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RELATION BETWEEN SELECTED ATTRIBUTES OF THE PERCEPTION SPACE AND THE EVALUATION OF SOUND FIDELITY

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The aim of the presented investigations was to determine the relations between the selected attributes of sound perception space and the subjective evaluation of sound "fidelity". Each sound examined was evaluated twice: for its "fidelity" with respect to the mental model and for the attributes of sound perception space ("clearness", "fullness", "spaciousness", "sharpness", "loudness", "lack of distortions"). We examined test signals (pink noise, white noise, speech signal and a musical piece) filtered by five kinds of filters and reproduced by a loudspeaker system. Hi-fi experts acted as subjects. Analysis of the results showed that "fullness", "sharpness" and "lack of distortions" determine the values of the subjective evaluation of sound "fidelity" when "fidelity" is evaluated with respect to a mental model.

1. Introduction

The quality of loudspeakers is evaluated by objective methods in which selected acoustic and electrical parameters are measured and by subjective methods in which the quality of reproduced sounds (of music and speech) is evaluated on the basis of a listening test. There are many methods of objective evaluation of loudspeakers. However, full correlation between the objective and subjective evaluations still lacks [1, 2]. This is why attempts are made to find such methods of objective evaluation of loudspeakers which would correlate with the subjective evaluation. In order to achieve this aim, we must first explain what physical parameters of a reproduced sound influence its evaluation in the listening test. To find these parameters must determine first how many independent criteria a subject uses to evaluate complex sound (such as speech or music). The authors have conducted investigations [3] on the basis of which they have identified six criteria of sound evaluation in a listening test: "fullness", "spaciousness", "sharpness", "clearness", "loudness" and "lack of distortions". These criteria have been called attributes of the sound perception space. It is known that auditory evaluation of loudspeakers is connected primarily with the evaluation of the "fidelity" of reproduction. Therefore, it was decided to determine which of the selected attributes of the sound perception space affect the auditory evaluation of its "fidelity".

The "fidelity" of a sound transmitted through a loudspeaker is evaluated objectively by the measurement of the difference between the physical parameters of the input signal at the microphone and the output signal at the loudspeaker, and subjectively by the evaluation of the difference in the perception of a sound transmitted by the loudspeaker and the original sound. If the differences are below the perception threshold, the transmitted sound is considered to be of "absolute fidelity". If few subjects perceive a difference between a sound radiated by the loudspeaker and the original sound, then the transmitted sound can be called a "high fidelity" sound [4].

The subjective evaluation of the "fidelity" with respect to the original sound is very rarely used in practice as such investigations are very laborious and costly. For these reasons, evaluations of "fidelly" are usually performed with respect to a certain model. The latter can be one of the following:
– an original sound remembered by the subject (mental model)
– a sound reproduced by a model loudspeaker
– a "simulated live" (a sound transmitted by the loudspeaker) the sound plays the role of the original sound [5].

In the present paper we discuss the results of investigations which allow to determine the relation between selected attributes of sound perception space and to evaluate its "fidelity" with respect to the mental model. The assumption is that this model of "fidelity" most closely approximates the practice of evaluation of the quality of reproduced sounds.

Knowing the physical parameters of sounds which affect the attributes of the sound perception space and knowing the relation between the evaluation of sound "fidelity" with the attributes of sound perception space, it is possible to determine which physical parameters of sound affect the evaluation of its "fidelity". Explanation of these relations will help to find the correlation between the objective and subjective evaluation of loudspeakers.

2. Method

2.1. *Signals and subjects*

Four one-minute test signals were examined:
*P*1 – pink noise (–3 dB/octave), sound level 80 dB (A)
*P*2 – speech – speaking male voice of the master of ceremonics in a theater. Sound level 75 dB (A). Gramophone record: PRONIT PLP0035
*P*3 – wideband music – orchestra, excerpt from "Les Préludes" by F. Liszt, performed by Berlin's Philharmonic Orchestra. Sound level about 75–85 dB (A). CD Deutsche Gramophone 413587-2 GH

*P*4 – white noise, sound level 80 dB (A).
All signals were filtered through each of the five filters whose frequency responses are shown in Fig. 1. The frequency responses of the filters have been selected to correspond to the frequency responses of various average class loudspeaker systems. After filtering, the number of signals to be investigated was 20, i.e., 4 test signals × 5 filters. They were reproduced through a stereo EXTRA FLAT loudspeaker system.

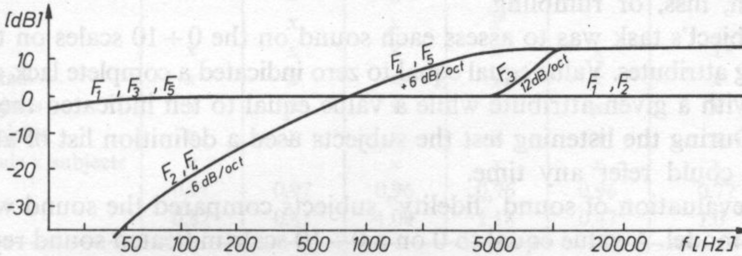

FIG. 1. Frequency responses of filters *F*1–*F*5

The sound levels given above refer to the level of the respective test signals as reproduced by the loudspeaker system with no filtering (*F*1) and measured by a sound level meter at the listener's position in the listening room.

The listening tests were presented in a listening room compatible with IEC standards [6].

Eight subjects (men aged 25–40 years) participated in the investigation. They were randomly chosen from among hi-fi experts.

2.2. *Procedure*

The evaluation of sounds was performed in two stages:

– at the first stage selected attributes of the sound perception space were evaluated

– at the second stage the "fidelity" of reproduced sound with respect to the mental model was evaluated.

The selection of sound attributes was based on the results of earlier investigations [3] in which it was found that the attributes may be defined as follows:

– "clearness" the sound is pure, clear; different instruments and voices can be easily distinguished, instruments and voices sound clear and pure without distortions, onsets, transients and other in the music details can be easily perceived

– "sharpness" the sound contains components whose mid- and high-frequency levels are too high

— "fullness" means that the sound contains the entire spectrum without any limitations, at least in the bass range. A sound which lacks the bass range is the opposite of a "full" sound

— "spaciousness" the reproductions is spacious, the sound is open, has width and depth, fills the room, gives the impression of the subject's presence in the space surrounded by sound

— "lack of distortions" indicates a pure sound, without distortions, one which is not harsh, hiss, or rumbling.

The subject's task was to assess each sound on the $0 \div 10$ scales on the basis of the following attributes. Value equal equal to zero indicated a complete lack of sensation connected with a given attribute while a value equal to ten indicated the maximum sensation. During the listening test the subjects used a definition list of attributes to which they could refer any time.

In the evaluation of sound "fidelity" subjects compared the sound with respect to a mental model. A value equal to 0 on a $0 \div 10$ scale indicated sound reproduction which differed most from the mental model while a value equal to 10 indicated an ideal reproduction of the mental model. Mental models of the white and pink noises were shaped in the subjects as a result of their long exposure to these types of sounds; the subjects were recruited from among designers of loudspeakers who are exposed to white and pink noises in their everyday work. At both stages of the investigations subjects evaluated each sound four times.

3. Results

The results of the subjective evaluation of sounds underwent a multidimensional analysis of variance (ANOVA) separately for each subject and for all subjects together [7]. A mixed model was used in which subjects were taken as a random factor, while test signals and filter characteristics were taken as a constant factor. The results of the evaluation of each attribute of sound were analyzed separately.

The analysis of variance makes possible estimates of reliability for each subject individually (the intra-individual reliability index r_w) and for all subjects together (the inter-individual reliability index r_b) [8]. The interpretation of reliability r_w and r_b should be considered with the random error MS_r. If $r_w > 0.70$ and $MS_r < 1.5$, the reliability is good, if $0.40 \leqslant r_w \leqslant 0.60$ and $MS_r < 1.50$, the reliability is satisfactory. However, if $r_w < 0.40$ and $MS_r \geqslant 1.50$, the reliability is not satisfactory.

The reliability index r_w ranged from 0.7 to 0.9 whereas MS_r ranged between 0.3 and 1.5, depending on the attribute and subject.

The obtained values of the reliability index r_w and random error MS_r show that the reliability for each subject is good.

Inter — individual variability r_b refers to the agreement between the ratings of different subjects. The results in Table 1 indicate that the subjects give similar weight to different perceptual dimensions.

Table 1. Results of the analysis of variance of group data, separately for particulary attributes of the perception space and for fidelity; x denotes statistically significant differences at the significance level $\alpha = 0.01$, r_b – reliability index for the agreement between subjects, MS_r – error variance

Source of variance	Clearness	Sharpness	Fullness	Spaciousness	Loudness	Lack of distortions	Fidelity
Filters	x	x	x	x	x		x
Signals		x	x	x			x
Subjects	x	x	x	x	x	x	x
Filters x signals	x	x	x	x	x	x	x
Filters x subjects	x	x	x	x	x	x	x
Signals x subjects	x	x	x	x	x	x	x
Filters x signals x subjects	x		x	x	x	x	x
r_b	0.91	0.97	0.96	0.96	0.96	0.77	0.97
MS_r	0.82	0.81	1.00	1.18	0.47	1.0	1.13

It follows from the analysis of individual and group data for a subjects that the evaluation of the attributes of the perception space of the sounds under investigation depends on:

a) the test signal – the sounds were differently evaluated depending on the test signal

b) subjects – different subjects tend to use somewhat different parts of the $0 \div 10$ scale

c) filter characteristics – the sounds were differentiated depending on the frequency responses of a filter through which the test signal was passed.

Table 1 shows results of the analysis of group data, separately for specific attributes of the perception space and "fidelity" (x denotes statistically significant differences between groups of sounds under comparison). Considering the fact that the analysis of variance showed statistically significant differences between the subjects, we can conclude that the subjects differed as to the absolute evaluation of sounds on the $0 \div 10$ scale. The results the subjective evaluation of sounds were therefore interpreted on the basis of the values of the median and not on those of the arithmetic mean, determined from the data obtained by all the subjects. Figure 2 shows values of the median of the subjective evaluation of sounds. The bottom and top quartils have been indicated.

It follows from Fig. 2 and Table 1 that:

– the evaluation of the "lack of distortions" of the sounds under investigations does not depend on the frequency response of a filter and the test signal but only on the interaction filter x test signal. This suggests that differentation of sounds is dependent on the kind of test signal filtered. This can be related to the fact that the influence of the filter frequency response on the spectrum of reproduced sound is dependent on the kind of test signal.

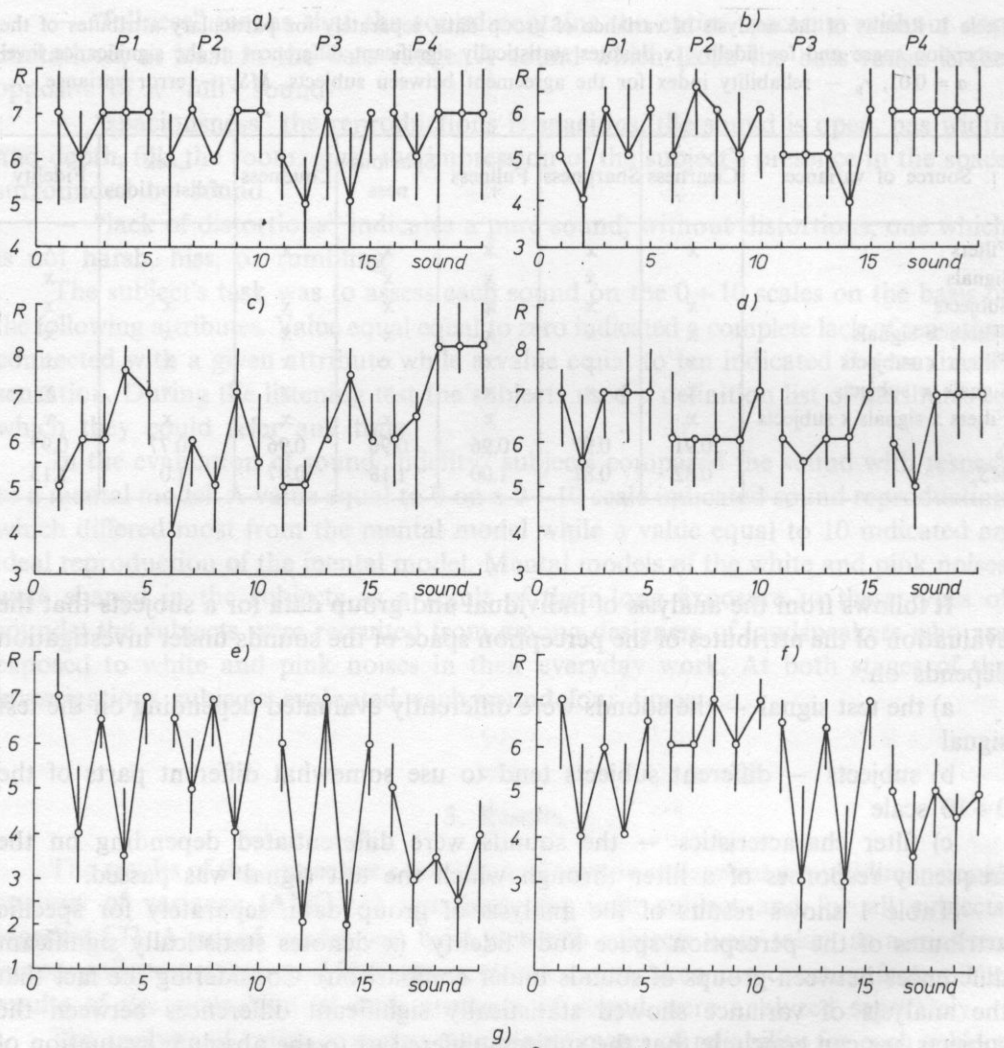

FIG. 2. Median values of the evaluation of attributes: a) "clearness", b) "lack of distortions", c) "sharpness", d) "loudness", e) "fullness", f) "spaciousness", g) "fidelity" of all sounds under investigation, where: R – denotes rating on the $0 \div 10$ scale $P1 \div P4$ – groups of sounds for particular test signals, correction with filters $F1 \div F5$. The bottom and top quartil have been marked

— the evaluation of "loudness" and "clearness" depends primarily on the frequency response of a filter through which the test signal was passed

— the evaluation of the remaining attributes of the perception space and "fidelity" is greatly affected by both the frequency response of a filter and the kind of test signals.

4. Analysis of the relation between the separate attributes of sound perception and the global evaluation of sound "fidelity"

4.1. *Methods of analysis*

The relation between the attributes of the perception space and sound "fidelity" has been examined by means of analysis of correlation and multiple regression. The analyses were made separately for three kinds of data:

1. The results of the evaluation of sounds for each test signal $P1 \div P4$ were considered separately. Since test signals were filtered through five different filtres $F1 \div F5$, five sounds corresponded to each test signal. Hence only five elements were included in the analysis of this kind of data. For this reason multiple regression could not be determined simultaneously for all attributes of the perception space (the number of elements was smaller than the number of variables examined). It was assumed that multiple regression must entail such attributes which have the greatest influence on the evaluation of "fidelity", i.e., whose variability determined the greatest number of variable "fidelity".

2. The results of the evaluation of all sounds under investigation were analysed, a total of 20 elements, i.e., 4 test signals x 5 filters. The results of the analysis could be affected in this case by the interaction filter x test signal (the influence of the filter frequency response on the evaluation of sound, dependent on the test signal).

3. The differences between median values of the sound evaluation and the mean value of median for the sound evaluation by the same test signal were considered.

Table 2 shows examples of the median values of the evaluation sound "fidelity" for the all sounds under investigation and arithmetic means of medians by the same

Table 2. Median values of the evaluation of sound "fidelity" for particular test signals P1 – P4, particular filters $F1 \div F5$ and mean values of median for particular test signals

	*F*1	*F*2	*F*3	*F*4	*F*5	Mean
*P*1	6	3	6	4	6	5
*P*2	5	6	6	5	7	5.8
*P*3	5	3	6	3	6	4.6
*P*4	5	3	4	3	4	3.8

test signal (given in the right-hand margin in the matrices in Table 2). The values shown in the rows reflect the results of the evaluation of sounds "fidelity", respectively, to the test signal $P1 \div P4$. The values shown in the columns reflect the results of the evaluation of sounds "fidelity" filtered through the filter with a specific frequency response, respectively, $F1 \div F5$. The data shown in Table 2 can be used to determine values equal to the differences between the median values of the evaluation of sounds under investigation and the mean value of these medians for the same test signal. The values are shown in Table 3.

Table 3. The differences between median values of the evaluation sound "fidelity" and the mean value of median for the sound evaluation, by the same test signal. The values were determined on the basis of the data shown in **Table 2**

	*F*1	*F*2	*F*3	*F*4	*F*5
*P*1	1	−2	1	−1	1
*P*2	−0.8	0.2	0.2	−0.8	1.2
*P*3	0.4	−1.6	2.4	−1.6	2.4
*P*4	1.2	−0.8	0.2	−0.8	0.2

These data, contrary to those of the second kind, are not affected by the interaction filter x test signal.

4.2. Results of the analysis

Table 4 shows the values of the linear correlation coefficient after PEARSON [9], which determine the relationship between the values of the evaluation of "fidelity" and the values of the evaluation of specific attributes of the perception space of the sounds under investigation. The square value of this coefficient multiplied by 100 determines the percentage of variability of "fidelity" caused by the variability of the

Table 4. Coefficients of liner correlation after Pearson, determined between evaluation of „fidelity" and particular attributes of the percepion space for three kinds of data – 1, 2, 3

Kinds of data \ Attributes		Clearness	Sharpness	Fullness	Spaciousness	Loudness	Lack of distortions
1.	*P*1	0.79	−0.27	**0.93**	**0.94**	0.79	0.84
	*P*2	0.53	0.00	0.53	0.76	0.80	0.75
	*P*3	**0.88**	−0.08	**0.95**	**0.96**	0.75	0.39
	*P*4	0.37	−0.54	**0.93**	0.51	−0.06	–
2.		**0.45**	**−0.48**	**0.88**	**0.88**	0.34	0.21
3.		**0.68**	−0.18	**0.85**	**0.82**	**0.52**	**0.60**

values of specific attributes of the perception space of the sounds under investigation. The values of correlation are shown separately for each kind of the data analysed – the values determining a statistically significant correlation at the significance level of $\alpha = 0.05$ are shown in bold type.

The correlation between the values of "fidelity" and the values of "lack of distortions" has not been determined for the case of a white noise (*P*4). The sounds there always awarded the same evaluation with respect to the "lack of distortions".

The analysis of the results shown in Table 4 helps state that the values of the "fullness" of sounds correlate statistically significantly for almost all kinds of data (except for data for the speech signal) with values of the sound "fidelity". Among the attributes whose values most often correlate with the values of the sound "fidelity" are "spaciousness" and "clearness". "Sharpness" is the only attribute whose coefficient of correlation has a negative value. The value of the correlation coefficient in the case of input data of the second and third kind differ especially with respect to "loudness", "sharpness" and "lack of distortions". This proves that in the case of these attributes the influence of the interaction test signal x filter was significant.

Multiple regression considered separately for each kind of data showed that:

1. In the case of data of the first kind:

– in the case of the pink noise (*P*1) the values of attributes "spaciousness" and "lack of distortions" determined 97% of the variability of the value of the sound "fidelity"

– in the case of the speech signal (*P*2) no correlation has been found between any of the attributes under investigation

– in the case of a musical piece (*P*3), the values of the "spaciousness" of sounds reflected 90% of the variability of the values of "fidelity"

– in the case of the white noise (*P*4), the values of the "fullness" of sounds determined 82% of the variability of the "fidelity" of sounds.

2. In the case of data of the second kind, values of all the attributes of the perception space determined 74% of the variability of the values of the sound "fidelity", and the same values of the "fullness" of sounds determined 76% of the variability.

3. In the case of data of the third kind, values of all the attributes of the perception space determined 73% of the variability of the values of "fidelity", and the values of three of them: "fullness", "lack of distortions" and "sharpness" determined 78% of "fidelity".

5. Conclusions

1. The relation between the evaluation of "fidelity" and the attributes of the perception space depends on the test signal. In the case of speech no relation between the attributes of the sound perception space and the evaluation of the sounds "fidelity" with respect to the mental model was found. This can be due to the limited number of measured elements (the degree of freedom was 3) as well as to the lack of

differentiation of the evaluation of "fidelity" of sounds when speech was the test signal (see Fig. 2).

2. The relationship between the attributes of the perception space and the evaluation of the "fidelity" of sounds indicates which attributes of the perception space significantly determine its evaluation with respect to the mental model.

Correlation between values of the evaluation of "fidelity" and values of the evaluation of selected attributes of the sounds (Table 4) shows that such attributes as "spaciousness", "fullness" and "clearness" correlate with the evaluation of the sound "fidelity". It was also found that the selected attributes of the perception space are, for a specific test signal, mutually correlated. In the case of the pink noise and music piece there is a correlation between the values of "fullness", "spaciousness" and "clearness" and in the case of the white noise there is a correlation between "sharpness" and "loudness".

Elimination of the influence of test signals on the results of the regression analysis helped isolate attributes which, irrespective of the kind of test signal used, are a significant contribution to the evaluation of sound "fidelity" with respect to the mental model. These are: "fullness", "sharpness" and "lack of distortions".

3. When considering the influence of the attribute "lack of distortions" on the evaluation of "fidelity", one should also take into account different kinds of distortions, e.g., linear distortions and nonlinear distortions. In the case under discussion, all kinds of distortion were considered simultaneously.

4. It requires explanation whether the evaluation of sound "fidelity" made with respect to a model other than mental leads to a similar relationship with selected attributes of the perception space. Explanation of this problem should facilitate the search for a uniform relationship between the subjective evaluation of the "fidelity" of sounds reproduced by loudspeakers and their physical parameters.

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