Effects of Front / Back Energy Ratios of Early and Late Reflections on Listener Envelopment

Masayuki Morimoto* and Kazuhiro Iida**

*Environmental Acoustics Laboratory, Faculty of Engineering, Kobe University, Nada, Kobe 657-8501 Japan
**AVC Res. Lab. Matsushita Comm. Ind. Co., Ltd., Saedo, Tsuzuki, Yokohama 224-8539 Japan

Abstract: This paper investigates which is more effective for the listener envelopment(LEV), the Front / Back energy ratio(F/B ratio) of early or late reflections. In the experiments, a music motif is used as a source signal. The F/B ratios of early and late reflections are changed independently, but the C-value and the degree of interaural cross-correlation are kept almost constant. The experimental results indicate that the F/B ratios of both early and late reflections have an effect on LEV and their contributions to LEV is almost equal.

INTRODUCTION

It has been considered that late reflections contribute to LEV but early reflections do not, for example, as shown in the definition of LEV in ISO(1) "state of diffusion of the reverberant sound field." It is however not yet proved that early reflections do not contribute to LEV. Some researchers suggested the relation between LEV and the law of the first wave front(2,3), namely, that all reflections which exceed the upper limit of the law must contribute to LEV. This means that early reflections also make the listener perceive LEV. A previous work(4) indicated that LEV grows as the energy of reflections coming from behind the listener increases, i.e., the F/B ratio decreases even if the degree of interaural cross correlation is constant. However, in the experiments, the F/B ratios of early and late reflections were identical. In this paper, the F/B ratios of early and late reflections are changed independently to investigate whether early reflections contribute to LEV or not and which is more effective for LEV, the F/B ratio of early or late reflections.

EXPERIMENTAL METHOD

The music motif used in the experiment was a violin solo performance of Saint-Saëns' "Introduction et Rondo Capriccioso" (14s long, bars 7-12). Six loudspeakers were arranged at azimuth angles of 0° and ±45° from the median plane. The sound field as a stimulus consisted of a direct sound, four early discrete reflections and four late reflections (reverberations). Early reflection delays were 20, 38, 53 and 65ms and late ones were 80, 89, 97 and 104ms. The direct sound was radiated from the loudspeaker in front of the subject and the others were radiated from loudspeakers at 0° and ±45°. The directions and the relative sound pressure levels of early and late reflections depend on the kind of stimulus. The F/B ratio of early reflections including the direct sound was set at +1.3, +4.8 and +18.6dB and that of late reflections was set at -15.0, +0.4 and +14.4dB. The total number of sound fields as a stimulus was nine. The C-values ranged from 0.2 to 1.1dB. The degree of interaural cross correlation ranged from 0.26 to 0.45 and was considered to be constant based on jnd(5). The binaural SPL(6) of all sound fields were constant at 80dBA. Paired comparison tests of LEV were performed. The task of the subject was to judge which sound field made him perceive greater LEV. Five male students with normal hearing sensitivity acted as subjects for the experiment. Each subject was tested 10 times for each pair individually.

EXPERIMENTAL RESULTS AND DISCUSSION

The psychological scales of LEV were obtained using the Thurstone Case V model. **Figure 1** shows LEV as a function of the F/B ratio of late reflections and as a parameter of that of early reflections. It is found that not only the F/B ratio of late reflections but also that of early reflections affect LEV. For any F/B ratio of early reflections, as the F/B ratio of late reflections decreases, LEV increases and the rate of increase of LEV is almost equal. Namely, LEV increases as the sound energy from behind the listener increases. On the other hand, for any F/B ratio of late reflections, as the F/B ratio of early reflections reduces from +18.4dB to +4.8dB and +1.3dB, LEV increases as well as the increase of LEV for the F/B ratio of late reflections. But there is no difference in LEV between +4.8dB and +1.3dB of the F/B ratio of early reflections. It can be considered that the difference of 3.5dB in F/B ratio is too small to cause the difference in LEV.

The multiple regression analysis was applied to investigate which is more effective for LEV, the F/B ratio of early reflections or that of late reflections. The multiple correlation coefficient is 0.956. Equation 1 is the multiple regression equation.

$$Z = -0.033X - 0.042Y + 1.185, \tag{1}$$

where Z is LEV, X is F/B ratio of early reflections and Y is F/B ratio of late reflections. The regression coefficients of X and Y are regarded as the degree of contribution of each F/B ratio of early and late reflections to LEV respectively. This result means that the contribution of F/B ratios of early and late reflections are almost equal. Furthermore, it suggests that there is a relation between the perception of LEV and the law of the first wave front, namely, that any reflection which exceeds the upper limit of the law contributes to LEV, regardless of its time delay.

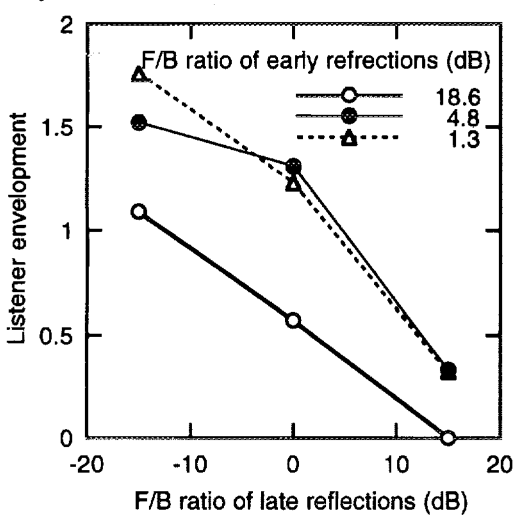

FIGURE 1.
Psychological scale of listener envelopment as a function of the Front / Back energy ratio of late reflections and as a parameter of the Front / Back energy ratio of early reflections.

CONCLUDING REMARKS

The most significant conclusion is that early as well as late reflections contribute to LEV. Therefore, the F/B ratio of early reflections must also be measured to evaluate LEV. Furthermore, it is necessary to provide a larger quantity of sound energy from behind the listener to produce greater LEV. From a practical point of view, however, it is not easy to provide many early reflections from behind without electroacoustical equipment in a concert hall. Naturally, it would be effective to control LEV by the F/B ratio of late reflections.

REFERENCES

(1) ISO 3382 (1997).
(2) Morimoto,M.and Maekawa,Z., "Auditory spaciousness and envelopment,"*Proc. 13th ICA(Belgrade)* 215-218,1989.
(3) Bradley, J.S. and Soulodre, G.A., *J. Acoust Soc. Am.*, **9 7**, 2263-2271 (1995).
(4) Morimoto, M and Iida, K., *J. Acoust. Soc. Am.*, **9 3**, 2282 (1993).
(5) Morimoto, M. and Iida, K., *J. Acoust. Soc. Jpn.(E)*, **1 6**, 59-69 (1995).
(6) Robinson, D.W. and Whittle, L.S., *Acustica*, **1 0**, 74-80 (1960).