DIRECTIONAL CHARACTERISTICS OF LATE SOUNDS IN CONCERT AUDITORIA

PACS REFERENCE: 43.55.Gx

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ABSTRACT

Objective measurements are performed in auditoria to clarify the directional characteristics of late sounds, which correlate with listener envelopment. The measured values with directional microphones reveal the ranges of the level variation of lateral, longitudinal and vertical energy in real sound fields. It is also found that the level attenuation coefficient of vertical component is highest. Furthermore, directional late energy ratios are considered in order to account for the spatial balance of late sounds arriving at a receiver. The results show that the directional distribution of late sound is an important factor in evaluating the sound fields of auditoria.

INTRODUCTION

Spatial impression is one of important psychological factors evaluating the sound field in concert auditoria. It was clarified that spatial impression consists of two aspects, apparent source width (ASW) and listener envelopment (LEV). As for LEV, it strongly depends on the late lateral energy, and some objective indices such as *LG* [1] have been proposed. In the actual halls, however, late sounds arrive from various directions, and it cannot be asserted that the late sound arriving from directions other than lateral does not influence on LEV at all.

In our previous works [2], the psychological experiments were performed with three-dimensional simulated sound fields including the late sound arriving from directions other than lateral in order to examine the relation between arrival directions of late sounds and LEV. The results showed that not only lateral sound level but also late sounds from above and behind the listener correlate strongly with LEV. This means that only late lateral sound level cannot explain LEV efficiently, and in order to grasp LEV accurately, energy level and energy fraction of the late sounds arriving from directions other than lateral as well as the listening sound pressure level should be considered.

It is indispensable for the establishment of an acoustical index considering the property of late sounds to grasp the directional characteristics of late sounds in real sound fields. However, it has not been clarified yet. In this paper, acoustical measurements were performed in existing halls, and the directional characteristics of late sounds were discussed.

OUTLINE OF ACOUSTICAL MEASUREMENT

Method A dodecahedron omni-directional loudspeaker was used as a sound source for the measurement and an impulse response was measured at each measuring point with a method of synchronous summation when a DC-pulse was emitted from the loudspeaker. The omni-directional and figure-of-eight microphones were used for the receiver in order to obtain three directional energy components of late sounds, namely lateral, vertical and longitudinal responses.

Surveyed Halls The outline of six surveyed halls (Halls A, B, C, D, E and F) is shown in Table 1. Halls A and C are multipurpose-halls with seats for the audience on the second floor. Hall B, a fan-shaped single story hall, is the most acoustically dead among six halls. Halls D, E and F are concert halls for classical music, and Halls D and E are shoe-box-type halls which have side balcony seats on the second and third floors. The numbers of measuring points are 10, 12, 12, 16, 16, and 16 for Halls A, B, C, D, E and F respectively.

Physical Parameters Of Late Sounds Strength G and late sound level G_{late} (late: t = 80 to ∞ ms) were calculated from the overall impulse responses measured by using an omni-directional microphone. As physical parameters to express the directional information of late sound, three directional late sound levels and three directional late energy ratios were defined as follows; Late longitudinal sound level GG_{late}, late lateral sound level LG_{late} and late vertical sound level VG_{late} were defined after LG proposed by Bradley. Directional late energy ratios GE_{late}, LE_{late} and VE_{late} were defined as ratios of each directional late energy to total late sound energy in a similar way.

Table 1
Acoustical outline of surveyed halls.

Hall	Seats	V (m^3)	V/S (m)	RT (s)	$\bar{\alpha}$
A	1,522	12,167	2.60	1.59	0.23
B	1,780	13,994	3.36	1.45	0.31
C	1,811	18,700	3.02	2.20	0.20
D	1,871	17,445	2.51	2.24	0.17
E	1,818	17,302	2.80	1.79	0.22
F	1,813	19,410	3.03	2.07	0.21

DISCUSSION

Hereinafter, the directional characteristics of late sounds are examined based on the data obtained from the measurements.

Range Of Change In Late Sound Level Average value of the late-sound parameters, and average, minimum and maximum values of the ranges of the level variation in six halls are shown in Table 2. The range of change in G_{late} is 2.0 to 5.7 dB, and 4.2 dB on the average. Observing them in each arrival direction, the range of the level variation is the narrowest in the longitudinal component GG_{late} (4.2 dB on the average), and the widest in the vertical component VG_{late} (9.1 dB on the average). These data are useful for setting the acoustical condition of simulated sound field in our psychological experiments.

Level Attenuation Of Late Sounds Due To Distance From A Sound Source The characteristics of attenuation of G and directional late sound levels, GG_{late}, LG_{late} and VG_{late}, due to source-receiver distance are shown in Fig.1, where each dot and solid line show the average value over the five frequency-bands from 250 to 4k Hz and the regression line by the method of least squares, respectively. The level attenuation coefficients m (dB/10 m) for five physical parameters mentioned above are calculated. The results are shown in Table 3.

First, the coefficients for G and G_{late} are larger with the increase of total absorption of room. This result is generally accepted. Next, the level attenuation coefficient m for directional components of late energy is focused. In all halls, except in the case of Hall C, m increases in order of VG_{late}, LG_{late} and GG_{late}. The attenuations of the vertical and lateral energy are larger than that of longitudinal energy. Especially, the attenuation of the vertical component is large. It is guessed that this is caused by the effect of absorptive seats area.

Furthermore, comparing ms in six halls, while the maximum difference of m is 0.9 in GG_{late}, 2.7 in LG_{late}, and 4.0 in VG_{late}. The differences of m in LG_{late} and VG_{late} are larger. For example, in Hall B, the attenuations of vertical and lateral components are remarkably larger than those in Halls D and E. It can be said that the difference of level between three directional components is very large. This fact suggests that the level distribution of the directional late sounds might give detailed information on diffusivity of sound field.

Table 2
Range of the level variation on late sound.

(dB)

	Average	Range		
		Average	Minimum	Maximum
G	4.1	4.8	3.6	6.8
G_{late}	1.1	4.2	2.0	5.7
GG_{late}	-3.2	4.2	3.4	5.3
LG_{late}	-4.8	5.7	2.2	8.7
VG_{late}	-4.9	9.1	5.6	17.5

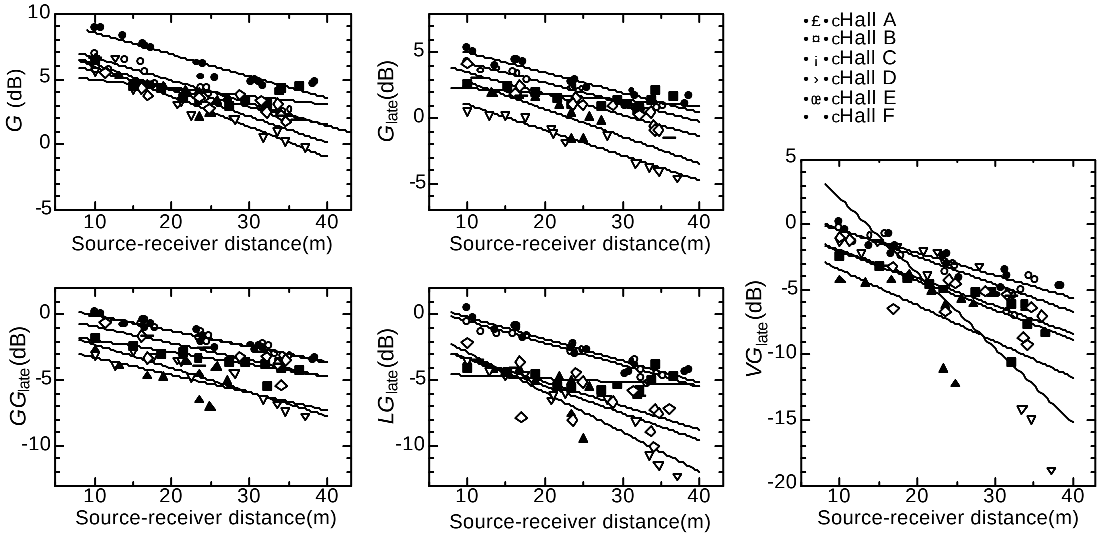


Fig. 1. Directional late sound level as a function of source-receiver distance in 6 halls. (points and solid least-squares fit line)

Table 3
Level attenuation due to source-receiver distance of late sound.

Hall	Level attenuation coefficient m (dB/10 m)				
	G	G_{late}	GG_{late}	LG_{late}	VG_{late}
A	2.0	2.1	1.4	2.1	2.8
B	2.3	1.9	1.8	3.0	5.7
C	0.6	0.5	0.9	0.3	2.2
D	1.7	1.5	1.2	1.7	2.1
E	1.7	1.5	1.2	1.7	1.7
F	1.4	1.6	1.3	1.8	2.1

<u>Directional Distribution Of Late Sounds</u> It is necessary for examining the relation between the characteristic of late sounds and LEV to investigate the spatial balance of arrival directions of late sound in real sound field. Therefore, GE^*_{late}, LE^*_{late} and VE^*_{late} were newly defined as directional late energy ratios which were normalized by the summation of GE_{late}, LE_{late}, and VE_{late}, and distribution of directional late sounds is discussed by using them. Here, when late sounds arrive equally from all directions, GE^*_{late}, LE^*_{late}, and VE^*_{late} are 1/3. And so, $\bar{d}_{late}$ was defined as an index evaluating the spatial balance about arrival directions of late sound. $\bar{d}_{late}$ is the spatial average value of the distance from the point (1/3, 1/3, 1/3) to the point (GE^*_{late}, LE^*_{late}, VE^*_{late}) on three-dimensional rectangular coordinate system. The distributions of GE^*_{late}, LE^*_{late}, and VE^*_{late} at five frequency-bands and the average value of them are shown in Fig.2 and Fig.3 respectively, and the $\bar{d}_{late}$ in six halls are shown in Table 4.

First, when the data is examined at each frequency band, it is understood that the values at the higher frequency show a concentration in the vicinity of a point (1/3, 1/3, 1/3). That is, the late sound energy at higher frequency arrives evenly from all directions. This agrees with a fact that the diffusivity at higher frequency-band is higher than that at lower frequency-band in general. Next, the values averaged over five frequency-bands are considered. In Hall B, which is a fan-shaped hall, late lateral energy ratio is very low and the difference between the observation points is large. On the other hand, in Hall E, which is a shoe-box-type concert hall, the values of directional late energy ratios are located in the vicinity of a point (1/3, 1/3, 1/3) and the difference between the observation points is small. The maximum of $\bar{d}_{late}$ is 5.2 for Hall B, and the minimum is 0.7 for Hall E.

Moreover, for the comparison, the distributions of normalized directional early energy ratios GE^{*}_{early}, LE^{*}_{early} and VE^{*}_{early} (the average value of frequency) are shown in Fig. 4. It is found that the position of distribution of directional early energy ratio shifts to the direction in which longitudinal ratio increases, and lateral and vertical ratios decrease. It shows that the tendency of directional distribution of early sounds is clearly different from that of late sounds. In addition, the difference in early sound between the halls is smaller than that in late sound.

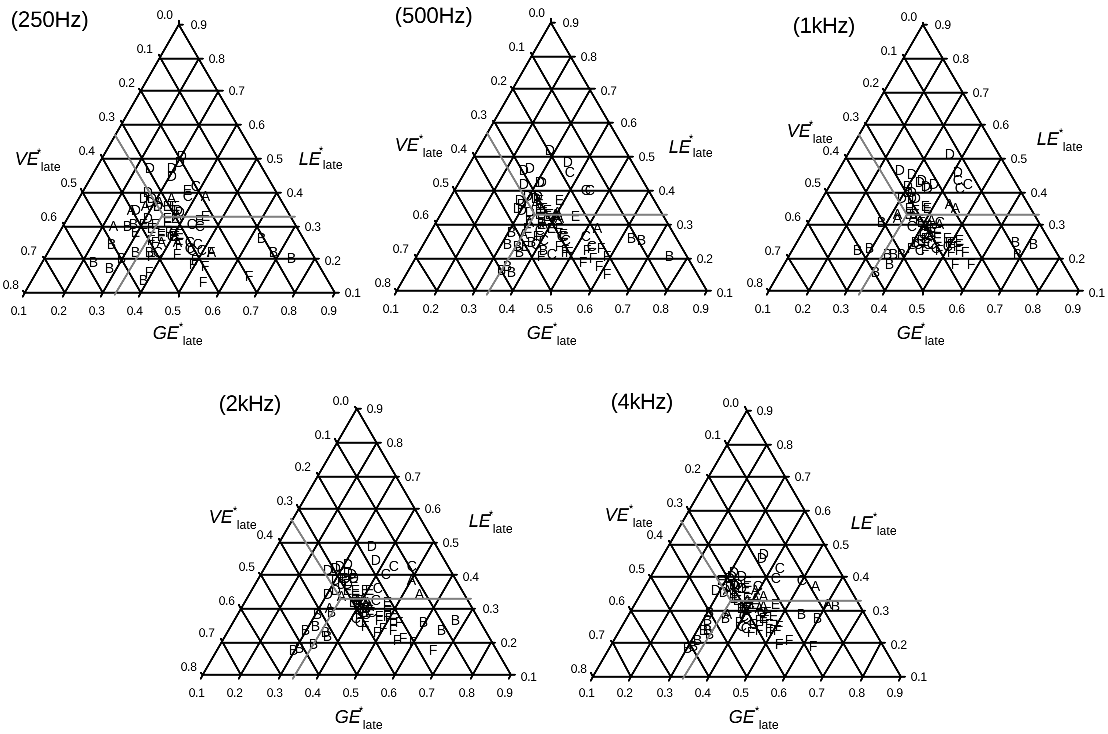


Fig. 2. Normalized directional late energy ratio at five frequency-bands. The letter in the figures indicates the name of hall.

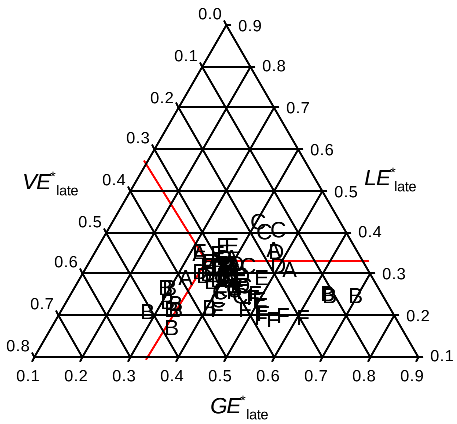
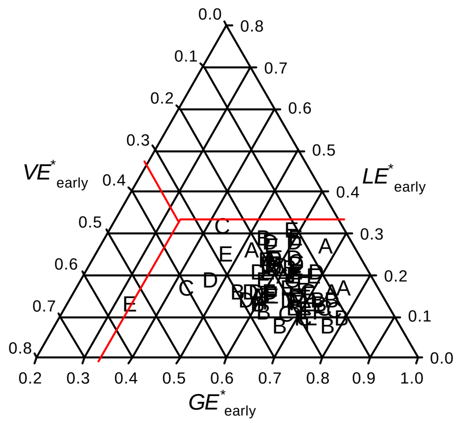


Fig. 3. Normalized directional late energy ratio. (averaged over five frequency-bands)

Table 4
Mean distance $\bar{d}_{late}$ between (GE^*_{late}, LE^*_{late}, VE^*_{late}) and (1/3, 1/3, 1/3).

Hall	$\bar{d}_{late}$ (10^{-2})					
	250Hz	500Hz	1kHz	2kHz	4kHz	Ave.
A	1.5	1.0	1.1	2.0	2.7	1.4
B	6.5	5.6	5.8	4.8	3.9	5.2
C	1.9	2.6	2.5	2.2	2.0	2.0
D	1.3	1.3	1.8	1.1	0.9	1.1
E	0.7	0.6	1.1	1.1	0.5	0.7
F	3.2	4.4	3.7	4.5	3.6	3.6



Hall	$\bar{d}_{early}$ (10^{-2})
A	12.0
B	14.0
C	11.9
D	8.9
E	9.4
F	13.0

Fig. 4. Normalized directional early energy ratio. (averaged over five frequency-bands)

CONCLUSION

New and useful information on the directional characteristics of late sounds were obtained by the acoustical measurement in real sound fields. The distance attenuation and directional distribution of late sounds in the hall were discussed. Directional distribution of late sounds depends on the diffusivity of sound fields and it might be an important factor to evaluate the sound fields of auditoria.

ACKNOWLEDGEMENT

The authors wish to thank the persons concerned in surveyed halls and the students of Kyushu University and Kyushu Kyoritsu University for their help in the measurements. This research was supported by Grant-in-Aid for Scientific Research from the Ministry of Education of Japan (No. 12650606).

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