises related to the psychological perspective introduce the analysis of significant researches in the field.

A questionnaire is generally defined as a tool for gathering information, consisting of a structured set of questions to which the subject responds by reporting and evaluating their experiences. These tools are closely linked to the knowledge acquired through contact with the surrounding reality [16]. The experiences that are the focus of this investigation are rooted in three main concepts, sensation, perception, and attention [17]:

- **Sensation** is a process that originates from a physical stimulus, which can be any form of matter or energy that affects the senses. A stimulus is any chemical or physical activator that elicits a response in a receptor, such as light stimuli in the eye or sound stimuli in the ear. The result is a psychological and subjective sensory experience.
- **Perception** is the ability to process, receive, and interpret information by extracting organized, meaningful, and useful representations.
- **Attention**, meanwhile, is a cognitive process that enables the selection of some environmental stimuli from among the many available at a given moment, while ignoring others.

The stimulus, which is physically measurable and objective, is internalized, classified and associated with some specific contexts, and is defined in psychology as a process of signification.

This last phase often involves a reconnection with one's own experiences, which are mainly made up of two circumstances: personal experience and the social sphere.

Personal experience can be associated with the historical memory of the subject, which is a database of emotions, situations, and contexts that characterize that person in a precise way.

The social context, on the other hand, is made up of its education and the set of cultural and relational conditions with other subjects, hence its position in the society in which it is born and grows.

In the scientific literature, several subjective investigations have been indicated to support the evaluation of noise annoyance both in external and internal environments. For example, in acoustics, a subjective survey can allow one to understand the reactions of the population to environmental noise. The subjective judgment does not always put traffic noise at the forefront. In Curitiba, Brazil, 860 questionnaires indicated that traffic was the main noise source causing disturbance (73%), but neighbourhood noise (such as noise from neighbours, animals, sirens, civil construction, religious temples, nightclubs, toys, and domestic electric appliances) was also mentioned. Therefore, actions that could reduce traffic noise should be combined with measures for better management of urban spaces and activities [18].

The results of subjective investigations in Skopje, Macedonia Republic showed the need for national building standards and public health-oriented urban planning. In this

study, 700 interviewed subjects indicated neighbourhood noise as the most annoying source, represented by construction and other human activities (75%) [19].

The results of a questionnaire study in a residential area of Lerum Municipality for the EU NOISUN project confirmed that the most important noise sources in the residential area were due to rail and road traffic, with noise from neighbours being the second-most important source [20]. The opportunity for noise barrier protection was investigated and confirmed to represent a good technical solution, increasing the satisfaction level of the residents.

From a health point of view, good correlation between subjective noise level assessments and objective noise measurements was found in a research study on young adults' noise awareness, supporting the encouragement of young adults to take protective action when they find themselves in a noisy situation [21].

These findings attest to the usefulness of subjective investigation methods to identify the most critical situations in terms of the annoyance they cause, rather than in relation to measurable sound levels.

The survey structure generally follows an "ad hoc" scheme, depending on the type of sound source or environmental context being analysed. The complexity of the assessment makes it impossible to standardize a methodology for its formulation. In several studies, a series of proposed questions aims to help us understand the sound events in urban landscapes as a whole, without investigating a specific sound source [22–26]. In these situations, the analysis of results is complex due to the large number of variables that depend on the different types of sources that contribute to the sound field. Specifically, one of the main obstacles is identifying the impact that each phenomenon has on individual perception, or how much more annoying one noise is than another.

To distinguish between noise sources, an in-depth analysis of the acoustic data measured in the areas of interest is carried out, considering percentile levels, sound levels, spectral analyses, and psychoacoustic parameters obtained through precise analyses [27].

In urban contexts, the subjective investigation directs the empirical evaluation towards a series of connections capable of justifying and explaining how users perceive a particular acoustic environment.

This approach becomes even more effective and interesting when applied to city contexts or other sound environments with similar characteristics.

However, subjective evaluation in these contexts needs to be structured according to different areas of investigation. First of all, personal data provides the first important aid for the collection and analysis of data.

As indicated in Annex C of ISO/TS 12913-1 [28], a standard more widely considered, in addition to age and occupation, information on hearing difficulty and diagnosis of hearing loss is also required.

Other elements suggested in various studies include knowledge of the urban situation, global assessment of the place, and finally, the assessment of the sound environment or of the acoustic comfort [29–31].

The measurement or simulation of physical parameters alone is not always sufficient to fully characterize a disturbance or to establish a direct correlation between the object of investigation and the perceptions of those interviewed. Knowledge of the phenomenon and opinions can only be obtained through field experience. Administering questionnaires to investigate certain acoustic phenomena, whether they originate from single sources or from several sources that characterize a soundscape, can yield a large amount of information that can serve as a foundation for creating a database [32].

Therefore, results from surveys previously conducted in a specific context can be useful in supporting new evaluations. It is worth noting that extensive studies and research have been conducted over time on the acoustic quality of indoor environments and on the annoyance that noise can cause in building occupants.

The procedures for structuring questionnaires in the field of acoustics are the subject of interest in the international standardization field. Guidelines for this are included in the

technical specification ISO/TS 15666 “Acoustics—Assessment of noise annoyance by means of social and socio-acoustic surveys” [33], which is currently being revised. The first version of ISO/TS 15666, published in 2003, attests the strong interest to put common rules and the need for standardized questions. The standard covers scaling, noise annoyance questions, assessment of annoyance degree, and other elements that can make a survey statistically relevant, and offer more and better-quality information for use by environmental policy makers. This includes the possibility of comparing survey results. However, the indications presented in ISO/TS 15666 refer specifically to surveys conducted to obtain information about noise annoyance experienced “at home”.

Furthermore, the importance of subjective investigations to understand the effects of noise inside homes has been the subject of various European projects. Under the Cost Action TU0901 (Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions), a questionnaire for socio-acoustic surveys in residential buildings was developed and translated into 20 languages to facilitate comparisons of perceived satisfaction or annoyance related to neighbour noise across different countries [34].

A systematic review of more than one thousand papers selected some studies that use questionnaires to survey the indoor acoustic environment as perceived by building occupants [35]. In the research, some results that can be extended to the outdoor environment were discussed. It was highlighted that aspects related to the nature of sounds and their spectral and temporal composition, as well as factors unrelated to the acoustic environment (such as urban context, building characteristics, personal traits, socio-economic features, situational circumstances, and environmental conditions), can significantly affect perceptual outcomes. The study suggested that the “the quieter, the better” strategy may not always be the best solution and confirmed that the integration of soundscape methodologies into indoor environmental quality research would enhance user health and comfort.

In soundscape studies, the current reference document for assessing all sounds perceived in an environment in all their complexity is the more recent technical specification ISO/TS 12913-2 “Acoustics—Soundscape—Part 2: Data collection and reporting requirements” [28]. This specification employs a variety of data related to human perception, acoustic environment, and context, with human perception considered more important than physical measurements.

Two methods, based on sound walks and questionnaires (Method A: questionnaire; Method B: questionnaire and open-answer), are proposed for data collection in an informative manner, while a third method involves narrative interviews. In [36], the first two methods were applied to test whether compatible results could be obtained, and positive results were achieved.

Following the technical standard indications, a soundscape procedure for evaluating urban spaces was proposed in [37]. Data on people’s perception of the acoustic environment in a seaport area were collected via a questionnaire. The approach aimed to avoid considering annoyance caused by noise and to propose a new concept of soundscape and acoustic planning for improving environmental quality.

In the following section (par. 3), some procedural indications for making the use of a subjective survey a very effective tool are outlined, based on the general principles of a suitable approach. Like all subjective investigations, a structural scheme is required that goes beyond the specific context but belongs to the generic formulation.

In the next section (par. 4), more targeted criteria related to the application of subjective surveys in the specific field of environmental acoustics are analysed, in order to obtain an overall methodological reference framework. In this context, the focus is on the individual’s perception of the stimulus and their reactions, rather than on the correlation between questionnaire survey results and objective measurements of sound levels.

3. General Observations on a Questionnaire Structure

The questionnaire is a tool commonly used to collect information from representative samples of the population. Its standardization and structure make it an excellent research

tool, as in most cases, the researcher does not need to conduct any direct intervention on the interviewee, but simply administers the questionnaire. The general structure of a questionnaire is summarized in Figure 1 (with the main elements explained in the corresponding paragraphs indicated in brackets). The following suggestions concern the structure of a questionnaire suitable for multiple research topics, not limited to acoustics.

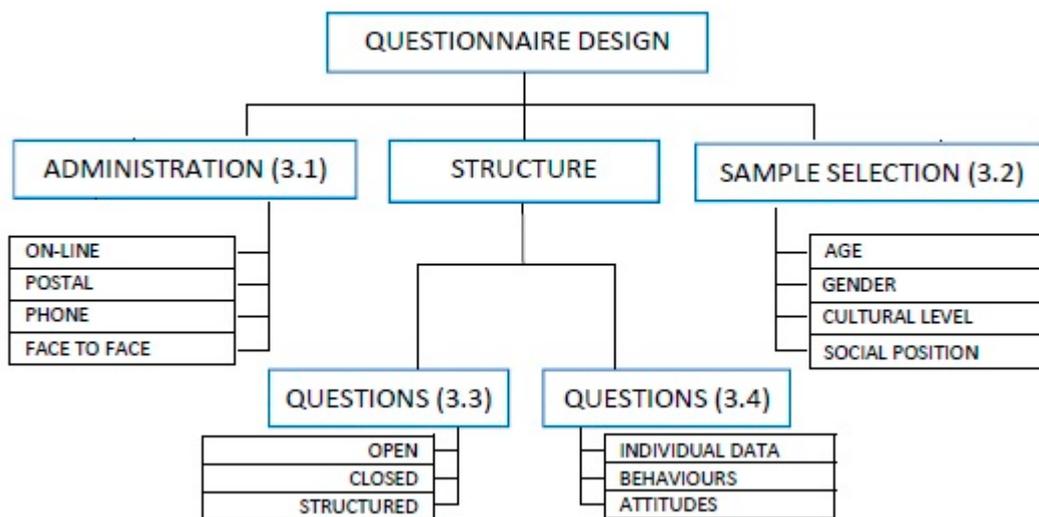


Figure 1. General structure of a questionnaire.

3.1. Administration Method

The first step in undertaking a subjective investigation to support technical and scientific assessments is to choose the appropriate instrument to use. Various investigation techniques differ according to the method of administration, such as direct (e.g., face-to-face) or indirect (telephone, online, etc.) interviews, questionnaires, direct observations (carried out only by the surveyor), diaries (particular types of questionnaires specially structured to record frequent and minor events such as low expenses or daily activities), mixed techniques (e.g., diary combined with the interview), etc. Based on the specific type of investigation and the characteristics of the population sample to be analysed, specific advantages and disadvantages can be identified. For example, for health surveys or population samples within a certain age group, certain types of investigation may be more advantageous due to a direct approach, or the technology used.

Only some general aspects of the various administration methods are outlined here.

In general, the choice of method is essentially based on two factors: the subject of the study and the availability of resources, while considering which of the possibilities mentioned below can lead to results in line with the research purposes:

1. Face-to-face questionnaires are suitable for complex formulations with the possibility of direct control over the interviewee and the environment in which they complete the questionnaire. In this case, the depth of the questionnaire can be managed freely by the researcher who can also influence or direct the respondent’s ideas.
2. Phone surveys, generally supported by computers, require that the questionnaire is completed under the dictation of the interviewee. These are fast and practical systems, but unlike face-to-face interviews, it is not possible to obtain a high degree of depth.
3. Postal and online questionnaires are based on self-completion, with the great advantage of extending research on a large territorial scale. The disadvantage is that the researcher cannot know the environment and the context in which the questionnaire is completed. The online method is an increasingly popular tool, but it should be carefully used by selecting a well-representative sample [38]. In recent times, smartphones have been considered as a useful tool for collecting data for acoustic quality assessments through digital questionnaires that can be easily accessed and distributed [39].

Advantages over traditional printed questionnaires include lower costs, immediate transmission upon completion, and automatic controls to ensure proper responses.

In a study on opinions regarding education policies, online and face-to-face administration methods were analysed to assess potential differences attributed to the mode of administration [40]. The survey results indicate that for online surveys, the population sample should be chosen in a way that includes both internet users and non-users, to provide representative insights for the entire population.

The findings emphasize the importance of interpreting responses in relation to the mode of administration, taking into account the nature of the question, particularly for sensitive questions.

One aspect to consider is the overall length of the questionnaire. Excessive information and/or requests can decrease the interviewee's attention and concentration, resulting in unreasonable and thus unrepresentative answers in some cases, and in others, it may lead to the non-completion of the questionnaire, rendering the survey invalid.

This issue can be solved by keeping the questionnaire concise and essential, but a more targeted solution is to provide information on the overall length of the questionnaire. For instance, in the case of a paper survey, page numbers can be inserted with the total number of pages (e.g., 1/2) at the bottom of each page (the location where most people are accustomed to reading documents). In online questionnaires, this information can be presented using graphic tools such as a bar that is coloured and/or filled in as the respondent progresses through the survey.

An important aspect to consider in the preliminary stage of any survey is preparing the participant, who should be informed about the objectives of the study. The presentation of the questionnaire should be simple and concise, yet effectively frame the subject of the study in a clear and direct manner. Therefore, the questionnaire should include a brief introduction that can be easily read and understood by the participant, enabling them to respond more appropriately to the subsequent questions. This aspect must be carefully addressed, especially in self-administered surveys where it is not possible to ask for clarifications during the completion process. The construction of the questionnaire starts with a design phase based on the target definition. Generally, the use of this tool begins even with minimal or unstructured knowledge of information related to the object or area to be investigated. The design of the questionnaire has three main purposes:

- defining the involved variables,
- establishing the reason for the investigation,
- identifying the target.

During this phase, macro-topics or macro-areas of interest should be defined, trying to divide the topics to be investigated as much as possible. The investigation focus can be addressed by articulating the formulation in sections and subsections, paying attention to factors such as the topic, the degree of respondent involvement, and the duration of the compilation, which is closely related to the length of the questionnaire.

3.2. Characterization of the Sample Population

In statistics, the population is defined as the "universe," while the sample represents a portion of it, including the number of people who will actually participate in the survey.

Preliminary considerations about the sample include:

The sample size, assuming a statistically adequate number of respondents;

The responsiveness of the interviewed sample, since it is possible that not all people to whom the questionnaire is administered will fill it out.

Sample selection is a complex operation based on specific statistical methods. The two types of sampling used in subjective investigations are defined according to a probabilistic or non-probabilistic scheme:

Sample selection can take place according to probabilistic schemes, in which each subject has a non-zero probability of being included in the sample. This form guarantees

the representability of the entire population, unlike the non-probabilistic case, in which the survey results cannot be generalized.

In non-probabilistic samples, the sample selection method can be reasoned or subjective, while representativeness is connected to theoretical evaluations carried out by the researcher.

Generally, the sample choice is based on the availability and reachability of the subjects. If participation in the survey relates to a specific type of response, what can be obtained has an effect defined as “selection bias.” Nonetheless, for example, if it is assumed that participation depends exclusively on age (or age groups), the interviewer can select a sample non-randomly, with the attention of respecting quotas of interviews by age in the sample, thus eliminating or reducing distortions.

However, the sample estimation process generates a result affected by a certain variability, as it is a partial and not global observation of the population [16]. It is necessary to take into account not only age and gender, but also other specific characteristics of the sample, mainly cultural level and social position. In the case of a probabilistic sampling approach, it is impossible to determine these attributes a priori. In the deterministic case, this operation is facilitated by making it easier to define the language and formulation for the survey.

3.3. Question Structuring

Building a questionnaire must follow a series of rules to achieve a certain degree of standardization and ensure clarity and consistency with the object of study. The preparation of questions is just one step in obtaining a good questionnaire, because control techniques are necessary for achieving thoroughness in the protocol.

Standardization processes are related to the stimulus-response technique in administration. Interviewees must receive uniform stimuli to obtain homogeneous responses with respect to the question formulation and the investigation's objective. The types of questions can vary depending on the design methods and the defined purposes, which must be well established beforehand. Specific notes on conducting an acoustic survey are indicated in technical standard [33].

In this section, question types at a more general level, valid in a wider context, are considered. Questions can be characterized by the type of answer they imply, and they can be divided into:

Open questions: These questions do not allow for a predetermined answer, and the interviewee can freely respond and provide interesting data. However, the statistical treatment of the data is complicated by the variability of the results.

Closed questions (dichotomous, polytomous, numerical, verbal, multiple scales): These questions propose possible answers, and the subject chooses from the options presented (generally two or three). Data collection is simple and rigorous, but this type of answer is only suitable for very precise questions, that are not always the most appropriate questions. For example, dichotomous questions provide a single answer between two options (examples: yes/no, true/false, agree/disagree), while polytomous questions provide a single choice between three or more answers.

Structured questions: These questions present a predetermined set of answers selected on the basis of previous studies by the researchers, on the basis of surveys already conducted in the same area. The subject is invited to choose one of the answers or possibly to insert his own answer. This approach allows the subject to select an answer they deem most consistent with their own judgment. From this form of questions, improperly structured data can be generated which require a more in-depth analysis, often of a manual type.

Inaccuracies related to clarity and comprehensibility, with respect to the reference objective, can be generated in the formulation phase of the questions.

A structured questionnaire, composed of closed-ended questions, leads to a greater degree of interpretative and elaborative simplicity of the results compared to semi-structured questionnaires.

Semi-structured questionnaires consist mainly of open-ended questions, which generate major difficulties in the same processes.

General indications mainly concern the use of simple language, the choice of non-negative formulations or doubled questions, the use of clear time references to facilitate estimates, the provision of a logical succession of topics, and so on.

3.4. Questions Classification and Type

The questions can be classified into three assessment areas:

- individual data (personal and sociographic data);
- behaviours;
- attitudes.

The questions that pertain to registry data or sociographic context are aimed at identifying the social and economic characteristics that distinguish the interviewee, and for this reason, they are considered individual questions. This category includes questions about gender, age, marital status, educational qualifications, and profession. In addition to these individual aspects, there are other contextual factors that are considered, such as the municipality of residence, the urban or rural context, etc.

An analysis was conducted in [41] regarding the influence of psychological well-being and demographic characteristics on the perception of the acoustic environment or soundscape. The results revealed a positive correlation between psychological well-being and pleasantness and a negative correlation between psychological well-being and eventfulness, mostly in males (who did not indicate their occupation in the questionnaire). Furthermore, the occupational status, specifically retirement as a proxy for age and gender, was found to contribute to both pleasantness and eventfulness.

Behaviours are closely linked to experiences and are therefore concrete, and far from the imaginary and abstract dimension of attitudes (motivations, ideals, values, judgments, etc.). This determines, in the first case, simpler question formulations, while in the latter case, a higher level of complexity is required.

To overcome these difficulties, it is possible to translate the abstract dimension into reality, by transforming thoughts or ideas into actions, while keeping in mind the cognitive and cultural level of the interviewee.

The types of questions that require the use of scales can be numeric, such as symmetrical scales with odd numbers (usually five, seven or eleven values) when there is a central or neutral value, or asymmetrical scales with even numbers (usually four or ten values). The use of numerical scales reduces the possibility of distortions caused by idiosyncratic interpretations of verbal classifications.

Scales with an odd number of responses increase the risk of thickening at intermediate values but do not force the interviewee to 'take sides' and underestimate the level of indecision, as what happens with an even number of choices.

Verbal scales usually consist of five (i.e., strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, strongly disagree) or seven answer options, often with numerical values attached to them, which allow for the attribution of scores. The validation of evaluation scales is a delicate process that requires a large statistical sample. There is a risk of not obtaining the predetermined result but instead getting a different or similar one. The design of the answers must be based on creating an objective and valid research tool for all respondents in relation to the context to analyse. In this context, it becomes important to define a logical structure that encourages and assists the interviewee in responding to what is being investigated.

3.5. Language and Graphic Limitations

The language used for creating questions and any verbal scales represents another important aspect for the standard formulation of questionnaires.

The difficulty arises in the type of language and syntax to be used, which must necessarily require a high level of comprehensibility and clarity in relation to the respondent's type.

For this reason, the choice of words and their arrangement in the question setting is a procedure that requires particular attention. Furthermore, if the questionnaire needs to be administered in other languages besides the one in which the research is conducted, there is also the difficulty of translation.

The meaning attributed to some terms is not universally the same in all languages. Therefore, the risk is to formulate questions that deviate from the study objective. A solution to the latter problem can be represented by a pre-test to be submitted to other researchers or experts in the field of research who are of a different nationality to understand if under competent judgment, the questionnaire meaning remains unchanged (see below).

Once the appropriate language has been defined for the field of study, another aspect to pay attention to is the graphic form of the questionnaire. The first objective in this context is to create an attractive look, with project objectives and section titles in evidence.

The presence of images, beyond those required for the investigation, which do not hinder the smoothness and essentiality of the structure and are not subject to piloting with respect to the answers to be given, is not excluded. Even the choice of colours, if provided, both for the writings and for the images must be based on some criteria:

- avoid generating visual strains in the reader, for example by using too light or too bright colours,
- avoid using random associations of colours, unless this use depends on the researcher's willingness to emphasize some concepts or contexts,
- try to pursue, as much as possible, monochromatism, with the advantage of not generating confusion in the reader.

When the draft of the questionnaire has been outlined, it needs to be tested on people belonging to the research context or on subjects external to the project. This check has the purpose of detecting the presence of ambiguous or unclear questions, verifying the length of the questionnaire, and ensuring correspondence with the objectives of the study.

Sometimes, it is useful to refer to a "control group", which is a series of subjects not directly involved in the investigation and who can express a judgment without being influenced by socio-psycho-perceptual dynamics that could affect the verification outcome.

Once an adequate degree of formulation for the investigation and a good level of consistency with the set objectives have been reached, the questionnaire will be ready to be administered according to a standard scheme. A well-designed investigative tool implies a significant reduction in uncertainties and errors in the subsequent phases of data collection, processing, and analysis.

It is good practice for the initial part to be dedicated to an illustrative section, in which the objectives of the research and the purposes it covers are explained and specified. This presentation, often considered superfluous, plays an important role in allowing the researcher to illustrate clearly the reasons for investigating the population's opinion and establishing a relationship of trust.

The compilation should then continue following a "funnel" scheme, gradually moving towards increasingly specific questions. It is a mistake to think that the registry/sociographic context should be placed in the final part of the questionnaire to prevent the initial premises from being contradicted, placing the interviewee in a suspicious position regarding the investigation and its purposes.

Useful indications for a general approach are presented in the ISO Technical Standard [28], even if it regards a survey model at home, and specifically refers to questions on noise annoyance. These guidelines are appropriate for conducting surveys on long-term noise annoyance. Two kinds of questions can be constructed: one with a verbal rating scale (Not at all—Slightly—Moderately—Very—Extremely) and the other with a numerical rating scale of 0 to 10, by indicating the meaning of the two extremes.

The standard is currently being reviewed, and a recent version proposes to conduct the overall evaluation using weighting factors. Recent studies propose values of the weighting factor for verbal responses to achieve a satisfactory comparison between the two

methods. This is performed to ensure that the verbal responses are taken into account in an appropriate and accurate manner [42,43].

The questionnaires for soundscape evaluation proposed in the technical specification ISO/TS 12913-2 [28] are edited in the English language. A problem related to the correct translation of each question and the possible answers in all the proposed methods has been addressed in [44]. In [45], the proper application of a translation methodology is outlined, especially in cases where there are no corresponding words in the target language.

4. Specific Observations on a Questionnaire for Acoustic Investigations

When administering a questionnaire for acoustic investigations, aspects related to sound/acoustic perception become obviously fundamental. These investigations concern the sensory sphere and involve subjective assessments, which are independent of the mere objectivity of the phenomenon being investigated. Noise perception is a particularly complex issue as it involves physical, neurological, and psychological areas. These aspects, when combined, can generate very different perceptions between different subjects, even with the same stimulus.

The variability of the results of an acoustic investigation is different if it refers to the evaluation of an internal environment (building or architectural acoustics) or an external environment (environmental acoustics). In the former case, attention is paid to the usability of the spaces and the comfort of the living environment, taking into account the influence of the phenomenon on daily life activities. In the latter case, the respondent is immersed in a sound landscape where the number of sources and environmental factors are difficult to control and subject to change.

To obtain a good response from the subjects involved in the investigation, it is necessary to contextualize the research and consider all possible aspects that may influence the responses and consequently the outcome of the study [46,47].

4.1. Annoying Noise Characteristics

The perception of noise is strongly influenced by the acoustic context in which it is generated. For example, a disturbance that occurs in an already compromised acoustic environment is generally less annoying than a disturbance that occurs in a low-noise situation. To complicate matters further, there are other factors, such as the temporal trend associated with annoying noise (continuous, fluctuating, impulsive) and the characteristics of the background noise (continuous, fluctuating) [48,49].

On a physical level, stationary noise has almost constant energy as a function of time, while fluctuating noise has characteristics of temporal variability according to a more or less regular trend. An impulsive noise is an event that occurs one or more times with a concentrated amount of energy in a very short interval of time.

In the perceptual environment, a continuous noise, if characterized by a contained level and without potentially annoying tonal components, can become part of the daily background through a neurological process that allows our brain to get used to recognizing it and “cancel” it out compared to the association with a disturbed condition.

This obviously does not apply to impulsive noises, as neurological processing, mostly atavistic, associates a threat with a sudden event. In addition, impulsive noises are perceived more intrusively than noises with a continuous or fluctuating course. For example, the sound of a dripping tap, although it has a very low acoustic energy content, can be unbearable for a person who is trying to fall asleep. Conversely, the same person, subject to the sound of a stream or pouring rain, with much greater energy than that of the tap, in most cases, finds this situation conducive to falling asleep.

It is important to highlight that noise can be more or less disturbing depending on the frequencies that constitute it. Fletcher’s masking studies [50] have demonstrated that one tone with a high amplitude can mask another tone that is close in frequency but with a lower amplitude. This indicates that the disturbance caused by an acoustic phenomenon is not only linked to the energy of the phenomenon itself, but also to other characteristics

such as variability in the time and frequency domains, as well as the acoustic context in which it occurs.

However, any assessment of acoustic quality is affected by subjective preferences for the perceived sound and the discomfort it may cause to individuals. For instance, evaluations of noise pollution in public parks [51] have identified areas where the sound level limits that should characterize quiet areas were exceeded, despite some interviewees expressing appreciation for the sound environment in the park. This implies that noise mitigation actions should be taken to reduce noise levels, even if some individuals enjoy the sound environment.

In another study that examined the effects of soundscape complexity on urban noise annoyance ratings, the impact of traffic-related sound sources received a higher score in the noise annoyance evaluation than nature-related sound sources, with comparable noise levels [52,53]. These results confirm that the type of sound, which can be classified as pleasant or unpleasant, also influences the judgment of annoyance associated with its presence in the urban environment.

An acoustic questionnaire needs to take into account that technical aspects should be linked to perception. They are part of the contextualization processes of the phenomenon, and therefore need to be analysed in order to characterize the sound sources present in the environment under investigation, as will be discussed later.

4.2. Boundary Conditions

Acoustic questionnaires are generally used to evaluate the discomfort caused by the presence of one or more noise sources in a given environment, or to understand the level of comfort related to the listening conditions. Since these assessments are related to sensory perception, it is important to include questions about the respondent's state of health and quality of life in the questionnaire and/or tests aimed at understanding their hearing ability.

To assess the respondent's hearing ability, a multimedia instrument that allows the interviewee to listen to soundtracks in specific frequency fields may be necessary. This would help to define the listening range with non-marginal limits due to device characteristics. These exploratory questions should be asked in a preliminary phase of the questionnaire to determine its validity. If multimedia tools are not available, the validity of the investigation relies on the sincerity of the respondent, without direct verification by the researcher.

Health-related questions may include requests to indicate if the respondent is suffering from any pathology or disease that may affect their responses. Quality of life can be investigated by asking about the level of satisfaction with daily activities [54,55].

Since these questionnaires are related to the user's experience, it is not possible to rely on market research to guide their design, as the respondent is not necessarily a consumer. Therefore, attention should be focused on the comfort connected to the respondent's life in the specific environment being investigated.

In the case of building or architectural acoustics, the questions relating to behaviour and attitudes should concern not only acoustic aspects but also specific assessments of the context under investigation and all the components that contribute to the comfort of the environment's users. Specifically, it is necessary to investigate not only acoustic aspects but also thermal, hygrometric, and lighting aspects. However, the acoustic aspect cannot be isolated from the context, as all factors together determine the overall comfort, and the poor quality of any one of the elements mentioned above can also affect the others.

Thermal comfort also affects the perception of acoustic comfort outdoors. In a study [56], the relationship between acoustic perception and thermal comfort was analysed, and it was found that people experienced higher thermal comfort with natural sounds and meaningful sound (broadcasting music). The authors found that satisfying thermal sensation was perceived when people were acoustically comfortable, while low thermal comfort was a consequence of acoustic discomfort. However, in a study involving elderly adults, it was found that thermal sensation and comfort judgments were susceptible to the acoustic and

visual environments, while the influence of the visual environment and temperature on acoustic sensation and comfort evaluation was not significant [57].

Moreover, it was observed that there is a seasonal dependence on these aspects: in the summer, overall comfort is mostly affected by thermal comfort, while in the spring, acoustic comfort has the highest impact on comfort. The thermal and acoustic environment has some influence on subjective evaluations. It was found that high traffic noise intensifies the sensation of heat in summer in the thermal evaluations. In the acoustic evaluations, low temperature in the winter and high temperature in the summer increase acoustic discomfort [58].

In general, the sensation produced by the other components that characterize the urban space under investigation has an influence on the judgment of the acoustic quality. In many cases, investigations should also take into account the assessment of aspects related to air pollution and air quality, urban safety and legality, presence of public green areas, urban layout, hygienic conditions, and the healthiness of areas, liveliness of the city, and presence of commercial and work activities.

For example, comparing a town square with high air pollution, disorder, and widespread urban decay to another characterized by the presence of public green areas, order, and cleanliness, both influenced by the same noise level, is likely to lead to a negative judgment for the first case rather than the second one.

From this, it can be deduced that the boundary conditions in terms of perception of the environment mutually influence each other, creating in the subject a prejudiced attitude towards aspects that characterize the environment.

Another aspect that deserves investigation in an acoustic questionnaire is the time spent in the places under investigation. An appropriate formulation for these types of questions could be: "How much time do you spend at home/office/outdoors/etc.?" with a structured response on a scale such as: "up to 8 h/8 to 12 h/from 12 to 16 h/over 16 h."

Temporal permanence is an important element because it allows the quantification of the time of exposure to the source of noise and therefore the impact that this can have on the psychophysical state of the interviewee.

As the investigation tool explores into increasingly specific questions regarding the object of study, according to the previously defined 'funnel' scheme, the level of processing difficulty of the investigation tool increases. In building/architectural acoustics, the size and number of sources are known variables and limited to the situation, as already highlighted; in environmental acoustics, these characteristics are not always predictable, and indeed they are often unknown.

A good solution could be represented by identifying macro-areas associated with sound environments in order to group a significant number of sound sources, both known and unknown, within a single sub-group. Here are some examples of macro-areas relating to different environmental noises:

- Anthropogenic noise (voices, footsteps, screams, laughter, nightlife, shops, etc.).
- Infrastructure noise (vehicular traffic, rail traffic, ship traffic, air traffic).
- Industrial noise (industrial activities such as textiles, metallurgy, drilling wells, etc.).
- Nature noise (wind, rain, sea, animals, etc.).
- Technological noise (HVAC, cooling/heating systems, fans, filters, etc., at home).

In relation to the indicated macro-areas, it would be useful to have an indication of how frequently the subjects hear these noises throughout the day, using structured or numerical response scales with defined limits (for example, from rarely to frequently). Furthermore, information on the perceived sound intensity corresponding to the noises heard, using similar response scales, is also important (for example, by setting "high/low" or "loud/weak" as scale limits).

In Figure 2, an example is given of categories of sound sources that can be considered in an acoustic survey [59].

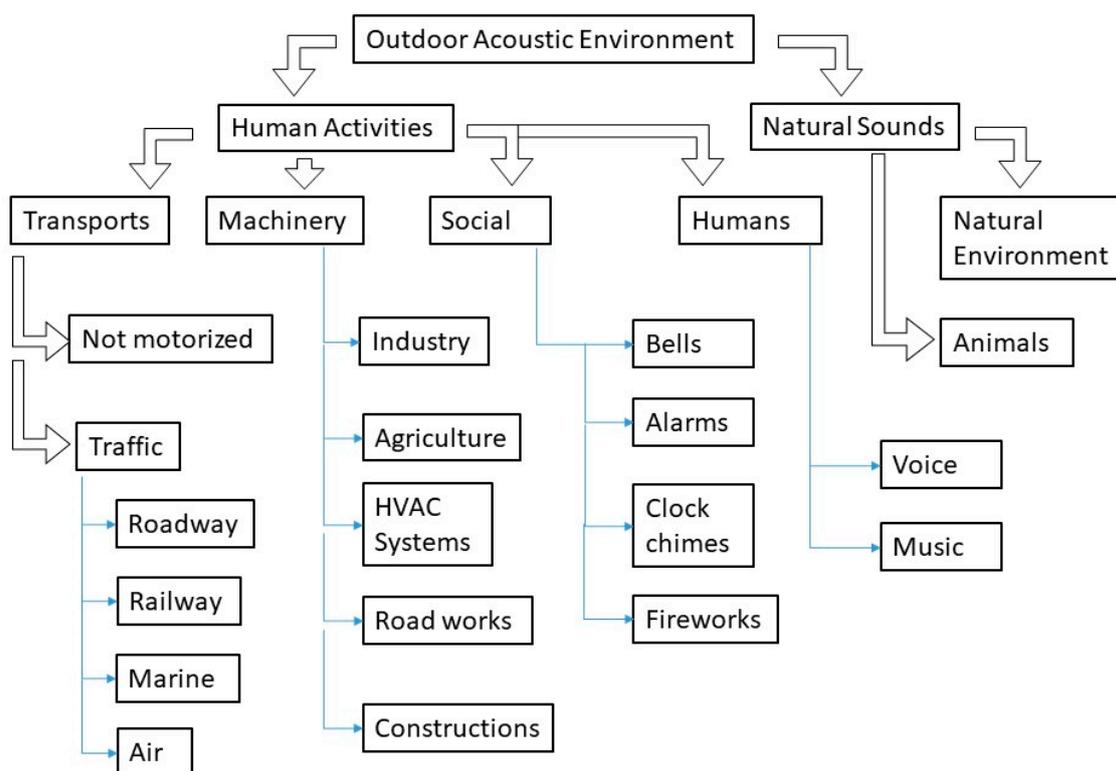


Figure 2. Example of sound-source categories.

The response scales used to indicate the noise that mainly refers to the sound environment can be structured and polytomic. They mainly use adjectives such as annoying, noisy, unpleasant, and disturbing, which contrast with others such as pleasant, silent, agreeable, and relaxing. If the extremes of the scale represented by contrary terms are not used, adverbs and other words can be used for the purpose of strengthening or weakening the concept (examples: little, enough, much, neither-nor, etc.).

4.3. Administration Related Issues

Questionnaires used in the field of acoustics belong to the category of surveys that aim to evaluate perception. As mentioned in the generic formulation of a questionnaire, perceptual aspects involve the presence of a sensory stimulus that initiates the process leading to the definition of an experience.

A good way to investigate a sensory aspect is to stimulate the sensory organ to activate it. Just as knowledge of the perception of flavour corresponds to the action of tasting, and knowledge of the perception of an odour corresponds to the action of smelling, noise also requires a particular action that corresponds to listening. However, these activities are often difficult or impossible to carry out due to the method of administration.

In general, the absence of direct stimulation of the sensory organ implies the activation of memory or, in any case, a mnemonic process, which has a particular sensation, and in some way, the re-elaborative activity of thought can be distorted, leading to a result that is not strictly objective.

If the sensation or emotion felt in relation to a particular sensory activity does not manifest itself strongly and precisely, making it difficult to remain inside, it is difficult to express a real judgment on the event. An optimal administration of a questionnaire linked to perception should be conducted, therefore, directly in the context of the investigation or in a different place but subjecting the subject to the sensory stimulus [60].

In the case of an acoustic questionnaire, this means that the compilation should take place in an external environment, in the case of environmental acoustic investigations [51,61], or in an internal environment, in case of investigations in building/architectural acoustics.

If it is impossible to put the respondent in these conditions, it is possible to set up audio, extracted from the contexts of investigations or similar to them. This excludes all postal and paper administrations a priori, with limiting effects also on the possibility of telephone inquiries.

In the event that the planned administration is online or face-to-face, there are still difficulties related to the limitations of the acoustic devices used. It is important to remember that devices such as computers, tablets, and smartphones are not able to reproduce low frequencies, with limits usually at 100 Hz, while distortions may be generated above some high frequencies.

Another issue is the regulation of listening volume, which again depends on the devices, and can only be solved in the case of online administration when the interviewees are in the same environment, using the same devices, and generating a homogeneous and unambiguous stimulus.

An important step in preparing the questionnaire is normalizing the audio tracks, a process where the signal amplitude is increased or reduced to standardize it and obtain uniform input for all respondents.

In addition to environmental conditions, attention must also be paid to the timing of administration. The psychological conditions of subjects can fluctuate considerably depending on the month of the year, day of the week, or different times of the day. Stress levels are typically higher before and after holidays, during the summer and Christmas, at the beginning of the week, and at the end of the day. These uncomfortable conditions can result in highly negative and intolerant responses. To avoid such influences, it is preferable to analyse in advance and identify the most appropriate moments for administration.

4.4. Procedural Implications due to the Source

The questions of an acoustic questionnaire largely concern the influence of the source(s) in the sound environment, both outdoors and indoors.

In building and architectural acoustics, the sources of noise are clearly identifiable, as well as the investigation objectives with reference to different environments. In the case of residential environments, the analysis is often connected to the reverberation time and the degree of acoustic insulation of floors, ceilings, walls, fixtures, etc., against noise coming from both adjacent spaces and the external environment. Depending on the place intended for the study, many factors can be investigated. The considerations made for residential environments can be extended to all private and public environments, such as schools, auditoriums, conference rooms, etc. In many cases, the assessment of speech intelligibility, by means of the Speech Transmission Index (STI), is also important, and should be considered in the evaluations.

In the external environment, the relationship between subjects and sources of noise, as well as their influence on the perception of the overall sound environment, are based on analyses that must take into account numerous other elements. One of these is the distance from the source or group of sources being examined. Depending on the position from the source, certain frequency components may prevail. Low-frequency components are perceived even at great distances, unlike high-frequency components that can be lost due to atmospheric attenuation effects.

Other important aspects are connected to meteorological conditions, particularly wind direction and thermal inversion phenomena. These conditions can contribute to modifying the propagation of sound waves and interfere with the perception of the phenomenon.

Regarding thermal inversion, the heat released by the ground causes the air to become colder near the Earth and warmer at higher altitudes. In this situation, the sound can reach points that it would not have reached under constant temperature conditions, with the possibility of going even further than in a normal situation.

Even the wind can 'redirect' noise to places other than those it would have reached in its absence. In this case, it is not a matter of transport, as is often mistakenly thought, but

rather of refractive effects, which generate a change in direction compared to the natural propagation path.

These aspects must also be considered during the preliminary assessments aimed at creating a questionnaire, especially in cases where the administration takes place directly at the location of interest. This is to ensure the maximum correspondence with the normal or usual situation of exposure to noise.

5. Discussion and Conclusions

In the previous sections, general observations on questionnaire structure that can be applied in different fields have covered some main aspects regarding the administration method, characterization of the sample population, question structuring, question classification and type, and language and graphic limitations. Moreover, referring to questionnaires for acoustic investigations, aspects related to characteristics of annoying noise, boundary conditions, administration-related issues, and procedural implications due to the source have been discussed.

To make the most effective use of technological development, improve investigation techniques through questionnaires, and make them more reliable, further steps can be taken, especially in the field of reproducing situations in virtual reality and in an extended use of mobile devices for questionnaire completion.

On one hand, the creation of virtual soundscapes and immersive solutions for representing the real environment recreated in the laboratory allows for the evaluation of very different situations in the same place and the effective comparison of various sound environments in shorter times. On the other hand, the possibility of using mobile-phone applications for questionnaire completion in the outdoor environment facilitates the distribution of survey forms to a large number of individuals and the collection of data.

Virtual reality has been tested in various scenarios, for example in [27] with the use of an online application, to simulate street design and traffic restriction scenarios. Some studies have analysed the differences between people's behaviour in virtual and real environments. In [62], the research results lead to affirm that a virtual simulation of the environment is closer to reality if its visual features are completed with acoustic characteristics.

To effectively represent the real environment, it is necessary to pay attention to various elements not only related to visual perception but also to the physical characteristics of the reproduced sounds, especially spectral components and temporal variations, as highlighted in [63]. The ability to analyse various scenarios using virtual reality representation techniques and conduct in-depth research on the visual cityscape perception of a large number of human subjects has been utilized in [64] to explore new frontiers in the application of digital technologies to smart-city planning.

An effective alternative to creating virtual environments that accurately represent external environments to consider a wide variety of situations and soundscapes is represented by a more extensive participation in surveys that can take place through mobile phone applications. In this case, the questionnaire completion can involve a wider variety of individuals compared to investigations using virtual reality. The advantages regarding the high number of questionnaires, the heterogeneity of the interviewees, and the rapidity of processing the responses are undeniable, although the sampling methods and other aspects that have been discussed in the previous sections still need to be defined.

Like all subjective investigations, those related to acoustics require a particular degree of attention and knowledge in the field of research. The creation of tools such as questionnaires is a complex operation in relation to the objective to be pursued. This study has provided comments on different aspects that can be included in a questionnaire. The observations intend to contribute to the realization of questionnaires in the acoustic field and support the aspects addressed in the ISO/TS 12913-2 technical standard, given the vastness of the subject and the variability of the contents.

From the considerations presented in this study, the critical phases related to a general formulation of a questionnaire survey can be identified in three processes: preliminary study and definition of the focus, structuring of the questionnaire (types of questions and answer scales), and method of administration.

Starting from the first steps, the effectiveness of the investigation depends on a large number of variables, and the degree of detail must be defined at once, assuming and foreseeing all possible situations that may generate interference or distortions in relation to the project focus. This is a very important and delicate phase, which could compromise the validity of the efforts and the analyses.

Some aspects have been analysed: the structure of the questionnaire, the administration method, the characterization of the sample population, the question structuring, the question classification and type, and the language and graphic limitations. Furthermore, in the acoustic field, the contextualization of the phenomenon under investigation is a fundamental procedure; the situation can take on completely different characteristics depending on the sound environment (internal or external), the type of expected annoying-noise source(s), and the surrounding conditions (other environmental parameters that contribute to the comfort of the user). Therefore, aspects related to the characteristics of annoying noise, boundary conditions, administration-related issues, and procedural implications due to the source have been discussed.

The final objective of the investigation can only be achieved through a scrupulous and thorough analysis of all these aspects in their entirety.

The study also provides some concluding notes on potential future developments related to the use and administration of questionnaires in the field of environmental noise and soundscape analysis. In the near future, our plan is to analyse questionnaire results with a focus on the aspects emphasized during their design. This analysis aims to assess the degree of success in relation to the level of accuracy employed in the questionnaire design.

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