PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

A Study on Discrimination of Acoustic Conditions in an Audience Area of an Auditorium

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ABSTRACT

The purpose of this study is to clarify the acoustical difference depending on the seat position in an auditorium, particularly the level of difference perceivable by the audience and acoustical cues for perception of difference.

Subjects were presented through headphones with pairs of impulse responses measured in different positions of an auditorium, and then answered for questions whether two impulse responses sounded the same or not. Answers of the subjects were subjected to cluster analysis and multidimensional analysis so that the audience area, which was previously divided into several zones, was grouped according to acoustic similarity.

As a result of comparison between the subject's answer and objective measurement obtained by the impulse responses in respective seats, it is likely that the subjects perceived the difference in the acoustic conditions on the basis of not only the subjective level of sound but also the perceived clarity of sound and perceived reverberance.

Keywords: Impulse Response, Subjective Judgment, Discrimination

1. INTRODUCTION

Acoustic characteristics of a music hall are sometimes expressed by a representative value of reverberation time. Since the acoustic condition, however, differs among audience seats, ISO3382-1 defines a standard of the number of measurement points to be set for acoustic measurement in audience seats of a hall[1].

Meanwhile, in consideration of human auditory sense, it is quite difficult to recognize all the differences in acoustic condition among audience seats, even though the acoustic condition differs for each seat in a strict sense. In particular, even different acoustic conditions can be perceived as identical if the difference is not more than a threshold. Although such conditions are actually different in terms of physical quantity, they can be regarded as identical from the psychological point of view of the audience.

Prior studies have been carried out by Wilkens[2], Yamaguchi[3], and Edwards[4], for example. In these studies, the dissimilarity of acoustic conditions according to determination by subjects was found, while the relationship between the determination by subjects and acoustic properties was discussed. The authors consider that the acoustic conditions in audience seats in a hall can be zoned on the basis of subjective determination by the audience, if the extent of perceivable difference is clarified.

The purpose of this study is to specify the extent of difference in acoustic condition perceivable by audience and a factor for the determination of difference in various seat positions of a hall. In addition, the difference in acoustic condition determined by subjects was analyzed to divide the audience seats into several zones each including seats determined to be acoustically identical.

2. EXPERIMENTS

2.1 Outline

The impulse response was measured at various points in an audience area of a music hall, and the

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measured impulse responses were paired. Each pair of impulse responses was presented to a subject. The subject answered whether the first and second impulse responses sounded the same or different. The experiment involved 20 subjects.

2.2 Preparation

The music hall used for the measurement of impulse response has 1410 seats. In the hall with a omnidirectional loudspeaker (D-10, Globo Technology) set at the center of the stage and monaural microphones (AT4050, Audio-Technica) set at several positions of the audience area, monaural impulse responses were recorded. The measurement of impulse response was carried out with the whole audience area of the hall divided into three areas, that is, Large area, Medium area, and Small area. Large area refers to the whole audience area (the number of impulse response measurement points: 12 points). Medium area refers to the vicinity of central area of the audience area (the number of impulse response measurement points: 9 points). Small area refers to an area where the interval between seats is narrower than that of Medium area (the number of impulse response measurement points: 12 points). Figure 1 shows the impulse response measurement points. The impulse responses were measured with the gain of the microphone kept constant so as to reproduce the difference in sound level depending on the sound receiving position.

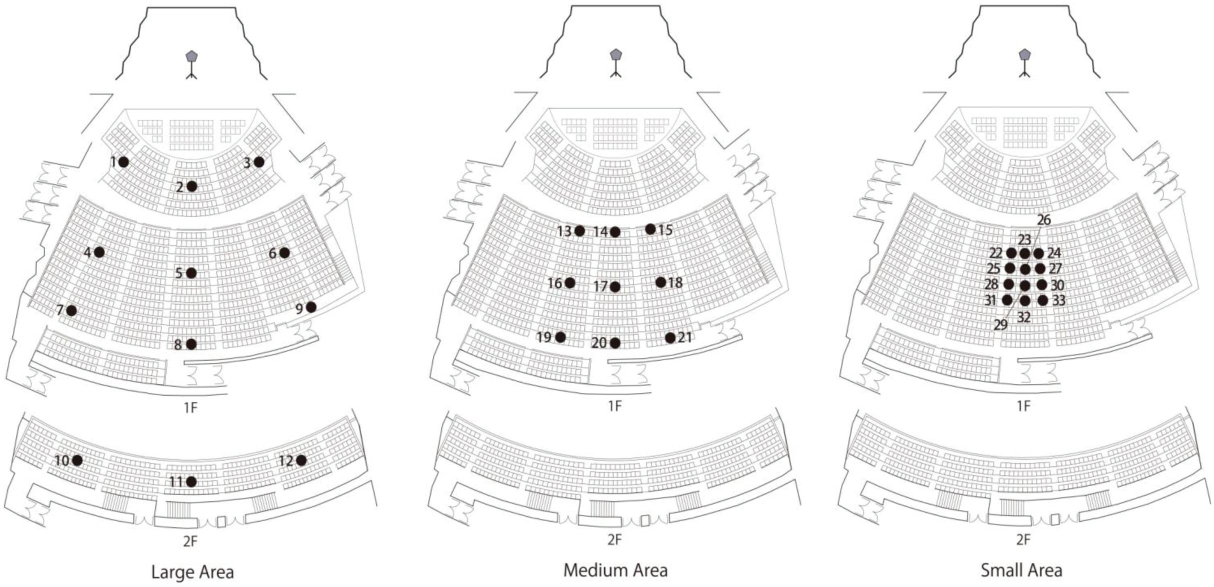

Figure 1 – Impulse response measurement points

The impulse responses measured at the positions illustrated above were used to prepared pairs of stimuli to be presented to the subjects as shown in Figure 2. Two impulse responses measured in the same area constitute each pair of stimuli. A pause of one second was provided between the two impulse responses. In order to confirm the reliability of answers from the subjects, five pairs of identical impulse responses were additionally prepared for each area and presented to the subjects.

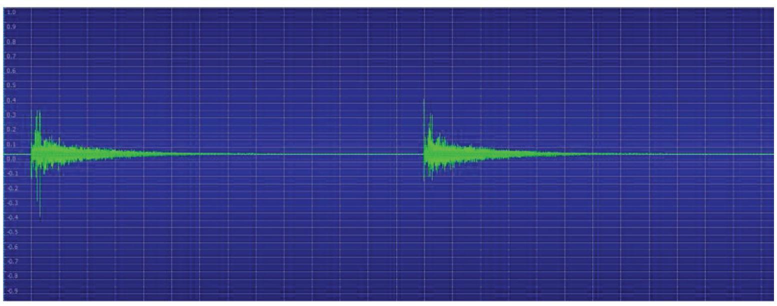

Figure 2 – Example of stimuli presented

2.3 Procedure

The subject listened to a pair of impulse responses through headphones (MDR-CD900ST, SONY) and subsequently answered whether the two impulse responses sounded the same or different. In the case where the subject desired to listen to the pair of impulse responses again, it was presented to the subject each time. The subject listened to 71 pairs of stimuli (66 kinds of pairs of stimuli + 5 pairs of identical stimuli) for Large area, 41 pairs of stimuli (36 kinds of pairs of stimuli + 5 pairs of identical stimuli) for Medium area, and 71 pairs of stimuli (66 kinds of pairs of stimuli + 5 pairs of identical stimuli) for Small area, and answered.

The experiment was carried out for each area, and the order of stimuli to be presented was randomly set. The volume of sound to be received by the subject was adjusted with use of a headphone amplifier (HUD-mx2, Audinst) so that the sound reproduced through the headphones was appropriate. As a result of the adjustment, L_{Amax} of the sound of measurement point 2, which was nearest to the sound source, was 78.5[dB].

3. RESULT AND DISCUSSION

3.1 Result of answer from subject

Tables 1 to 3 show the result of experiment regarding Large area, Medium area, and Small area, respectively.

Table 1 – The number of cases where impulse responses of each pair were determined as different, Large area

	1	2	3	4	5	6	7	8	9	10	11	12
1		15	4	15	14	13	9	12	15	18	17	17
2			11	14	9	10	18	16	19	17	19	18
3				13	15	9	18	18	13	15	17	15
4					12	2	10	9	12	13	7	11
5						13	13	10	14	14	7	12
6							11	16	7	7	7	6
7								3	7	7	8	13
8									9	8	9	9
9										9	9	6
10											10	5
11												6
12												

Table 2 – The number of cases where impulse responses of each pair were determined as different, Medium area

	13	14	15	16	17	18	19	20	21
13		16	10	5	11	7	16	15	16
14			8	15	14	15	17	20	19
15				12	13	10	19	19	18
16					6	6	10	15	13
17						5	12	12	9
18							10	17	11
19								9	5
20									7
21									

Table 3 – The number of cases where impulse responses of each pair were determined as different, Small area

	22	23	24	25	26	27	28	29	30	31	32	33
22		13	3	6	6	11	10	10	3	7	14	12
23			7	9	3	17	4	8	11	9	7	7
24				5	6	16	13	9	5	7	16	12
25					5	6	12	11	7	10	15	11
26						11	10	9	5	8	14	9
27							14	15	3	11	18	14
28								17	8	11	10	11
29									15	6	8	7
30										15	20	15
31											10	7
32												8
33												

The values in the tables each indicate the number of answers "sounded different". That is, a larger value indicates that two impulse responses of the pair were perceived as more different by subjects, and thus the dissimilarity between such impulse responses is construed as being higher.

Throughout the experiment, each subject was required to answer regarding 15 pairs of identical impulse responses. Identical impulse responses were sometimes determined as "sounded different" as a matter of course; however, no subject made more than 50% wrong answers, and therefore all the answers from the 20 subjects were taken as targets of analysis. The highest percentage of wrong answers of a subject was 33.3%, and an average percentage of wrong answers of all the 20 subjects was 10.3%. Seven subjects answered "sounded the same" regarding 15 pairs of identical stimuli.

3.2 Analysis by multi dimensional scaling

Results shown in Tables 1 to 3 were subjected to multi dimensional scaling (MDS) to be plotted as illustrated in Figure 3. Impulse responses of a pair determined as "sounded the same" by many subjects were determined as quite similar to each other and plotted at near positions in a three-dimensional space.

The stress in the figure is an index regarding the goodness of fit of the spatial model obtained by MDS. The goodness of fit of the model increases as the stress value decreases. According to Kruskal[5], Large area and Small area are evaluated as fair, whereas Medium area is evaluated as good in terms of goodness of fit of this case obtained by MDS.

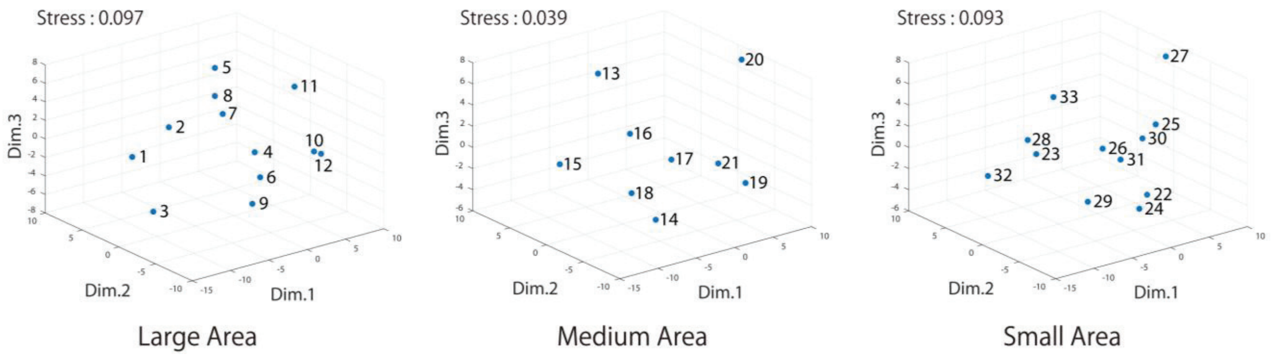

Figure 3 – Stimuli plotted on graphs obtained by MDS

Coordinate axes obtained by MDS can be understood by comparison between the coordinate value of each stimulus obtained by MDS and the tendency of fluctuation of acoustic index for each stimulus. Tables 4, 5, and 6 show correlation coefficients between the coordinate values obtained by MDS and the objective parameters of stimuli for the respective areas. A-value in each table indicates a value calculated from amplitude ratio between direct sound and reflected sound of impulse response[6]. The A-value tends to be small in the case of dominant direct sound.

Table 4 – Correlation coefficient between Dim. obtained by MDS and objective parameter, Large area

	Dim.1				Dim.2				Dim.3			
	AP	125 [Hz]	500 [Hz]	2000 [Hz]	AP	125 [Hz]	500 [Hz]	2000 [Hz]	AP	125 [Hz]	500 [Hz]	2000 [Hz]
SPL [dB]	−0.911**	−0.534	−0.936**	−0.856**	0.249	−0.158	0.205	0.258	−0.067	0.435	−0.046	−0.235
A-value [−]	0.480	0.564	0.532	0.518	0.031	−0.191	−0.103	−0.145	0.535	0.350	0.178	0.463
T_{20} [s]	0.808**	0.278	0.002	0.562	−0.396	0.016	0.132	−0.438	−0.091	−0.565	−0.218	0.315
T_{30} [s]	0.354	0.518	−0.098	0.602*	−0.186	0.001	0.207	−0.343	0.047	−0.564	−0.293	0.378
EDT [s]	−0.863**	−0.474	−0.765**	−0.811**	−0.207	0.312	0.007	−0.265	0.198	−0.146	0.050	0.231
C_{50} [dB]	−0.043	−0.404	0.432	−0.228	−0.086	−0.140	0.038	−0.028	−0.343	−0.637*	−0.683*	−0.252
C_{80} [dB]	0.667*	0.602*	0.750**	0.402	0.283	−0.382	0.156	0.367	−0.395	−0.064	−0.464	−0.440
D_{50} [%]	−0.045	−0.460	0.429	−0.233	−0.086	−0.047	0.038	−0.028	−0.342	−0.651*	−0.677*	−0.252
Ts [s]	−0.632*	−0.413	−0.748**	−0.239	−0.193	0.380	−0.177	−0.226	0.461	0.081	0.449	0.505

Table 5 – Correlation coefficient between Dim. obtained by MDS and objective parameter, Medium area

	Dim.1				Dim.2				Dim.3			
	AP	125 [Hz]	500 [Hz]	2000 [Hz]	AP	125 [Hz]	500 [Hz]	2000 [Hz]	AP	125 [Hz]	500 [Hz]	2000 [Hz]
SPL [dB]	−0.959**	−0.667*	−0.927**	−0.950**	−0.106	−0.579	−0.238	−0.066	0.068	0.120	−0.117	0.058
A-value [−]	−0.142	0.000	0.498	−0.612	−0.524	−0.263	−0.369	−0.056	−0.425	−0.051	−0.778*	−0.308
T_{20} [s]	0.486	−0.820**	−0.147	0.165	−0.268	0.158	0.083	−0.657	−0.609	0.144	−0.368	0.014
T_{30} [s]	0.581	−0.231	0.328	0.264	−0.193	−0.029	−0.226	−0.176	−0.378	−0.305	−0.406	0.355
EDT [s]	−0.575	0.353	−0.588	−0.310	0.256	0.574	0.594	0.346	0.372	−0.162	0.425	0.430
C_{50} [dB]	−0.615	−0.301	0.550	−0.558	−0.078	−0.651	−0.090	−0.030	−0.005	−0.016	−0.281	0.022
C_{80} [dB]	0.322	0.417	0.954**	0.013	−0.210	−0.731*	0.074	−0.220	−0.128	−0.030	−0.084	−0.318
D_{50} [%]	−0.615	−0.347	0.542	−0.556	−0.077	−0.685*	−0.090	−0.025	−0.004	−0.059	−0.286	0.021
Ts [s]	−0.144	−0.305	−0.877**	−0.088	0.243	0.738*	0.169	0.291	0.355	−0.012	0.316	0.370

Table 6 – Correlation coefficient between Dim. obtained by MDS and objective parameter, Small area

	Dim.1				Dim.2				Dim.3			
	AP	125 [Hz]	500 [Hz]	2000 [Hz]	AP	125 [Hz]	500 [Hz]	2000 [Hz]	AP	125 [Hz]	500 [Hz]	2000 [Hz]
SPL [dB]	−0.921**	−0.784**	−0.432	−0.912**	0.245	0.461	0.483	−0.002	−0.263	0.145	−0.672*	0.065
A-value [−]	0.416	0.277	0.355	0.342	0.476	0.493	0.575	0.123	−0.363	−0.021	−0.532	−0.148
T_{20} [s]	0.267	−0.126	0.103	0.369	−0.743*	0.093	−0.812**	−0.260	0.150	−0.103	0.293	0.721**
T_{30} [s]	0.424	0.376	0.210	0.378	−0.725*	−0.068	−0.762**	−0.242	0.413	0.458	0.527	0.541
EDT [s]	−0.162	0.239	−0.092	−0.414	−0.223	−0.779**	−0.124	−0.166	0.376	−0.385	0.788**	−0.105
C_{50} [dB]	−0.230	−0.341	0.349	−0.421	−0.371	−0.370	−0.549	0.035	0.229	−0.344	0.221	0.346
C_{80} [dB]	0.296	−0.623*	0.621*	0.217	−0.231	−0.290	−0.101	0.090	0.232	−0.233	0.157	0.541
D_{50} [%]	−0.232	−0.352	0.336	−0.423	−0.372	−0.284	−0.548	0.036	0.230	−0.360	0.217	0.345
Ts [s]	−0.117	0.410	−0.679*	−0.197	0.254	−0.467	0.293	−0.131	−0.209	0.025	0.390	−0.624*

In view of overall tendency of the results shown in Tables above, Dim.1 is significantly correlated with many objective parameters. In Table 6, Dim.2 and Dim.3 are more significantly correlated with objective parameters compared to those in Tables 4 and 5. For example, Dim.2 in Table 6 is significantly correlated with an objective parameter relating to perceived reverberance, which is not correlated with Dim.1. This suggests a possibility that the factor for discrimination varies depending on the extent of the difference between acoustic conditions being presented.

Table 7 shows correlation coefficients between results shown in Tables 1 to 3 and ratios of objective parameter of impulse response corresponding to the results.

Table 7 – Correlation coefficient between result of answer from subject and ratio of objective parameter

	SPL [dB]	A-value [−]	T_{20} [s]	T_{30} [s]	EDT [s]	C_{50} [dB]	C_{80} [dB]	D_{50} [%]	Ts [s]
Large area	0.631**	0.407**	0.445**	0.050	−0.516**	0.267*	0.239	−0.054	−0.255*
Medium area	0.765**	0.012	0.245	0.410*	−0.434**	−0.106	0.003	−0.486**	0.076
Small area	−0.396**	−0.237	−0.226	−0.205	0.185	−0.008	−0.383**	−0.049	0.393**

In Large area and Medium area, the answers from subjects are correlated with SPL greatly and also with EDT significantly. This suggests the possibility that the subjects made determinations on the basis of not only the sound level but also perceived reverberance.

In Small area, although the answers are significantly correlated with SPL, the correlation coefficient value regarding SPL is smaller than those of the other areas. In addition, correlation coefficient values regarding C_{80} and Ts (centre time) are as high as that regarding SPL, which suggests the possibility that the subjects made determinations on the basis of perceived clarity of sound as well.

Figure 4 planarly illustrates the result of MDS for Large area. In Figure 4, positions 1, 2, 3, which are relatively near the stage, are plotted in the negative direction, whereas positions on the second floor 10, 11 12, which are relatively far away from the stage, are plotted in the positive direction on the Dim.1 axis. Thus, it can be understood that Dim.1 represents the distance from the stage. Positions 2, 5, 11, which are on the center axis of the hall, are plotted on the relatively large coordinates on the

Dim.3 axis. Thus, it can be understood that Dim.3 represents the centeredness of each seat position. Meanwhile, since the stimuli presented in this experiment were impulse responses recorded by monaural microphone, the tendency of the results should be supported by additional experiment involving stimuli prepared using a dummy head.

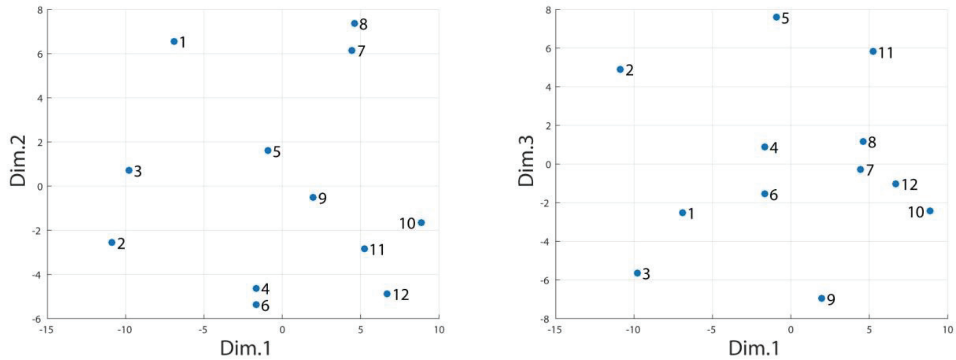

Figure 4 – Planar illustration of Result of MDS, Large area

Figure 5 planarly illustrates the result of MDS for Medium area.

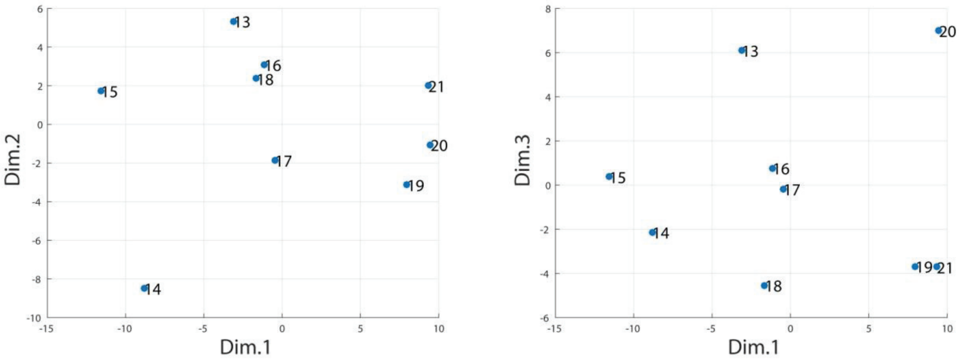

Figure 5 – Planar illustration of Result of MDS, Medium area

In Figure 5, Dim.1 exhibits a tendency similar to that of Figure 4, whereas Dim.2 and Dim.3 exhibit no clear tendency. In Small area, no clear tendency was found even for Dim.1.

3.3 Zoning by cluster analysis

Figure 6 shows the result of classification into respective categories by cluster analysis by Ward's algorithm.

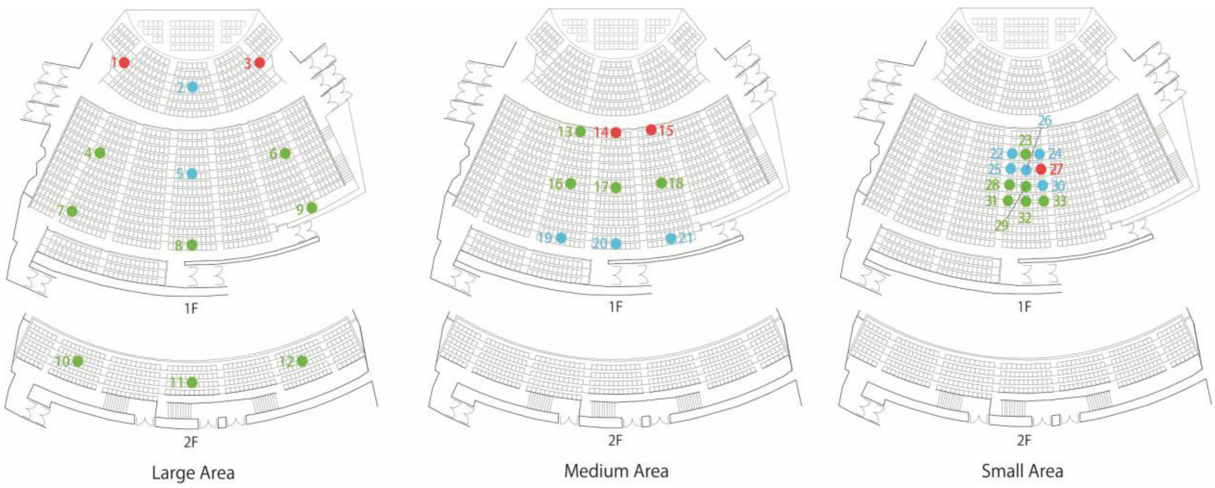

Figure 6 – Classification of measurement points by cluster analysis

As to Large area, the measurement points were categorized into symmetrical zones, and thus the answers from subjects had some regularity. Medium area was broadly categorized into the front, center, and rear zones, so that it can be expected that the subjects answered on the basis of an acoustic factor relating to the distance from the stage. In contrast, no regularity was found as to zoning of Small area, which implies that the determination criterion of the subjects was vague.

4. CONCLUSIONS

In this study, subjective evaluation experiment was carried out regarding perception of the difference in acoustic condition in audience seats in a hall, and as a result, the following findings were obtained.

- It was clarified that the relationship between the result of MDS obtained from subject's answers and objective parameters obtained from impulse responses presented as stimuli tends to vary according to the size of target seat area.
- Dim.1 of MDS is likely to represent the distance between the stage and the seat position.
- Zoning from the view point of only the acoustic condition is effective for Large area and Medium area, whereas whether the difference can be perceived is unclear for Small area.

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