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Does the method matter? A review of the main testing methods for the subjective evaluation of room acoustics through listening tests

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ABSTRACT

The listening tests are experimental procedures in which a group of participants are asked to express their opinion about certain questions regarding some stimuli that they have been urged to listen to. The listening tests have proved their effectiveness as methods for the subjective assessment of perception in different fields of acoustics, and particularly in room acoustics and sound insulation. The way in which the listening test is conducted, how the participant's response is expressed and how the stimuli are presented to the participants define what is known as the testing/query method. There is not yet a common methodological framework that defines which testing method is the best for each purpose and under what conditions the experiments are to be carried out. The purpose of this communication is to review the most commonly used testing methods in the subjective perception of sound and to present the advantages and disadvantages of each of them when they are used to evaluate the subjective perception of a sample of population.

Keywords: listening test, room acoustics

1. INTRODUCTION

Sensory evaluation tests allow to obtain the subjective perception of human beings regarding certain stimuli that are presented to them. This type of test has been found to be very useful in the commercial sector, when aiming to improve, consolidate or renew products, so that the population better perceives them. They are also used to assess how reducing costs on certain materials or processes affects the perceived quality of the final product. In this sense, these types of tests are used regularly in the fields of food (1), fragrances (2) and design (3), among others.

Although the use of subjective tests is not new in the field of acoustics, this kind of testing has gained great importance in recent decades. A paradigm shift in acoustics is taking place, centred on the fact that the objective descriptors used to assess acoustic quality should be more representative of the subjective perception of human beings.

In particular, in the field of environmental acoustics, concepts such as "soundscape" (4) and psychoacoustic parameters have taken on an important relevance in recent years. Listening tests are being used to evaluate how human beings perceive soundscapes and how this perception can affect their actions (5,6).

In the field of building acoustics, the most recent research related to the assessment of sound insulation is also based on listening tests. These tests are mainly focused on evaluating the degree of agreement between the SNQs (Single Number Quantities), commonly used to assess the protection contributed by a sound insulation element, and the subjective perception of loudness and annoyance (7,8).

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In the field of room acoustics, in recent years, listening tests have also gained great interest. They are mainly aimed to determine the just noticeable differences (JND) of the room acoustic descriptors that are frequently used to evaluate the acoustic quality of venues. Among these descriptors reverberation time, clarity or definition, as well as spatial parameters such as apparent source width (ASW) or listener envelopment (LEV) are of great interest (9,10).

Finally, since the term auralization was coined and, in particular, since this term is supported by the rise of new virtual reality applications, listening tests are of great importance in this field. Main research is related with the model calibration requirements as well as the precision of the simulation software, models and HRTFs (Head-Related Transfer Functions). The common aim is that differences between real situations and simulations are as small as possible and that auralizations are always perceived as plausible (11–13).

In other completely different fields, such as food research, great efforts are being made to develop subjective tests that are as reproducible as possible (14,15). Therefore, numerous studies have been conducted in the last years in order to determine the best testing method and design of the experiment, so that the tests are comparable and accurate. In the field of acoustics, although numerous listening tests are being performed, there are not yet clear methodologies for their design and performance. This fact can make the comparison between the results of different investigations difficult and tedious.

The purpose of this communication is to review the listening tests that have been recently undertaken in the field of room acoustics, in order to assess to what extent, the different works are following similar or different methodologies in each of the stages of the process. The main differences between researches are discussed and certain conclusions are drawn, which may be useful for improving the subjective evaluation in the field of room acoustics.

2. METHODOLOGY

The methodology followed in this review was divided into several steps: First, a detailed search for references in the fields of study was performed. Then, the references found were filtered in order to select only those that were relevant. Finally, a series of common concepts were defined and collected from each reference. Each of these steps is described individually below:

2.1 Literature search

In order to carry out this review, an extensive search has been carried out for the most recent bibliographical references (mostly between 2009 and 2017) in the field of subjective assessment of room acoustics descriptors, although some older references (between 1993 and 2005) have also been considered due to their relevance in the field under study. This search for the state of the art was done during the months of December 2018 and February 2019, although some of the references were originally collected in August 2017.

In order to perform this search, scientific databases have been used, as well as scientific social networks and specific search engines. In particular, most of the references have been found through Google Scholar, ScienceDirect and ResearchGate. Different procedures were followed for the search:

1. ***Search by keywords**:* This was the main search method. Scientific search engines and databases were used for keywords such as "perception", "perceptual", "subjective", "room acoustics", "reverberation time", "clarity", "JND", "just-noticeable-difference" or "virtual”.
2. ***Search by affinity:*** Databases such as ScienceDirect suggest similar references to the last consulted by affinity between concepts.
3. ***Search by references:*** Consultation of the bibliography of the most recent articles allows, on some occasions, to obtain references to previous related articles.
4. ***Search by author:*** Some authors focus all their research activity on the same field, so that on some occasions several articles by the same researcher were found in the field of study.

2.2 Filtering of the literature

From the conducted search, 15 references were obtained (9,10,16–28), which were selected, in a preliminary way, only by reviewing the title or the abstract. After completing the search tasks, a deeper filtering of the articles was done in order to use only those that were directly related to the purpose of the review. Therefore, only journal and conference papers, in which a subjective study was performed by means of listening tests and in which the methodological design and the analysis of the listening test results had an important contribution were used. This task reduced the number of papers to 8 (9,10,16,20,22,23,25,28).

2.3 Definition of common concepts

As already mentioned in the introduction, listening tests are tools for the subjective characterization of sound in which a series of participants are presented with various stimuli and their judgement about these stimuli is collected through some system. Since a listening test is a tool that interacts with the human being, there are several sources of bias that can reduce the relevance of the experiment or even lead to erroneous conclusions. Therefore, when reviewing listening test studies, it is important to evaluate concepts such as the following:

1. ***Purpose of the experiment:*** What is the experiment intended to study?
2. ***Testing method:*** How is the consultation and collection of results addressed?
3. ***Selection and preparation of stimuli:*** What sound samples were used? How were they processed?
4. ***Method of analysis:*** Which statistical method was employed for the analysis of the results?
5. ***Quality of the design:*** Is the performed design robust? How many participants did the experiment have? Is it possible to identify design actions that were presumably aimed to reduce bias?

For the sake of simplicity, the particular results of each of these studies are not taken into account, as this is not within the scope of this review, which relates to the design of the listening test methods.

3. RESULTS

In this section, each of the eight articles presented in the previous section is described in detail, considering each of the five common concepts. A summary of this analysis is shown in Table 1.

In reference (22), the purpose of the research was to measure the smallest perceivable change in the objective room acoustic parameters associated with spatial impression and clarity. For that purpose, the difference limens for ELEF (early lateral energy fraction), IACC (inter-aural cross correlation), Ts (centre time) and C80(clarity) were addressed. In order to find the difference limens, the "Method of Minimal Changes" was used with 7 to 10 participants. The experiment was conducted in an anechoic environment where simulated variations of a concert hall were played through a loudspeaker system, comprising delays, effects and attenuators. Two sound samples were used for the listening test, a 8s. excerpt of "Handel's Watermusic" and a 5s. excerpt of "Mendelsohn's Symphony no.3 Opus 56 *The Scottish*". The analysis of the results was mainly based on the calculation of the difference limens as the smallest perceivable changes that are perceived by at least 50% of the participants, which is the regular method of analysis for a Minimal Changes testing method. Confidence intervals at 95% were also given. Presumably, a couple of actions were aimed to the reduction of bias. First, only normal hearing participants could perform the test, even though their hearing was not tested. Fatigue effects were checked through F-test analysis.

The suitability of various objective measures as predictors of subjective ratings was examined in(23). In particular the relation between the EDT (early decay time), Ts, C80, G (loudness), early bass level and treble ratio, and the subjective perception was addressed. For that purpose, a sample of 10 subjects performed 8 different listening tests ranking several sound fields in terms of loudness, clarity, reverberance, envelopment, apparent source width and overall preference. The testing method was based on double blind paired comparisons (attribute-related 2-AFC). The sound fields were generated through near-field loudspeakers, equipped with mechanical barriers to avoid crosstalk. Just one sound sample was used during the listening test, a 15s. passage of "Mozart's La Nozze di Figaro". The analysis of the results was based on the regression analysis between the preference counts of the subjective perception attributes and the room acoustic objective parameters described. Regarding bias control, it is said that being a difference test, any imperfection in the reproduction chain would be minimized. A description of the parameters to evaluate was given before the test and a brief training sequence performed.

The purpose of (9) was to find the just noticeable difference for C50. For that purpose simulated sound fields representing realistic situations were played through a 8-loudspeaker system, similar to that of (22), in an anechoic environment. 10 participants took part in a listening test, which consisted in deciding whether there was difference between pairs of sound fields, with step changes in clarity of 0.5, 1.0, 1.5, 2.0, 2.5 and 4 dB. This test was repeated for three different sound fields with different reverberation times. A sound sample was played through the loudspeakers to allow the participants to perform the test, an anechoic male modified rhyme test at 3.0 syllables per second. To determine the JND for C50, the percentage of participants that perceived a difference was accounted for each clarity step, similar to the procedure described in (22). Also, regression was calculated between the subjective results and the reverberation time, to evaluate the change in perceived clarity with reverberation time. Two actions can be found, which presumably are aimed to reduce bias. First, the pairs of sounds were randomized. Also, a training was given before the test, in which the participants tested the extreme cases.

In (25), an experiment was developed to examine the discrimination threshold for the direct-to-reverberant energy ratio (v). For that purpose, 6 participants took part in a test following an adaptive 3-down 1-up two-alternative forced choice procedure through headphones. The individualized BRIR (binaural room impulse response) was measured for 5 out of the 6 participants and the different stimuli were obtained by scaling the reverberant energy of the BRIR. Four sound samples were convolved with the BRIR: a short duration noise burst of 50 ms with 2.5 ms onset/offset times, a long duration burst of 300 ms with 150 onset/offset times, a male speech sample of syllable /da/ of 300 ms and an impulsive signal, which was the BRIR itself. Several trials were repeated before the procedure stopped. Runs terminated after 20 reversals and the thresholds were determined as the average of the last 5 reversals. Also, psychometric functions were fitted for each stimulus and evaluated by Chi-square test. The reduction of bias was presumably the aim of different actions, such as the performance of an audiometry for each participant, the individualized measurement of the BRIRs as well as the individualized headphone equalization (HpTF).

A research was performed in (10), with the aim of determining the difference limen for single number parameters relating the ASW and LEV. For that purpose, the BRIRs of different venues were measured with a dummy head in positions with different LF (lateral energy fraction) and LG (lateral sound level). These BRIRs were later convoluted with a sound sample and presented to the participants through a crosstalk cancellation loudspeaker system. The sound sample was a 14s. excerpt of "Haydn's Trumpet Concerto played with an E flat Cornet". Different participants samples were used in individual listening tests for LF changes (12 participants) and LG changes (7 participants). The testing method was similar to the others, were the participants listened to stimuli in pairs and had to make a judgment about the stimuli being the same or different. From the results of the listening test, the difference limens were calculated by means of the fitting of the psychometric function a Monte Carlo simulation for the goodness of fit. Several actions could be found, which presumably aimed to reduce bias. In particular, the participants might not repeat the hearing of the samples. That way, it was assured that identical audio presentation is given to each participant. Also, all participants received an audiometry, to check the hearing. A training and familiarization process was performed by the participants prior to the test, where extreme cases could be listened. Instructions were given by means of a written guide. The experimenter collected data about the difficulty perceived by the participants.

The approach of (16) was to investigate the possible dependence of the JND of the Ts and C80 as a function of the reverberation time in large reverberant enclosures. Impulse responses were measured in B-format and later varied in clarity parameters. These impulse responses were then convolved with two sound samples and played in a silent room through four loudspeakers. A 5s. excerpt of "Pange Lingua" and a 9s. excerpt from "Weber's Theme for Cello" were used. The "Method of Minimal Changes" was then used, in which around 40 participants were presented with two stimuli and had to decide whether they were the same or different. If the participants identified the stimuli as different, they had also to report which was the clearer. As the "Method of Minimal Changes" was employed, the JND was defined as the smallest perceivable change detected by 50% of the participants. Regarding bias, the participants were not test for hearing but asked about hearing issues. Sound samples were presented randomly. To avoid any learning or memory effect, listening test for each stimulus were carried in different days. Participants were asked about the design of the experiment and some reported difficulties regarding the concept of clarity, with graphical interface and with failing to find an effective listening method.

The determination of the necessary change of the primary cues, such as ITD (interaural time difference), ILD (interaural level difference) and IACC for subjects to detect them was investigated in (20) . For that purpose, the ITD and ILD of the early part of measured BRIRs, corresponding to three different environments, were manipulated. Eight participants conducted an adaptive three-interval 2-AFC test, following a 1-up 2-down staircase procedure. A 2s. excerpt of three different sound samples was randomly selected. Sound samples were recordings of a guitar, a violin and snare drum. The results were presented as mean values and standard errors of detection for the different rooms and instruments. Regarding bias control, each test is repeated four times. However, there is no mention in the article regarding training or familiarization processes, the environment, equipment or equalization of the playback chain.

Finally, in (28), the focus was on the evaluation of the JND of C80 and the assessment of whether a variation in the way the stimuli are presented to the participants gave the same or different results for the JND. For that purpose, several simulated impulses responses were used, and sound samples convoluted with these IR (impulse responses) used as stimuli. The stimuli were presented to the participants, in an anechoic environment, through a 8-channel loudspeaker system. 51 participants were presented with the first variant of the test, where the participants were presented with stimuli in pairs and had to listening to both stimuli, in order and in full, and judge whether the they were the same or not. They might listen to the stimuli as much as they wanted but they had to listen both stimuli, completely and following a fixed order, each time. 11 subjects were presented with the second variant of the test, where the participants might switch between stimuli during the reproduction of the sound sample as much as they wanted and didn't have to listen to the stimuli in full. Three different sound samples were used for the first listening test. A 10.9s. passage of the "Third movement of Bizet's L'Arlésienne Suite No. 2", a 10.3s. excerpt of "Weber's Theme" and a 10.3s. motif of the beginning of "Handel's Water Music". For the second test, the Bizet piece was used again. In addition, a sample which length was not reported was used of the "Debussy's Prelude to the Afternoon of the Faun". The analysis of the results followed the same as for the method of Minimal Changes. Regarding the control of bias, the impulses responses and sound samples were randomized. Training was given prior to the listening test, with samples and impulses responses not used later during the test. Hearing level was measured for each participant.

4. DISCUSSION

Several research articles are presented, in which the main purpose is the study of the JND for several room acoustic parameters. Even though some trends can be found regarding the testing method used for the presentation of the stimuli and consultation of the participants, three main different methods are identified; the Method of Minimal Changes, the attribute-related 2-AFC and adaptive up-down approaches based on non-attributive 2-AFC procedures. In particular, the third is a more precise and efficient method of the first. Both the first and the third are based on a non-attributive 2-AFC also called same-different method. Being this method prone to tendency bias among others (29), it is considered that further research is necessary, to find newer testing methods that are more efficient and less prone to bias. Not only how the participants are consulted but also how the participants interact with the stimuli should be considered for deeper analysis. It can be found that some works (9,16,23) prefer to leave the participants freedom of choice, allowing them to control the reproduction, while others prefer to fix how the stimuli are presented (10,25). Specially interesting are the results of (28), where performing the listening test with different procedures regarding this matter reported different results.

Table 1 – Summary of common concepts for all the reviewed articles

Reference	(22)	(23)	(9)	(25)	(10)	(16)	(20)	(28)
Purpose of the study	ELEF, IACC, Ts, C80	EDT, Ts, C80, G, treble, bass	C50	*v*	ASW, LEV	Ts, C80	ITD, ILD, IACC	C80
Participants	7 - 10	10	10	6	7 - 12	40	8	11 - 51
Testing method	Minimal Changes	Attribute 2-AFC	Same - different	Adaptive 2-AFC	Same - different	Minimal Changes	Adaptive 3I/2-AFC	Same-different
Stimuli and duration	S1. Water Music – 8s S2. The Scottish - 5s	S1. Nozze Figaro – 15s	S1. Male rhyme test - Loop	S1. Burst - 50 ms S2. Burst - 300 ms S3. /da/ - 300 ms S4. Impulse	S1. Trumpet concerto Cornet – 15s	S1. Pange Lingua – 5s S2. Theme for Cello – 9s	S1. Guitar – 2s S2. Violin - 2s S3. Snare drum – 2s	S1. L'Arlésienne Suite n.2 – 10.9s S2. Theme for Cello – 10.3s S3. Water Music – 10.3s S4. Prelude…
Analysis method	Diff. limen 50% F-test analysis	Regression	% difference and regression	Psychometric function. Chi-square fit test	Psychometric function. Monte Carlo fit	Diff. limen 50% Psychometric function.	Mean and standard errors of detection	Diff. limen 50% Regression
Playback system	8 Loudspeakers	2 Loudspeakers	8 Loudspeakers	Headphones	2 Loudspeakers	4 Loudspeakers	Not mentioned	8 Loudspeakers
Training	Not mentioned	Yes	Yes	Not mentioned	Yes	Yes	Not mentioned	Yes
Playback method	Not mentioned	Free switching	Free switching	Fixed	Fixed	Free switching	Not mentioned	Both (fixed/free)
Audiometry	No	No	No	Yes	Yes	No	Not mentioned	Yes
Additional bias control	-	Written instructions	Random order of stimuli	Individual BRIR and HpTF	Written instructions	Participant feedback	Random choice of sound sample	Random order of stimuli

Regarding the sound samples, each research uses different samples and different durations. Even though in some occasions the papers justify why certain sound samples are selected, no clear background is given sustaining the selection. It is not clear for the authors whether unified sound samples should be described for all listening test regarding room acoustics. However, it is considered necessary that further deeper and detailed research is performed to evaluate the importance of the sound samples and their duration in the subjective perception of room acoustics. It is also considered, that the excerpts used by published works should be available for other researchers, so that they can used them for reproducible research.

Regarding the analysis of the results, a base descriptor should be selected among existing methods of analysis or research should be done to describe a new descriptor that can be extracted, independently of the nature of the difference and the purpose of the experiment that can make the results of different researches comparable.

Bias is an important factor that must be kept under control when performing subjective tests. Some sources of bias are related with the testing method and might be reduced by using better testing methods. However, other sources of bias can be related to the design of the experiment, the interaction between the participants and the experimenter, the participants themselves and the environment in which the listening test is to be performed. In this review, several actions that are presumably aimed to control and reduce bias could be found, which was not applied by all the works. The last four rows of table 1 exemplify this fact easily. In those cases where a mention was made regarding the training and familiarization of the participants, the playback method, the hearing level audiometry and playback chain equalization, different procedures were followed. More explanations should be given in the papers about the background sustaining the taken actions and further analysis must be done in those cases where no relevant background can be given.

In summary, citing Weinzierl and Vorländer (30) "*In room acoustics, we look back on more than 50 years of research on developing psychological measuring instruments for the concept of 'room acoustical impression', and on more than 100 years of research on the development of physical measures which could serve as technical predictors for these perceptual qualities. On both sides, the state of the art is surprisingly unsatisfactory.".* Therefore research in the field of subjective perception of room acoustics should not only focus on the application of listening tests to assess perceptible differences, but also on the evaluation, understanding and improvement of methods, so that clear methodologies can be described, which are followed by all researches in this field. In other words, it must be pursued that the study of the subjective perception of room acoustics is carried out through reproducible research.

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