EFFECTS OF FREQUENCY CHARACTERISTICS OF REVERBERATION TIME ON LISTENER ENVELOPMENT

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ABSTRACT

It is well-known that reverberation contributes to listener envelopment (LEV). In this paper, three listening tests were performed to make clear effects of the reverberation time (RT) and its frequency characteristics on LEV. The result of the first test with RT as a parameter shows that it affects LEV significantly. The results of the second and third tests with frequency characteristics of RT as a parameter of show that RT at low frequencies affects LEV as well as RT at high frequencies.

INTRODUCTION

Listener envelopment (LEV) is one of spatial impressions which is the most important in concert halls. Many pieces of research on LEV have reported that reverberation (late reflections) contributes significantly to the perception of LEV[1-7]. The parameters relating to reverberation which contribute to LEV can be divided into the spatial structure and the temporal structure of reverberation.

With the spatial structure, the degree of interaural cross-correlation[1], lateral energy fraction[3,4] front/back energy ratio of reverberation[2,5] and SBTs[6] are proposed as the physical measure for LEV. Meanwhile, with the temporal structure, the effects of C80[3-5] and reverberation time (RT)[4,6] on LEV are demonstrated.

However, the effect of frequency characteristics of RT on LEV is not clarified. Considering that the frequency components of a direct sound and reflections affect apparent source width (ASW) which is the other spatial impression[9-11], it is estimated that the frequency of characteristics of RT affects LEV, too. In this paper, in the first experiment the effect of RT on LEV is investigated and in the second and the third experiments the effects of frequency characteristics of RT on LEV is clarified.

METHOD

In the experiments, 7s section of the first movement of Mozart's "Divertiment" recorded in an anechoic chamber was used as a music motif. The motif was reproduced with a limited frequency range from 100Hz to 10kHz.

Figure 1 shows the impulse response of a stimulus. The sound field used as the stimulus consisted of a direct sound, two early discrete reflections and five reverberant signals. Figure 2 shows the arrangement of loudspeakers. Six loudspeakers, each of which is installed in a cylindrical enclosure (diameter: 108mm, length: 350mm), were arranged at azimuth angles of 0° ± 45° from the median plane, that is, they were arranged symmetrically to the aural axis, in an anechoic chamber. The distance between the center of subject's head and the loudspeakers was 1.5m.

Paired comparison tests were performed in the experiments. Each subject was tested individually and 10 times for each pair, while seated, with head fixed. The task of the subject was to judge which LEV is greater. The psychological scales of LEV were obtained using Thurstone Case V model[12] and Gulliksen method[13].

The following must be considered in interpreting the psychological scales obtained using Thurstone Case V model: The difference of 0.68 on the psychological scale means that the probability of discrimination of difference between two stimuli is 75%. Therefore, it is generally considered that the difference of 0.68 on the psychological scale corresponds to the just noticeable difference (jnd).

EXPERIMENT 1: EFFECTS OF REVERBERATION TIME ON LEV

<u>Experimental Conditions</u>

Table 1 shows the stimuli used in this experiment. RT changes as well as C80, keeping ÄL of all stimuli constant at -26.3dB. The frequency characteristics of RT were flat. C80 was controlled by changing the density of reverberant signals. The binaural sound pressure levels[14] were constant at 80.0 ± 0.1dBA slow, peak, measured at two ears of KEMAR dummy head without an artificial ear simulator. The degree of interaural cross-correlation (DICC)[15] of the reverberant signals were constant at 0.43 ± 0.03 measured by KEMAR dummy head without an artificial ear simulator. Seven students with normal hearing sensitivity acted as subjects for the experiment.

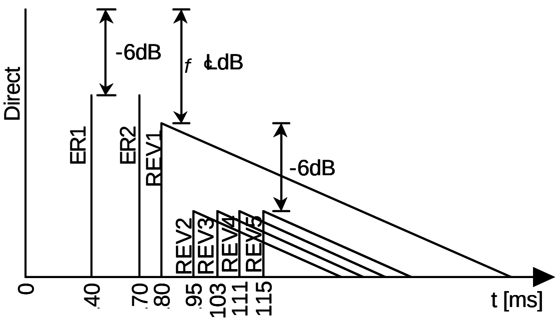

Figure 1. Schematic diagram of impulse response of the stimulus used in the experiments.

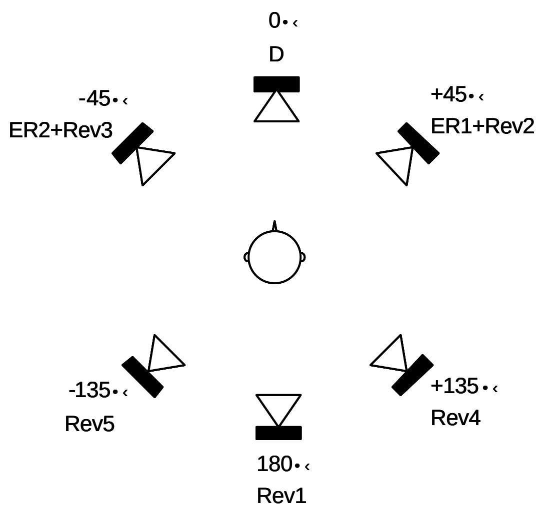

Figure 2. Arrangement of loudspeakers in the experiments.

Table 1. Kinds of stimulus in the experiment 1.

Stimulus	Parameter		
	RT [s]	C80 [dB]	ÄL [dB]
1	1.0	6.0	-26.3
2	1.0	2.8	-26.3
3	1.0	0.9	-26.3
4	2.0	5.5	-26.3
5	2.0	2.7	-26.3
6	2.0	0.7	-26.3

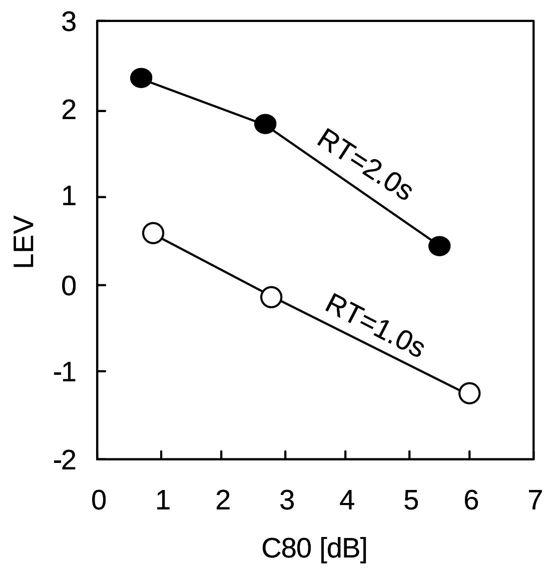

Figure 3. Psychological scale of LEV vs. C80 as a parameter of RT in the experiment 1.

Experimental Results and Discussion

Figure 3 shows the psychological scale of LEV in the experiment 1, that is, LEV with a parameter of RT and as a function of C80. For each C80 value, LEV for RT=2.0s is greater than that for RT=1.0s. The difference between them exceeds 0.68 for each C80 value. This means that RT significantly affects LEV which the listener perceives. Namely, LEV increases as RT becomes longer. Meanwhile, for each RT value, LEV increases as C80 decreases. The difference between the maximum and the minimum LEV exceeds 0.68 for each RT. This means that C80 significantly affects LEV, too.

EXPERIMENT 2: EFFECTS OF REVERBERATION TIME AT LOW FREQUENCIES ON LEV

Experimental Conditions

In the experiment 2, the effects of RT at low frequencies on LEV were investigated for RT=1.0s and 2.0s with flat frequency characteristics. Table 2 shows the frequency characteristics of RT of stimuli used in the experiment. The stimulus of No.3 for each RT value has flat frequency characteristics of RT. C80 of all stimuli were constant at 0dB. ÄL for the stimulus of No3 was constant at -25.6dB and -27.6dB for RT=1.0s and 2.0s, respectively. The binaural sound pressure levels of all stimuli were constant at 79.9 ± 0.1dBA and 80.0dBA for RT=1.0s and 2.0s, respectively. DICC of the reverberant signals of all stimuli were constant at 0.32 ± 0.03. A paired comparison test was carried out separately for each RT. Six students with normal hearing sensitivity acted as subjects for the experiment.

Table 2. Frequency characteristics of RT of stimuli in the experiment 2.

Stimulus	Center frequency of 1/3 oct. band [Hz]						
	125	250	500	1k	2k	4k	8k
				Experiment 2(a) (RT=1.0s)			
1	0.50	0.63	0.75	0.85	0.93	1.00	1.00
2	0.66	0.77	0.77	0.91	0.94	1.00	1.01
3	1.13	1.00	1.04	1.02	0.96	1.00	1.01
4	1.82	1.28	1.19	1.06	1.01	1.06	0.99
5	2.11	1.58	1.30	1.10	1.01	1.02	1.00
6	2.34	1.82	1.41	1.10	1.03	1.02	0.99
				Experiment 2(b) (RT=2.0s)			
1	0.49	0.92	1.21	1.61	1.81	1.91	1.93
2	1.16	1.18	1.46	1.87	1.90	1.91	1.93
3	2.20	1.93	1.91	2.03	1.96	1.92	1.94
4	2.92	2.67	2.18	2.12	1.99	1.93	1.94
5	3.33	3.22	2.45	2.17	1.98	1.91	1.94
6	3.82	3.33	2.63	2.20	2.03	1.94	1.94

(unit : sec.)

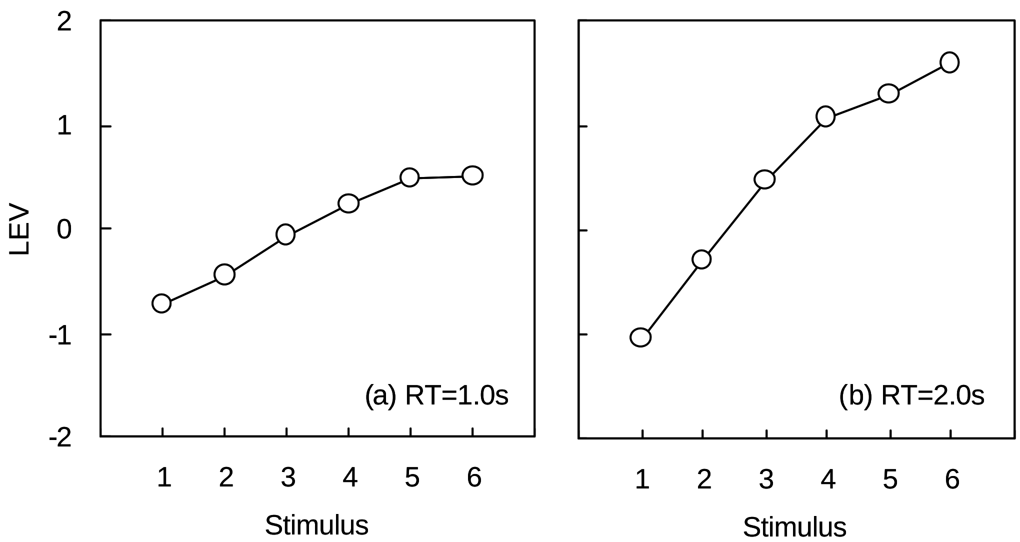

Figure 4. Psychological scal of LEV vs frequency characteristics of RT for (a) RT=1.0s and (b) 2.0s in the experiment 2.

Experimental Results and Discussion

Figure 4 shows the psychological scales of LEV in the experiment 2, that is, LEV vs. RT at low frequencies for each RT with flat frequency characteristics. For each RT value, LEV increases as RT at low frequencies becomes longer and vice versa, comparing with LEV for the stimulus (No.3) with flat frequency characteristics of RT. Furthermore, the difference between the maximum and minimum LEV exceeds 0.68 for each RT. This means that RT at low frequencies affects significantly LEV.

EXPERIMENT 3: EFFECTS OF REVERBERATION TIME OF LOW AND HIGH FREQUENCIES ON LEV

Experimental Conditions

Table 3 shows the frequency characteristics of RT of stimuli used in the experiment. The stimulus of No. 3 has a flat frequency characteristics of RT. C80 of all stimuli were constant at 0dB. ÄL for

Table 3. Frequency characteristics of RT of stimuli in the experiment 3.

Stimulus	Center frequency of 1/3 oct. band [Hz]						
	125	250	500	1k	2k	4k	8k
1	1.05	1.54	1.68	1.89	1.97	2.01	2.00
2	1.44	1.57	1.73	1.91	1.97	2.01	2.01
3	2.00	1.97	2.02	1.99	1.98	1.99	1.98
4	2.03	2.05	2.03	1.99	1.82	1.63	1.34
5	2.04	2.04	2.01	1.97	1.84	1.57	1.23

(unit : sec.)

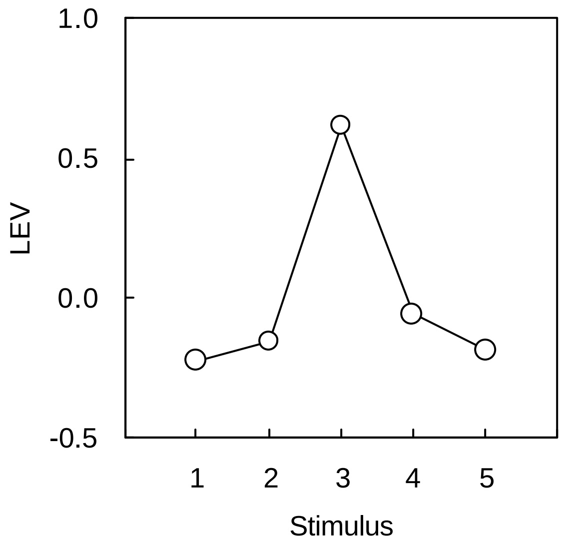

Figure 5. Psychological scal of LEV vs frequency characteristics of RT in the experiment 3.

the stimulus of No.3 was constant at -26.3dB. Th e binaural sound pressure levels were constant at 79.9 ± 0.1dBA. DICC of the reverberant signals of all stimuli were constant at 0.43 ± 0.03. A paired comparison test was carried out separately for each RT. Five students with normal hearing sensitivity acted as subjects for the experiment.

Experimental Results and Discussion

Figure 5 shows the psychological scales of LEV in the experiment 3, that is, LEV vs. RT at low and high frequencies. LEV decreases as RT at low frequencies becomes shorter as well as high frequencies, comparing with LEV for the stimulus (No.3) with flat frequency characteristics of RT. The decrease exceeds 0.68. This means that RT at not only low frequencies but also high frequencies affect significantly LEV. This phenomenon is different from the perception of ASW which is affected by low frequency components but high frequency components.

CONCLUSIONS

The results of three subjective experiments on LEV clarify:

(1) The frequency characteristics of reverberation time affect LEV significantly as well as C80. LEV increases as RT becomes longer and C80 decreases.

(2) Reverberation times at not only low frequencies but also high frequencies affect LEV significantly. LEV decreases as they decrease.

REFERENCES

[1] Morimoto M, Maekawa Z. Auditory spaciousness and envelopment. Proc 13th ICA (Belgrade) 1989; 2: 215-218.

[2] Morimoto M, Iida K. A new physical measure for psychological evaluation of a sound field; front/back energy ratio as a measure of envelopment. J. Acoust. Soc. Am 1993; 93:2282.

[3] Bradley JS, Soulodre GA. The influence of late arriving energy on spatial impression. J Acoust Soc Am 1995; 97: 2263-2271.

[4] Bradley JS, Soulodre GA. Objective measures of listener envelopment. J Acoust Soc Am 1995; 97: 2590-2597.

[5] Morimoto M, Iida K, Sakagami K. The role of reflections from behind the listener in spatial impression. Applied Acoustics 2001; 62: 109-124.

[6] Hanyu T, Kimura S. A new objective measure for evaluation of listener envelopment focusing on the spatial balance of reflections. Applied Acoustics 2001; 62: 155-184.

[7] Bradley JS, Reich RD, Norcross SG. On the combined effects of early- and late-arriving sound on spatial impression in concert halls. J Acoust Soc Am 2000; 108: 651-661.

[8] Barron M, Marshall AH. Spatial impression due to early lateral reflections in concert halls: The deviation of a physical measure. Journal of Sound and Vibration 1981; 77: 211-232.

[9] Blauert J, Lindemann W. Auditory spaciousness: Some further psychoacoustic analysis. J Acoust Soc Am 1986; 80: 533-542.

[10] Blauert J, Mobius U, Lindemann W. Supplementary psychoacoustical results on auditory spaciousness. Acustica 1986; 59: 292-293.

[11] Morimoto M, Setoyama H, Iida K. Consistent physical measures of auditory source width for various frequency components of reflections. Proc. of 3rd Joint meeting of ASJ and ASA 1996: 83-86.

[12] Thurstone LL. A law of comparative judgment. Psychological Review 1927; 34: 273-286.

[13] Gulliksen H. A least squares solution for paired comparison with incomplete data. Psychometrika 1956; 21: 125-134.

[14] Robinson DW, Whittle LS. The loudness of directional sound field. Acustica 1960; 10: 74-80.

[15] Morimoto M, Iida K. A practical evaluation method of auditory source width in concert halls. J Acoust Soc Jpn (E) 1995; 16: 59-69.