

An attempt to estimate listeners' preferences by comparing conventional and DML loudspeakers

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Abstract The ratio of direct to reflected sound energy in a listening room is known to affect the perception of reproduced sound and its qualitative evaluations. More direct sound favours better recognition of detail and more precise localization of virtual sound sources. More reflected sound favours perceived spaciousness. Little is known about quantitative relation between this ratio and sensation. Another unexplored research topic is whether there are considerable differences between listeners in their preference for more or less spaciousness. Research in this area is impeded by experimental requirements. Therefore we tried to approach a similar problem by using two different types of loudspeakers: (i) a conventional one, (ii) the Distributed Mode Loudspeaker (DML). They have very different directional characteristics. The latter radiates substantially more energy towards walls of a room than along the loudspeaker axis. Thus, the DML produces a lower ratio of direct to reflected sound energy in the listening position than the conventional loudspeaker. Directional loudspeaker characteristics and room acoustics have very similar effects on perception, but they are not easily transferrable. Therefore we concentrated on perceptual comparison of the loudspeakers themselves. In this work we selected a portion of the results from a large experiment comparing perception of sounds from the two loudspeaker types and analysed and processed them in order to find out how the differences between the two loudspeakers affect contradicting sensations of precision and spatiality.

Keywords: DML, loudspeakers, loudspeaker directivity, listening tests, audio quality assessment.

1. Introduction

The relationships among the directivity of loudspeakers, the acoustics of home listening rooms, and perception have been investigated by a number of researchers. Key findings can be summarized as follows: a joint indicator that combines both the directivity of a loudspeaker and the acoustic properties of a room is the ratio of the direct to the early-reflected sounds. This indicator is closely related to the perception of reproduced sounds, with its higher values (more-direct sound) favouring the accurate localizations of sound sources and its lower values favouring the perception of space. Widening the radiation of the loudspeaker and increasing the reflectivity of the room boundaries both reduce the ratio of the direct to the early-reflected sounds. Reducing the lateral reflections in a listening room tends to have the same effect as narrowing the loudspeaker dispersion [1].

The preference for more- or less-dry listening spaces may depend on the purpose of the listening. Audio engineers tend to favour drier conditions, while more reverberance is preferred for recreational listening [2].

In his paper from 1985 [3], Berlant postulated that "...conventional front-firing loudspeakers are inherently incapable, in home listening rooms, of achieving an accurate spectral balance and an undistorted spatial perspective." He attributed this to their cardioid directivity response patterns and power responses decreasing as the frequency rose. In what follows, a conventional loudspeaker – both as a unit or as a system (which includes a dome-shaped unit) – will be further referred to as a "cone loudspeaker" (CL).

There are a number of other works besides [3] that support the opinion that the wide directivity of loudspeakers is preferable when compared to the directivity of CLs. Bauer [4] proposed broadening a stereophonic listening area by the use of dipole speakers. This direction was developed by Linkwitz [5]. Bose [6] postulated that 80–90% of the total energy from a loudspeaker be radiated toward the wall behind it. Ferralli and Moulton [7] interpreted the narrowing of an acoustic beam at high frequencies as leading to the spatial and spectral infidelity of a sound field and analyzed the use of acoustic lenses to obtain a 360°-wide horizontal beam width. Moulton [1] concluded that broad horizontal dispersion, with the engagement

of specularly responsive side walls, yielded a preferred sonic quality for stereo playback. Flindell et al. [8] performed perceptual experiments with simulated loudspeaker systems with the same on-axis response but with different directivity patterns in an anechoic chamber and found that there was no clear consensus of preferences across listeners and programs, although there was a tendency for naive listeners to prefer a more omni-directional response. The dilemma between the precision of a stereo image (more directivity) and the sense of the original ambience (less directivity) was discussed by Allison [9]. He noticed that, during a concert experience, reflected sounds prevailed the direct sound, and the exact physical location of the instruments was lost, but that it was not important. Queen [10] and other workers emphasized that the uniformity of a directional pattern with frequency was essential for achieving good imaging and clarity in sound reproduction. Berg and Rumsey [11] found a positive correlation between the perceptual “envelopment” and “preference” attributes and a negative correlation between “source width” and “localization.” It seemed their subjects felt that, as a source widened, it became harder to localize.

Extensive work on the subject was carried out by Toole [12–15, 2]. In the first edition of his book [2], he summarized (Sec. 8.2.2.) “...wide dispersion loudspeakers, used in rooms that allow for early lateral reflections, are preferred by listeners especially, but not exclusively, for recreational listening. There appear to be no notable sacrifices in the ‘imaging’ qualities of stereo reproduction.”

The research on subjective preferences towards higher or lower ratio of direct to reverberant sound in loudspeaker listening, as opposed to headphone listening, is impeded by experimental requirements. Human memory for subtle differences in timbre is very short, in the order of a few seconds [16], therefore fast switching between samples of signals is necessary. In loudspeaker listening this would involve fast switching between listening rooms or acoustics of one listening room, both of which are unrealizable. Indirect methods, like recording the reproductions in rooms with different acoustics through one of 3D sound recording/reproduction or auralization methods [17] introduces confounding variables, as a later reproduction is only an approximation of a real sound event in the room. However, in view of the above literature review, loudspeakers with substantially different directivity characteristics could be used instead. Three options are available here for wide directivity reproduction versus usual narrow one from a front-firing CL. First, a system of CLs directed into several directions, second – a CL firing at a dispersing object, and the third – a loudspeaker made with a technology with inherent wide directivity. Such a technology is a distributed mode loudspeaker (DML) (also referred to as the flat panel loudspeaker).

A DML employs a different sound-radiating element than a CL does. In the DML, the radiator is a flat and stiff panel of a rectangular shape and considerable mass. An electrodynamic or piezoelectric exciter attached to the panel induces uniformly distributed bending wave vibration. This is entirely different from the operation of the CL, which was designed to vibrate like a rigid piston.

The comprehensive anechoic measurements that were performed by the authors of [18] at 325 points over the measurement hemisphere revealed that the directivity characteristics were irregular over the azimuth, elevation, and frequency; overall, however, the property of omnidirectionality was maintained.

An overall indicator of directional characteristics of a loudspeaker is the directivity index (DI). The DI of DMLs used in this work had negative values over most frequencies [19], thus indicating the substantial dominance of its off-axis energy. The DIs of CL systems (including the one that was used in the experiment) follow a different pattern consisting of only positive values that rise with frequency from 0 dB through just below 10 dB; this indicates the dominance of the on-axis energy over the middle and high frequencies.

Another property of DMLs that originates from their inherent multi-modal resonant structure is that their frequency responses are distinctively more undulating than those of CLs. This holds not only for the on-axis measurement (which is entirely inappropriate for DMLs) but also for multi-point responses or the power response.

Improvements to DML technology together with the current trend in the home-entertainment market toward multi-speaker and multi-room installations is likely to increase the interest in DMLs. Therefore, a comparison of the perceptual qualities of DMLs and CLs is a timely topic.

In [19] a comprehensive report on subjectively perceived differences between DMLs and CLs has been presented. The listening arrangement was the most widespread stereo format. In general, the results demonstrated significant differences in the criteria of “stage width”, “envelopment” and “localization”, and partly significant differences in the “clarity” criterion. This confirmed earlier assertions or findings on the perception of the ratio: direct to reverberant sound, obtained by other methods.

In this work, some results not reported in [19] have been analyzed and presented in order to find out whether: (i) the perceptions of precision and spatiality differed between the two types of loudspeakers (DMLs and CLs) (ii) these two perceptions were independent and (iii) listeners differed in their preference towards either precision or spatiality.

2. The original experiment

In this section, the original experiment presented in [19] is briefly summarized.

2.1. Aim, scope and conditions of experiment

The aim of the experiment was to find any perceptual differences between the two distinct loudspeaker technologies: CLs and DMLs. The main assumption was to design the experiment so that it would be sensitive to those perceptual differences that were brought about by the contrasting property of these technologies: directivity. It is widely agreed that the flatness of the amplitude response is the key factor in the preference ratings of loudspeakers [20, 21]. Therefore, equalization of the frequency response of DMLs, which are inherently uneven, was required. A mild, amplitude-only equalization of loudspeakers in the listening room was applied. All loudspeakers compared within the experiment were equalized, left and right channel speaker independently.

Two types of DMLs were evaluated in order to make the conclusions of the technology more representative (DML1 and DML2). To avoid commercialism, we do not give their brands, but the details can be obtained from the authors. A reference quality three-way active studio monitor system was chosen as an example of the CL.

Another distinctive feature of the DML technology is its insufficient bass extension. The quality of bass reproduction is an important attribute that underlies most preferences for loudspeakers [20, 21]. Therefore, the same subwoofer was used for all pairs of compared loudspeakers.

The arrangement of loudspeakers during the experiment was fixed, to allow fast switching between the compared units. It was designed carefully to reduce any position-related bias to below the threshold of perception. The arrangement is presented in Fig. 1.

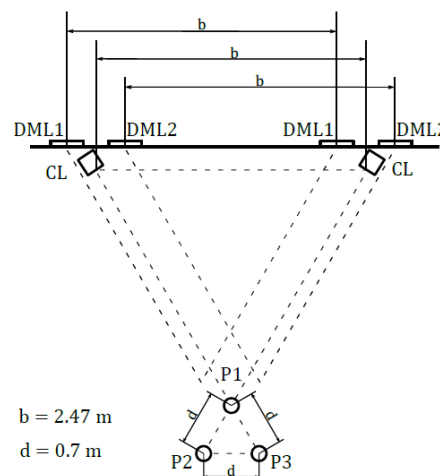


Figure 1. The setup of loudspeakers used in the experiment, including positions of the listeners: P1, P2 and P3. Adapted from [19].

The experiment was held in the newly adapted listening room of the Department of Mechanics and Vibroacoustics of AGH University of Science and Technology, conforming to the ITU-R BS.1116-2 standard [22]. The reverberation time (RT30) was 0.22 s.

2.2. Sessions and groups of listeners

The experiment was participated by 77 subjects. Each listener took part in listening sessions individually. In what follows, the term “session” refers to an individual subject’s participation in a complete set of trials in one of the listening positions (P1, P2, or P3). In each session, the musical excerpts (12 altogether) were reproduced alternatively by the three loudspeaker pairs compared: DML1, DML2 and CL. The musical excerpts contained examples of the following music genres: classical (four excerpts), jazz (two), rock (two), pop (one), progressive rock (one), electronic (one), country (one), details can be found in [19]. The plan was to hold three listening sessions for each participant – one in each listening position (see Fig. 1) – while the other conditions were unchanged (except for sound excerpts, which varied between P1, P2 and P3). Two listener groups were included: G123 with 42 listeners available across three sessions, and G1

with 35 listeners available for only one session. Listening position P1 was the sweet spot, so all members of Group G1 listened only in this position. Both the G123 and G1 groups listened in position P1, while only the members of Group G123 listened in positions P2 and P3.

2.3. Design of experiment

The attributes selected for the experiment are shown in Tab. 1.

Table 1. Attributes of evaluation and their limits – as given to listeners in experiment instructions.

Attribute	Lower limit (0)	Upper limit (10)
Pleasantness of audition	Low, not inviting	High, inviting
Realism	Artificial reproduction	Natural reproduction
Clarity (selectivity)	Low	High
Envelopment	Directional sound	Enveloping sound
Stage width	Narrow	Wide
Localization	Hard to determine	Easy to determine

In further parts of the paper, the criteria “pleasantness of audition” and “stage width” will be denoted as “pleasantness” and “width”.

The average reproduction level was adjusted individually by each subject at the beginning of each session (within a range of 72 to 80 dB). The excerpts were 20 to 45 s long. The evaluation attributes as given in Table 1 were shown in the interactive test interface, where a subject introduced his assessment with the use of a slider. The scoring scale was from 0 through 10, with one decimal point. The subject chose a loudspeaker system to be auditioned by pressing one of the letters A, B and C in the interface and could continue choosing them for as many times as they felt appropriate. The assignment of loudspeakers to letters was randomly set for each trial (music excerpt). The participants were not audiotically checked but were asked to report any known problems with hearing in a questionnaire that they filled before the first session.

3. Analysis of preference for spatiality

As mentioned in the Introduction, in this section new results of the experiment referred to in Section 2 will be presented and further analysis will be carried out to find whether listeners’ preferences towards more or less spatiality can be identified. In this work this will be determined on the basis of preferences for two different loudspeaker types (DMLs and CLs). When placed in one room, their principles of operation provide more or less reflections in the listener’s position.

Main analysis of the results was carried out based on scores collected in position P1 - listeners from groups G1 and respective part of G123, as this listener group was the most numerous. It was not possible to analyse the results from all positions together because more than half of the listeners took part in all experimental positions and their preferences would have had a greater influence on the correlation studied. However, the results obtained in the second and third positions were used to impute missing observations. Among the 77 listeners, a group of 21 experts was identified. To make it easier to understand which data set is used in each stage of the analysis, we introduce the following notations for four versions of analysis:

- V1 – the scores obtained in the first position (77 listeners from groups G1 and G123),
- V1.E – the scores of the expert listeners collected in the first position (21 listeners),
- V1.NE – the scores of the non-expert sub-group of 56 listeners in the first position,
- V2 – the scores obtained in all three positions (42 listeners from group G123).

3.1. Data and descriptive statistics

The analysis began with methods of descriptive statistics, including the analysis of histograms and box plots. Initial data exploration revealed data gaps and outliers. For this reason, it was decided to carry out a partial imputation of missing observations and normalization of the data. These procedures were performed in this order so that any supplemented data did not affect the group means used in normalization. It was possible because of missing value specificity, described below.

3.1.1. Normalization and data imputation

All missing observations occurred within the first session results. There were two sources of missing data. For one listener from group G123, the results for one excerpt were not saved. There were also missing scores of 20 listeners (including 10 from group G123) for the pleasantness attribute, due to a temporary error in our software. Missing observations account for less than 1% of the data, the structure of gaps was well known, and the data were not missing at random. Any advanced methods of handling missing data do not suit the specific missing data in our experiment, but it is recommended to carry such a procedure out [23, 24]. Moreover, chosen data analysis methods required equal subsets of responses. Removing all listeners whose response sets showed missing values would reduce the data set by almost 29%. That is why we worked out a specific compromise for analysed data between avoiding loss of information or statistical power, and biasing results. The means calculated from respective listeners' scores on similar excerpts in other sessions were used to impute results. Excerpt genres determined the choices of similar excerpts. The imputation did not affect the data distribution.

Because intermediate anchor points were not used for score scales, following the recommendation in [25], we implemented the normalization reducing individual tendencies in scores connected with personal use of the scales within attributes. Comparing our solution with the recommended in [21], the only difference is that we calculated subjects' mean scores and standard deviations for each pair: attribute x excerpt, not for the whole sessions, the same way as was used in a treatment in Berg and Rumsey (2001) [11]. That was to preserve diversity within both factors.

There were 3 systems (DML1, DML2 and CL) assessed per each pair: attribute and excerpt. The mean scores and standard deviations for each listener per attribute and excerpt (appropriately \bar{x}_{ijk} and s_{ijk}) were calculated in accordance with Eqs. (1) and (2):

$$\bar{x}_{ijk} = \frac{1}{3} \sum_{l=1}^3 x_{ijkl}, \quad (1)$$

$$s_{ijk} = \sqrt{\frac{1}{2} \sum_{l=1}^3 (x_{ijkl} - \bar{x}_{ijk})^2}, \quad (2)$$

where:

- $i = 1, \dots, n_i$ - represents listeners and $n_i \in \{41, 56, 76\}$ depending on the analysis version,
- $j = 1, \dots, 6$ - represents attributes,
- $k = 1, \dots, n_k$ - represents excerpts and $n_k \in \{4, 12\}$ respectively for versions V1 and V2 of the analysis,
- $l = 1, \dots, 3$ - represents systems under evaluation.

While maintaining variable designations, the means and standard deviations for groups were calculated in accordance with Eqs. (3) and (4):

$$\bar{x}_{jkl} = \frac{1}{n_i - 1} \sum_{i=1}^{n_i} x_{ijkl}, \quad (3)$$

$$s_{jkl} = \sqrt{\frac{1}{n_i - 1} \sum_{i=1}^{n_i} (x_{ijkl} - \bar{x}_{jkl})^2}. \quad (4)$$

Then the z scores, calculated in accordance with Eq. (5), were normalized values of the original grades.

$$z_{ijkl} = \frac{x_{ijkl} - \bar{x}_{ijk}}{s_{ijk}} \cdot s_{jkl} + \bar{x}_{jkl}, \quad (5)$$

where $s_{ijk} \neq 0$. For $s_{ijk} = 0$ Eq. (5) simplifies to $z_{ijkl} = \bar{x}_{jkl}$. The normalization used led to the reduction of outliers observed.

3.1.2. Descriptive statistics

Figs. 2 - 5 show data in all analysed versions (V1, V2, V1.E, V1.NE) after initial processing - data normalization and imputation for each attribute and system separately. Figures contain jittered data, boxplots, mean values, and half-density plots.

By comparing graphs, initial theses can be claimed. Differences in both mean scores and medians are observed across all versions for most of the four selected attributes: Clarity, Width, Envelopment, and Localization. In all versions and most attributes, the differences in average scores are visible. Independent of the analysis version, a consistent response pattern is observed for two attribute pairs. Envelopment and width attributes are rated higher for the DML system, whereas localization and clarity are rated higher for the CL systems. This suggests that correlations between attribute pairs may warrant further examination and that dimensionality reduction of the evaluation space could be considered, for example by replacing each pair with a single evaluation criterion. Accordingly, principal component analysis (PCA) was employed in the subsequent data analysis to further explore these relationships.

Listener scores within width and envelopment criteria were more consistent in position P1 (data in version V1) than for data acquired at three positions (data in version V2). At the same time, regardless of the attribute, the position factor does not influence the trend visible in system evaluations. Comparison of the interquartile ranges on data in the V1.E and V1.NE versions indicates that the experts' assessments were more consistent, especially in the case of the width and envelopment criteria assessments, to the detriment of the CL system. Therefore, an experience factor should be included within statistical inference. The distributions of empirical data deviate from bell curves and skewness appears. For this reason, parametric methods are avoided in the statistical analysis.

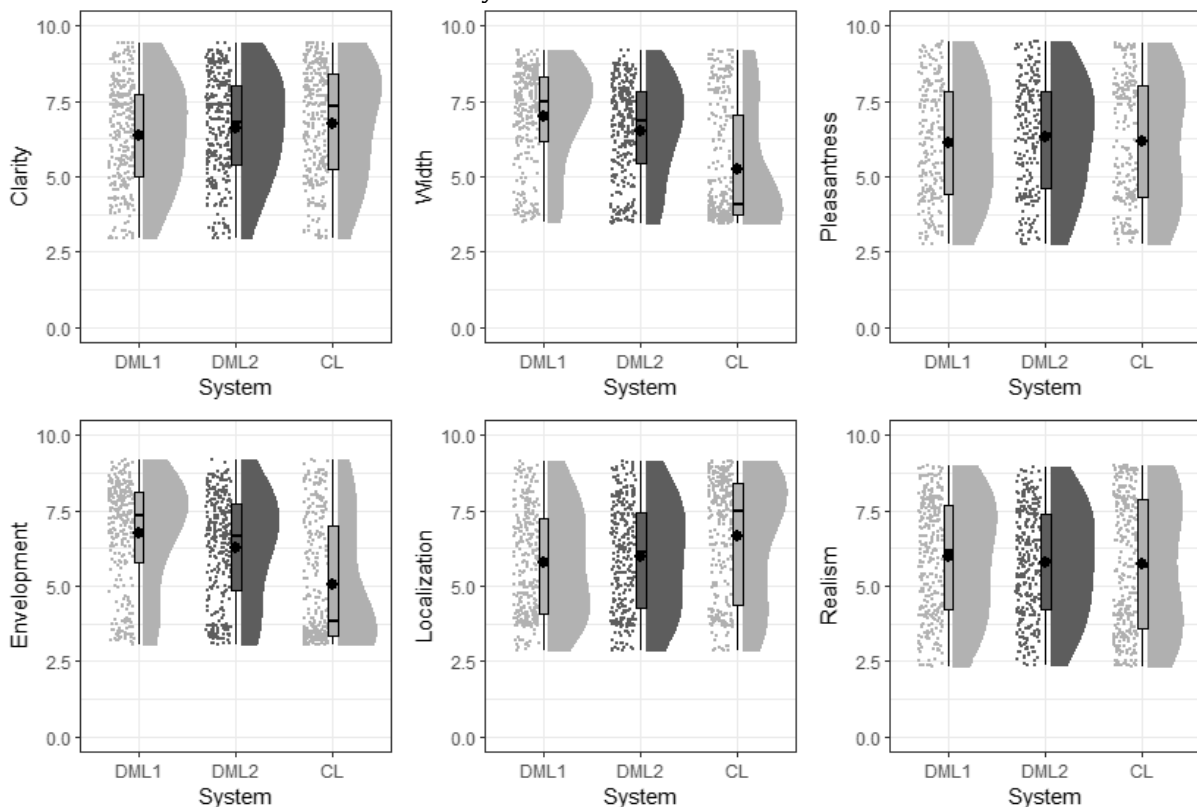


Figure 2. Data in version V1 of the analysis visualized using jittered pre-processed data, boxplots with mean values marked as points, and half-density plots for each System and Attribute.

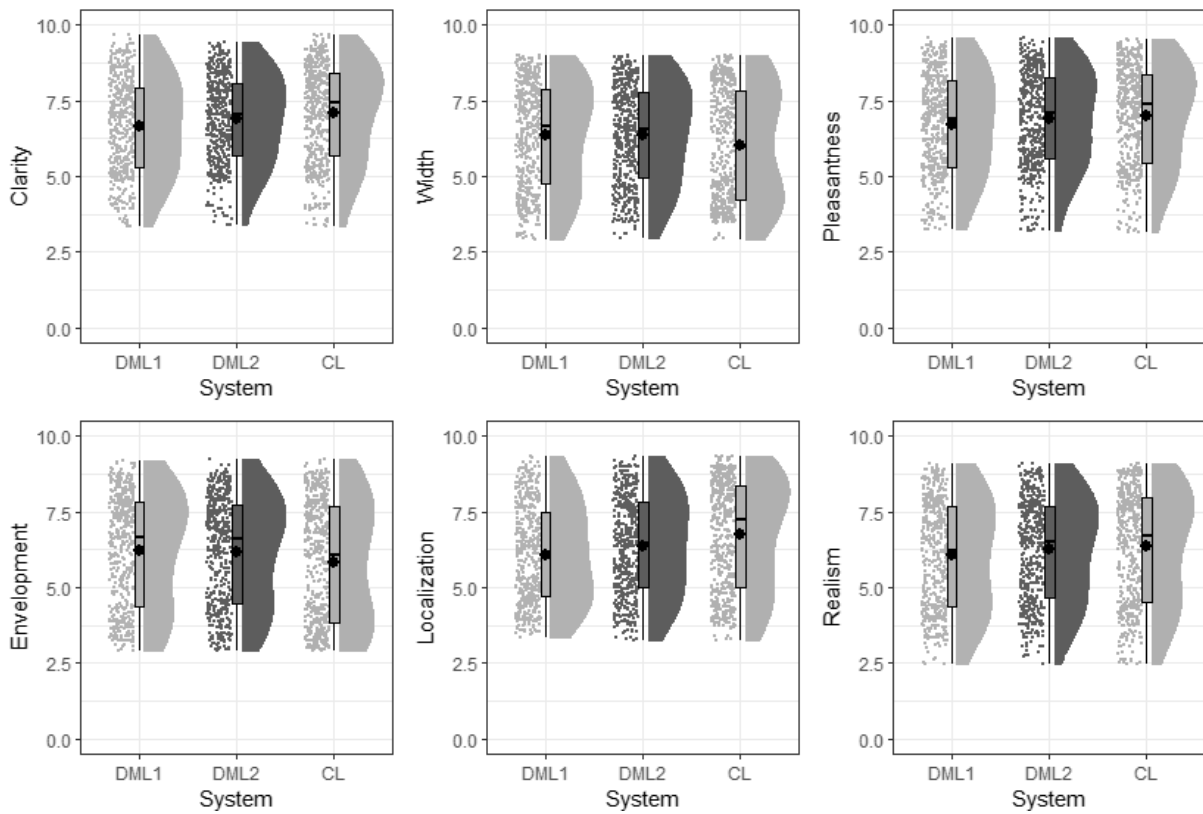


Figure 3. Data in version V2 of the analysis visualized using jittered pre-processed data, boxplots with mean values marked as points, and half-density plots for each System and Attribute.

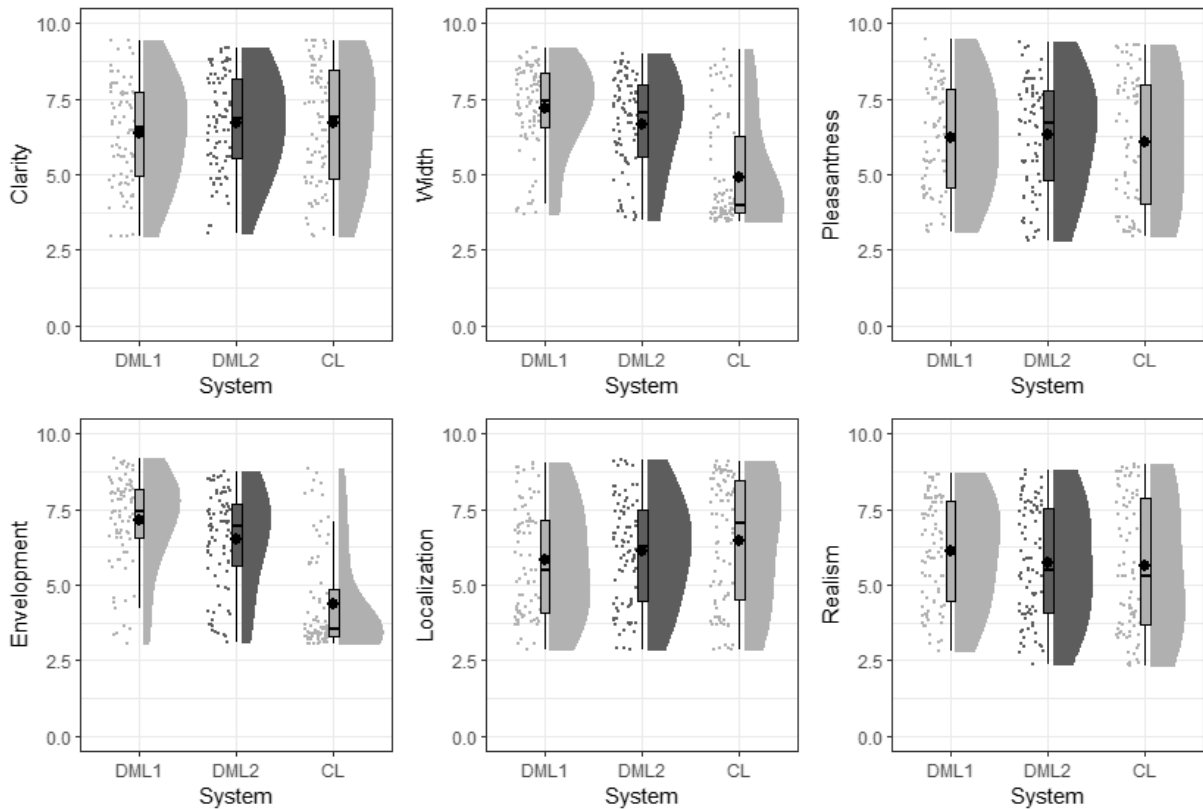


Figure 4. Data in version V1.E of the analysis visualized using jittered pre-processed data, boxplots with mean values marked as points, and half-density plots for each System and Attribute.

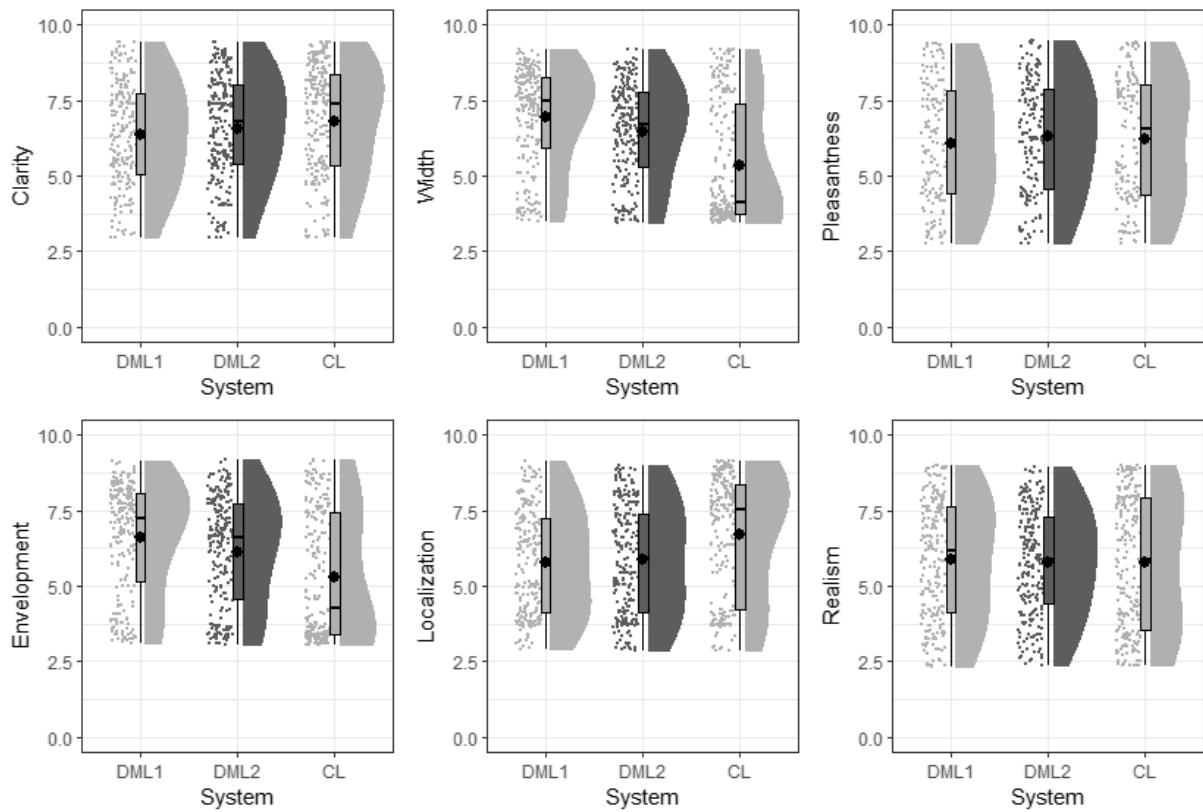


Figure 5. Data in version V1.NE of the analysis visualized using jittered pre-processed data, boxplots with mean values marked as points, and half-density plots for each System and Attribute.

3.2. Statistical processing

All hypotheses were tested at a significance level of $\alpha=0.05$. Pearson correlation was used to assess the multicollinearity. For data in version V1, the pairwise Pearson correlation coefficients fall within a range of 0.19 to 0.64. For data in version V2, this coefficient decreases slightly to a range of 0.12 to 0.54, but all results are statistically significant ($p < 0.001$). Regardless of the version, factor pairs can be grouped depending on the positive correlation level, what is presented in Tab. 2. Only for the Clarity-Width pair Pearson coefficient changes value so that very weak correlation at level 0.19 in the V1 version increases to 0.36 in the V2 version.

Table 2. Pairs of factors grouped according to level of correlation.

Level of positive correlation	Range of pairwise Pearson correlation coefficients	Pairs of factors
medium	0.48 – 0.64	Realism - Clarity, Realism - Pleasantness, Localization - Clarity Envelopment – Width
weak	0.21 – 0.47	Realism - Width Clarity - Pleasantness Pleasantness - Envelopment, Pleasantness – Width, Pleasantness – Localization, Realism – Localization, Realism – Envelopment, Clarity - Envelopment, Clarity-Width (V2)
very weak	0.12 – 0.20	Envelopment-Localization Clarity-Width (V1)

Conclusion regarding the lowest correlation is even stronger in V1.E version of analysis, as based on experts' results, there is no statistically significant correlation in these three pairs and in the pair Envelopment – Clarity ($p \in \{0.09, 0.14, 0.79, 0.99\}$). Thus, the attributes of Envelopment and Width are moderately correlated, whereas, despite statistical significance, the pairs Localization - Envelopment, Localization - Width, Clarity-Envelopment, and Clarity-Width exhibit very weak correlations.

Based on the multicollinearity analysis, the criteria of Width, Envelopment, Localization, and Clarity were chosen for further research. Statistically significant correlations were found for the pairs Localization-Clarity and Width-Envelopment, while no correlation was observed for the pairs Localization-Width, Localization-Envelopment, Clarity-Width, and Clarity-Envelopment. This suggests that principal component analysis (PCA) should be effective in providing a better representation of these criteria by reducing the number of variables and maximizing variance. PCA was carried out independently of the system, based on data from version V1, with justification provided in the introductory part of this section. Fig. 6 shows the biplot of the attributes. The PCA analysis confirms the finding that there is a correlation within the pairs Envelopment-Width and Localization-Clarity, but no dependence exists between the attributes of these pairs. Despite evaluating the systems according to six criteria, the four selected criteria, when replaced by two principal components, account for 80% of the variance in the dataset.

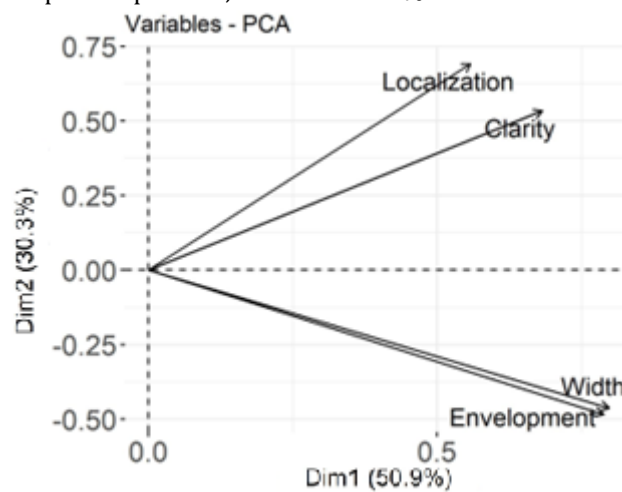


Figure 6. Biplot of the variables Localization, Clarity, Width, Envelopment with respect to the principal components.

On the basis of the PCA output, the results of version of analysis V1 can be expressed in the new variables spatiality (S) and precision (P), where S represents the combination of Envelopment and Width, and P combines Clarity and Localization. For each listener, mean scores were calculated based on all ratings of a given system by the criteria S and P separately. Hence, each listener's preferences were expressed by 6 numbers: 3 systems \times 2 criteria (S and P). Based on each pair of S and P ratings for a given listener and system, a variable X was calculated, as expressed in Eq. (6), representing the percentage to which a listener preferred precision when evaluating a given system. There is symmetry between the variable X and the analogous variable representing the percentage to which spatiality is preferred. Therefore, it is sufficient to analyse the variable X to determine the percentage of the preference for spatiality: the smaller the value of X, the lower the preference for precision and the greater the preference for spatiality.

$$X_i = \frac{P_i}{P_i + S_i} \cdot 100\% \quad (6)$$

Fig. 7 presents the estimated density of probability distributions for variable X depending on the assessed system (analysis version V1). The similar plot limited to the expert listeners' (analysis version V1.E) scores is shown in Fig. 8. It can be concluded that when evaluating DML speakers all listeners marginally prefer their spatiality over precision. This conclusion is based on the observation that in Fig. 7 the peaks of the DML distributions are only slightly above $X = 50$ and that the distributions exhibit left skewness, so the actual evaluation of DML is likely to tend toward spatiality. The same listeners, when evaluating the CLs value their precision substantially more than spaciousness. The dependency becomes even more apparent in the results for expert listeners (Fig. 8). In this subgroup, the difference in preferences revealed evaluating DML and CL loudspeakers is more pronounced. The distributions in the density plots for DMLs are bimodal, or in the case of the CL system trimodal. This indicates that among the experts, there

were those who strongly preferred precision when evaluating CL loudspeakers or spaciousness when evaluating DML loudspeakers. A small group of experts who prefer spaciousness regardless of the system forms an exception. This can be inferred from the local maximum observed in Fig. 8 for the CL system within the low-precision range. The difference between Figs. 7 and 8 can also be interpreted as a demonstration that expert listeners are more sensitive to differences between loudspeakers.

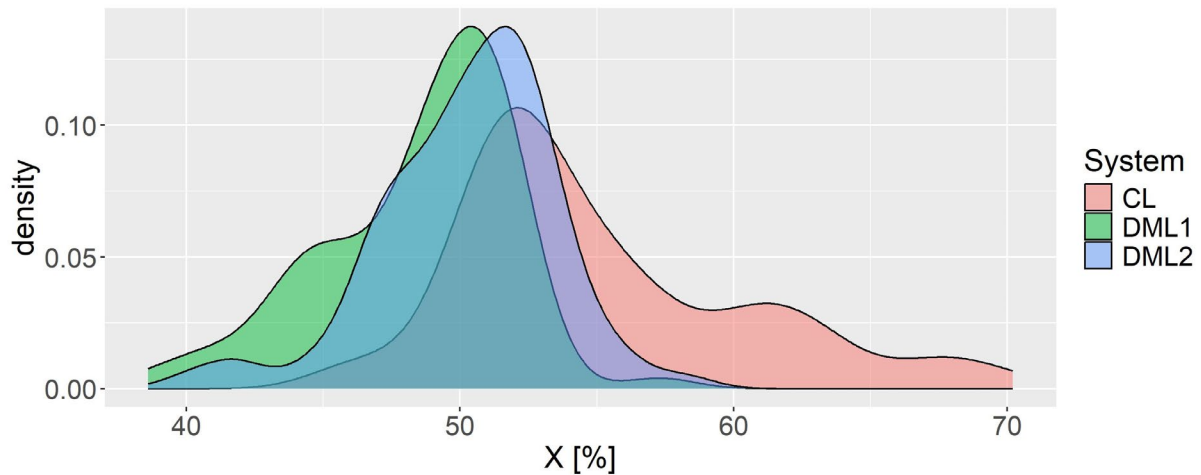


Figure 7. Density plot of listeners' preference for precision across system. High values of X indicate that a system under test was evaluated as precise, low values that it was evaluated as spacious.

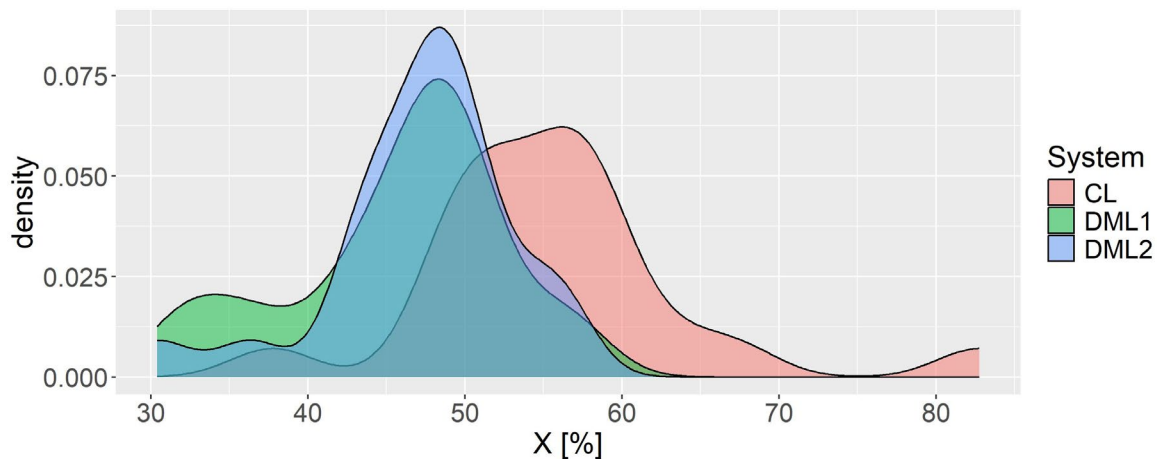


Figure 8. Density plot of expert listeners' preference for precision across system. High values of X indicate that a system under test was evaluated as precise, low values that it was evaluated as spacious.

4. Conclusions

Although the loudspeaker systems in the main study [19] were evaluated based on six criteria, in this work we found, on the basis of the multicollinearity analysis, that Envelopment, Width, Clarity, and Localization were the most influential criteria, and specific dependencies were revealed among them. Out of the four selected criteria two principal components were found that accounted for 80% of the variance in the original data (six criteria). New variables, spatiality and precision, have been defined to represent the combination of the envelopment-width and localization-clarity pairs, respectively.

The conducted research enabled answering the research questions. When analyzing the distribution of precision scores across systems, listeners' responses are generally consistent and centered around the means, with noticeable directional asymmetry between the systems. When evaluating DML loudspeakers, all listeners tend to marginally prioritize their spatiality, whereas in the case of CL loudspeakers precision is scored substantially higher. The members of the experts sub-group share the same priorities, but their choices are clearly more pronounced, confirming their higher sensitivity to properties of loudspeakers. This

leads to the conclusion that the differences between the two types of loudspeakers (DMLs and CLs) strongly affect sensations of precision and spatiality. This difference in perceptual attributes can be compared to differences resulting from acoustic conditions of rooms, characterised by bigger or lower direct to reverberant sound ratio. Overall, the results suggest that precision is slightly preferred to spatiality.

The distributions of listeners' preferences have a clear dominant, i.e. they do not differ substantially in their preference towards either precision or spatiality. The preference is even more strong among expert listeners' scores (Fig. 8), as indicated by higher concentration around the dominant in that case. Among the experts, some strongly preferred precision when evaluating CL loudspeakers or spaciousness when evaluating DML loudspeakers. A small group of experts, who prefer spaciousness regardless of the system, constitutes the exception.

This work has indirectly confirmed a known fact, that listeners do associate the perception of precision in sound reproduction with a higher direct-to-reverberant sound ratio, and the perception of spatiality with lower direct-to-reverberant sound ratio. This is quantitatively indicated by the directivity index, substantially higher in the case of CL loudspeakers.

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Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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