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A chart of %-split of sound image

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Split of sound image is an auditory phenomenon which must be avoided in designing and controlling sound fields such as concert halls, auditoria and theaters. This paper proposes a practical chart to predict the degree of split of sound image for speech. The chart was obtained from the results of a psychoacoustical experiment in which a direct sound and a single reflection were presented to a large number of subjects. The chart should be utilized to predict the degree of split of sound image, which is a different phenomenon from echo threshold and echo disturbance.

Keywords: Echo threshold, Split of sound image, Preceding effect, First wave front, Sound image control

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1. INTRODUCTION

In the acoustical design of concert halls, strong lateral reflections are sometimes created in order to increase auditory spaciousness. On the one hand, the sound image control technique, which provides electrically artificial reflections and reverberation to an audience in order to control spatial attributes of sound image, such as direction, distance, and spaciousness, is often introduced in auditoria and theaters. One phenomenon that must be avoided in both cases is split of sound image. Echo disturbance and echo threshold have been often studied, while fewer studies have been conducted on the split of sound image. These phenomena appear similar to each other and yet there is a distinct difference between them. In an experiment on echo threshold, the listening target of a subject is a reflection, whereas in experiments on split of sound image and echo disturbance, the target is a direct sound. The degree of disturbance is judged by a subject in the experiment on echo disturbance, regardless of whether or not a sound image splits. Therefore, data obtained by the experiments on echo disturbance and echo threshold are not acceptable for avoiding split of sound image.

In this paper, we performed a psychological experiment on split of sound image with a large number of subjects in order to propose a practical chart of %-split of sound image for speech. We then compared the results with echo disturbance and echo threshold for speech and discussed these results on an application of the chart.

2. EXPERIMENTAL METHOD

The subjects consisted of sixty-four male and seven female students, aged 19~25 years with normal hearing sensitivity.

The experiment was performed in an anechoic chamber. The source signal used in the experiment was a Japanese speech of a male announcer (period: 7 s, speech rate: 6 syllables/s). Stimuli consisted of a direct sound and a single reflection as shown in

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Fig. 1. The reflection had the same spectrum as the direct sound.

The time delay of the reflection from the direct sound was changed in five steps of 10 ms from 10 ms to 50 ms. The relative sound pressure level of the reflection to the direct sound was changed in ten steps of 2 dB from a level at which authors could clearly perceive split of sound image down to a level at which they could not perceive at all, at each time delay. Totally, fifty kinds of stimuli were used in the experiment as shown in Table 1. Each stimulus was delivered once in a random order. The peak sound pressure level of the direct sound was fixed at A-weighted 65 dB with time-constant of slow.

Figure 2 shows the arrangement of two loudspeakers used in the experiment. The direct sound was emitted from a front loudspeaker and the reflection was emitted from a loudspeaker which was mounted at 60° left of center in the horizontal plane on which the ear axis lied. This method was used because a reflection arriving from 60° easily produced an echo according to the results by Morimoto *et al.*[1] The loudspeakers were cylindrical ones (diameter: 108 mm, length: 350 mm) and those frequency characteristics were flattened to within ±3 dB in the frequency range from 106 Hz to 9,600 Hz by a 1/3 oct. band frequency equalizer.

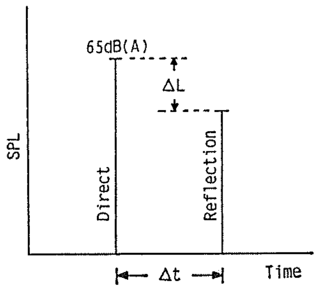

Fig. 1 Signal configuration in the experiment: Δt: time delay of a reflection from a direct sound, ΔL: relative SPL of a reflection to a direct sound.

Table 1 Combination of time delay and SPL of a reflection of stimuli used in the experiment.

Time delay (ms)[a]	SPL (dB)[b] (in 10 steps of 2dB)
10	+6～−12
20	+6～−12
30	+2～−16
40	−4～−22
50	−8～−26

a) time delay from a direct sound.
b) relative SPL to a direct sound.

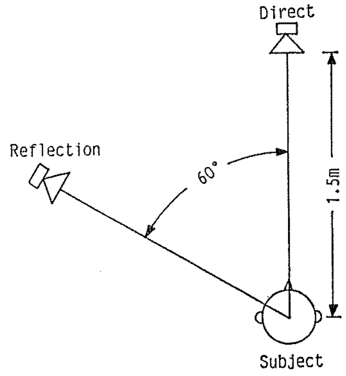

Fig. 2 Loudspeaker arrangement in the experiment.

Each subject was individually tested while seated, head fixed, in a partially darkened anechoic chamber. Fifty recording sheets with a circle printed on it were supplied to the subjects. The mapping method was adopted to avoid the subject being too sensitive to the reflection. Namely, the subjects' task was to mark down the direction of the sound image on a circle on the recording sheet for each stimulus. When the subject perceived plural sound images, he was requested to mark down all those directions on the same circle. The seven second interstimulus interval allowed the subject to mark down the perceived directions and to take up the next recording sheet. The only light in the chamber was placed such that it provided just enough illumination for the subject to see and utilize the recording sheet.

3. ANALYSIS OF DATA

The sound image was considered split if plural marks were found on the recording sheet with the following exceptions; (a) plural marks were close to each other (within 10°) and (b) they were in the median plane.

The reflection levels at which the sound image is first split were decided for each subject at each time delay of a reflection according to the Cornell technique.[2] Then Guttman's coefficient[2] of repro-

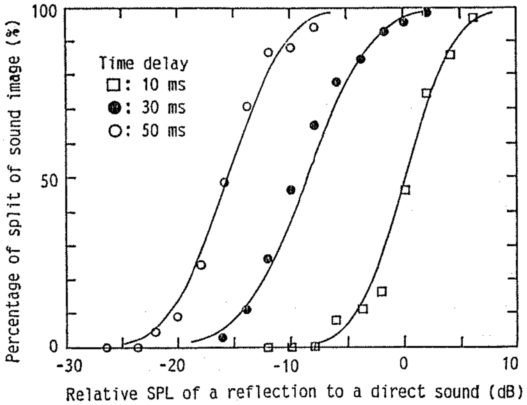

Fig. 3 Examples of percentage of split of sound image obtained in the experiment as a function of reflection level.

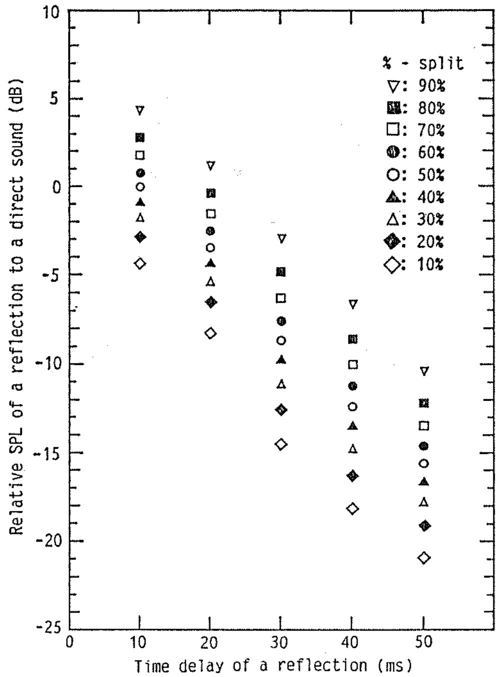

Fig. 4 Reflection level at every 10% split of sound image as a function of time delay of a reflection.

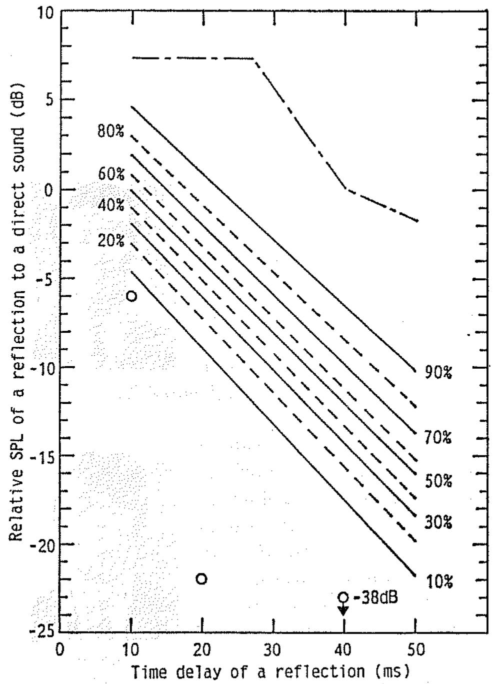

Fig. 5 A chart of %-split sound image for speech: —·—; 10% echo-disturbance by Bolt and Doak. ○: echo threshold by Morimoto *et al.*

ducibility on judgement was examined for each subject at each time delay of a reflection. As a result, the responses of fifty-nine males and six females, whose coefficient of reproducibility exceeded 0.9, were adopted to obtain a chart of %-split of sound image.

The percentage of split of sound image plotted as a function of reflection level for each time delay indicated a nearly normal distribution curve as shown in Fig. 3. Then, the reflection level at every 10% split was read from the curve for each time delay and plotted as a function of time delay as shown in Fig. 4. Since a high correlation ($r = -0.99 \sim -1.00$) was found between reflection level at every 10% split and time delay, a regression line was drawn for every 10% split as shown in Fig. 5. Gradient of the regression lines is approximately -4 dB/10 ms.

4. DISCUSSION

Following the scientific method, we obtained a chart of %-split of sound image, which would be useful in the acoustical design and control of sound fields.

In this connection, let us compare split of sound image with echo disturbance and echo threshold for speech. A dashed-dotted line in Fig. 5 shows the

10% contour of %-echo disturbance proposed by Bolt and Doak[3] on the basis of Haas's results about echo disturbance for a German speech. It can be seen that it is more than 3 dB higher than the contour indicating 90% split of sound image. On the other hand, circles in Fig. 5 indicate echo thresholds for a Japanese speech, measured by Morimoto *et al.*,[1] with a reflection arriving from 60° from center in the horizontal plane. It can be seen that they are more than 10 dB lower than the contour indicating 10% split of sound image at 20 ms and 40 ms, and less for that at 10 ms. From this comparison, it is clear that split of sound image is a different phenomenon from echo threshold and echo disturbance.

Consequently, the chart proposed in this paper should be utilized to predict the degree of split of sound image.

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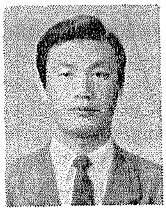

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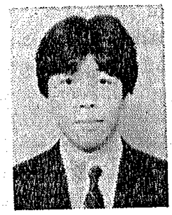

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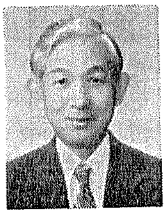

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