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# Relation between Auditory Source Width in Various Sound Fields and Degree of Interaural Cross-Correlation: Confirmation by Constant Method

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*ABSTRACT*

*The purpose of this paper is to confirm the inference from an experiment reported in a previous paper (Morimoto, M., Iida, K. & Furue, Y.,* Applied Acoustics, *38 (1993) 291–301) that auditory source widths perceived in different sound fields with the same degree of interaural cross-correlation are equal to each other, regardless of the number and arriving direction of reflections. In this paper, the method of constant is used in the experiment, instead of the method of adjustment which was used in the previous paper. The results confirm the conclusion inferred in the previous paper.*

## 1 INTRODUCTION

A previous paper[1] investigated the question whether or not the degree of interaural cross-correlation could be widely applied as a physical factor to estimate auditory source width (ASW) perceived in any sound field. In that paper, results of psychological experiments inferred that ASWs perceived in different sound fields with the same degree of interaural cross-correlation are equal to each other, regardless of the number and arriving direction of reflections. But a definite conclusion could not be drawn, because of the bias of subjective judgment caused by the method of adjustment by a subject. In this paper, the same question is confirmed by using the method of constant.

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# 2 EXPERIMENT

The method of the psychological experiment performed in this paper was the method of constant, using the paired comparison test between the fixed test field with a constant degree of interaural cross-correlation and one of the variable comparison fields with different degrees of interaural cross-correlation.

## 2.1 Experimental conditions

### *2.1.1 Musical motif*

The motif used in this experiment was a six-second section from bar 94 of the fourth movement of Mozart's Jupiter Symphony (No. 41), which was the beginning of the same motif used in the previous paper.

### *2.1.2 Apparatus*

Thirteen cylindrical loudspeakers (diameter 108 mm, length 350 mm) were arranged at horizontal angles of 0°, ±30°, ±45°, ±60°, ±90°, ±120°, and ±150° from the median plane at 1·5 m distance. The loudspeaker at 0° radiated a direct sound and the other loudspeakers radiated reflections. The frequency characteristics of all loudspeakers were equalized within ±2·5 dB in the frequency range from 100 Hz to 10 kHz by a digital frequency equalizer (Technics DSE-10).

### *2.1.3 Kinds of structure of reflections*

The structures of reflections of the variable comparison fields and the fixed test field are the same as those used in the previous paper.[1]

Figure 1 shows the structure of reflections of the variable comparison field. The field consists of a direct sound and two reflections. The direct sound was radiated from the front of a subject and the reflections

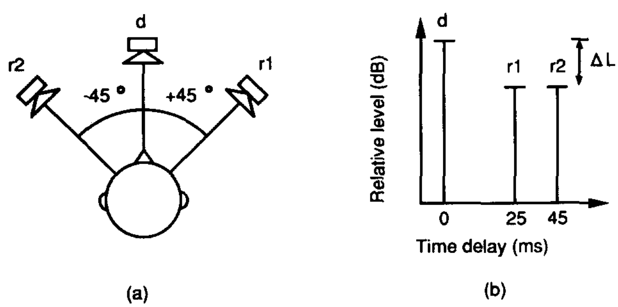


**Fig. 1.** Structure of reflections (a) and impulse response (b) of a comparison field: $d$ is a direct sound and $r1$ and $r2$ are reflections; $\Delta L$ is SPL relative to a direct sound.

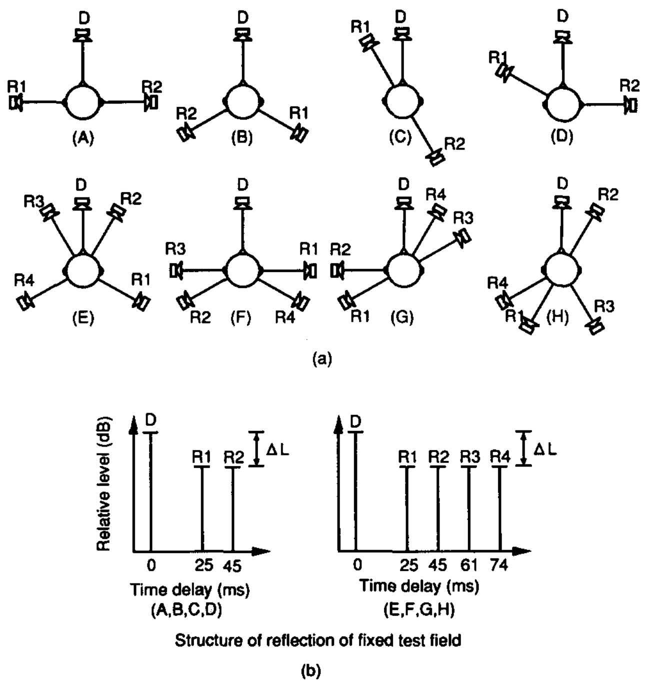


**Fig. 2.** Kinds of structure of reflections (a) and impulse response (b) of fixed test fields: $D$ is a direct sound and $R1$–$R4$ are reflections; $\Delta L$ is SPL relative to a direct sound.

were radiated from horizontal angles of ±45°. Reflection delays were 25 and 45 ms. The sound pressure levels of reflections were made equal. The relative level of the reflections to the direct sound was changed with a differential attenuator to control the degree of interaural cross-correlation.

Figure 2 shows the structures of reflections of the fixed test fields. The field consists of a direct sound and two or four reflections. Eight kinds (A–H) of combination of arriving direction of reflections were selected, considering the front–back and the left–right symmetry and asymmetry. Reflection delays were 25, 45, 61 and 74 ms. The sound pressure levels of reflections were made equal. The relative level of the reflections to the direct sound was fixed at a level where the degree of interaural cross-correlation was kept constant. Furthermore, the same reflection structure as in the variable comparison field shown in Fig. 1 was added as a fixed test field T for reference.

The degree of interaural cross-correlation of the fixed test fields was set to 0·80 ± 0·01 and can be considered to be constant. On the other hand, the degree of interaural cross-correlation of the variable comparison field was changed in nine steps, from 0·65 to 0·90, as follows: 0·65, 0·71, 0·73, 0·75, 0·77, 0·79, 0·83, 0·85, and 0·90. The reason why the steps were irregular is that the degree of interaural cross-correlation was controlled by changing the relative level of the reflections to the direct sound in steps of 0·5 dB. The reflections were measured for the musical motif used in the psychological experiment by using a KEMAR dummy head without an artificial ear simulator (BK DB-100) and a microphone amplifier with a flat frequency response.[2]

The total sound pressure level of all fields was constant at 70 dB(A) ±0·1 dB slow, peak, which was calculated by the equation to obtain a binaural summation of loudness,[3] using the measured values at the left and the right ear entrances of the KEMAR dummy head without an artificial ear simulator (BK DB-100).

#### *2.1.4 Procedure*

Paired comparison tests of ASW were carried out separately for each fixed test field. A pair consisted of the fixed test field with a constant degree of interaural cross-correlation and one of the variable comparison fields with nine different degrees of interaural cross-correlation. The fixed test field preceded the variable comparison field in all pairs. The interval between them was 1 s. All pairs were arranged, followed by an interval of 5 s, in random order. Each subject was presented with the same pair five times in one test and was tested five times for each fixed test field. Accordingly, 25 responses to each pair were obtained for each subject. The experiment began with the fixed test field T for all subjects. But the order of the experiments of the other fixed test fields differed for each subject.

Each subject was tested individually, while seated, with his head fixed in a darkened anechoic chamber. The task of the subject was to judge whether or not the ASW of the variable comparison field was wider than that of the fixed test field.

#### *2.1.5 Subjects*

Three male students (22 years) with normal hearing sensitivity acted as subjects in the experiment. They were different from the subjects in the previous paper and had no experience of psychoacoustical experiments such as this experiment.

### 2.2 Experimental results and discussion

All subjects perceived no echo in any of the sound fields. Before the experiment, a few practice trials to each fixed test field were performed, and they were excluded from the results.

At first, the data analysis was carried out separately for each subject and for each fixed test field. The percentage by which the ASW for the variable comparison field was wider than that for the fixed test field was obtained. Furthermore, the $z$-transformation of the percentage was performed. The correlation coefficient between the $z$-value and the degree of interaural cross-correlation of the variable comparison field exceeded 0·895 for any fixed test field. This means that the distribution of response by any subject to any fixed test fields could be regarded as the normal distribution. Then, the regression equation was obtained by the least-squares method. The average value and the standard deviation of responses by each subject to each fixed test field were obtained from the regression equation. The $t$-tests of significance for the difference between three subjects' average values for each fixed test field were performed. The results showed that there was no significant difference between them ($p < 0.1$). Therefore, the responses of the three subjects were analyzed in a group.

For each fixed test field, the percentage of responses by the three subjects by which the ASW for the variable comparison field was wider than that for the fixed test field was obtained and the $z$-transformation of the percentage was performed. The correlation coefficient between the $z$-value and the degree of interaural cross-correlation of the variable comparison field exceeded 0·960 for all fixed test fields. This means that the distribution of response by all subjects to any fixed test field could be regarded as the normal distribution. As an end result, the average value and the standard deviation of response by all three subjects to each fixed test field were obtained by the procedure mentioned above. They are shown in Fig. 3. The average value means the degree of interaural cross-correlation of the variable comparison field, the ASW for which was judged to be equal to the ASW for each of nine fixed test fields by all the subjects.

First, consider the result for the fixed test field T which consists of the same reflection structure as the variable comparison field. The average value is almost 0·80. The difference does not exceed 0·01. This means that the subjects have the ability to correctly judge ASW. Next, consider the results for the other fixed test fields. The maximum difference of the average value from the degree of interaural cross-correlation of the fixed test field ($0.80 \pm 0.01$) is 0·04 for the field E. This difference is less than the just noticeable difference of degree of interaural cross-correlation with regard to the ASW of the same musical motif.[4] The $t$-tests of significance for the difference between the average values of the nine fixed test fields were performed. The results showed no significant difference between them ($p < 0.1$). From these discussions, it can be concluded that the ASW produced by the nine fixed test fields (A–H and T) are equal to each other.

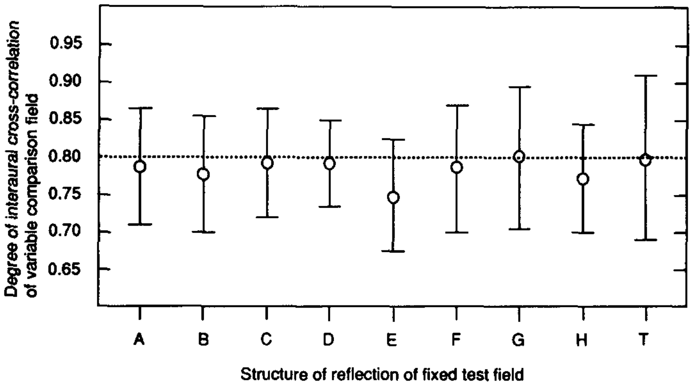


**Fig. 3.** Average (circle) and standard deviation (bar) of degree of interaural cross-correlation of a comparison field, the auditory source width (ASW) for which is equal to the ASW for fixed test fields in this experiment. The test field T consists of the same structure of reflection as the comparison field. The dotted line is the degree of interaural cross-correlation of fixed test fields.

## 3 CONCLUSION

In this paper, the relation between the auditory source width (ASW) produced by different sound fields with different structures of reflection, and the degree of interaural cross-correlation, is confirmed by using the method of constant. The experimental data yield the same result as in the previous paper. Namely, it is definitely concluded that ASWs perceived in different sound fields with the same degree of interaural cross-correlation are equal to each other, regardless of the number and arriving direction of reflections.

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