2pEAb9. Comparison of precedence effect behavior in anechoic chamber with that in ordinary room

Koji Abe*, Shouichi Takane, Sojun Sato and Kanji Watanabe

*Corresponding author's address: Faculty of Systems Science and Technology, Akita Prefecural University, 84 -4 Ebinokuchi Tsuchiya, Yuri-Honjyo, 0150055, Akita, Japan, koji@akita-pu.ac.jp

The precedence effect is well known as one of auditory illusions occurred by using multiple sound sources with similar sound output. When a sound is followed by similar sound separated with relatively short time delay, a single fused sound image is localized at the source position corresponding to the first-arriving sound. This feature is applicable to public address systems, which make audience perceive the sound image different from the actual sound source positions prepared for the system, with some sound reinforcement achieved. In spite of many studies in this phenomenon, the behavior of the precedence effect has been investigated for limited sound source arrangements in laboratory environments like anechoic chamber. On the other hand, this behavior in the ordinary room is not obvious, and it is effective to clarify the difference of the behavior of the precedence effect in anechoic chamber from that in the ordinary room for the application of the precedence effect to the public address system. In this study, the similar sound sources were installed both in the lecture room and in the anechoic chamber, and the behavior of the precedence effect was compared each other with the given time and level difference among sound sources.
INTRODUCTION

The precedence effect is well known as one of auditory illusions occurred by using multiple sound sources with similar sound output [1-3]. When a sound is followed by similar sound separated with relatively short time delay, a single fused sound image is localized at the source position corresponding to the first-arriving sound. This feature is applicable to public address systems. For example, OZ-T100 based on Delta Stereophony is one of the applications [4,5]. In spite of many studies in this phenomenon, the behavior of the precedence effect has been investigated for limited sound source arrangements in laboratory environments like anechoic chamber.

In order to construct the public address system (PA system) utilizing the precedence effect, the effect of reflection must be taken into account. Therefore, it is necessary to estimate the behavior of sound localization in environment with reflection for each place to install the PA system. However, it is impractical to conduct point by point experiment in each field to set up a PA system. If conditions (configuration of sound sources, the level and time difference, and so on) required for generation of the precedence effect in an anechoic chamber can be used in the design of the PA system in ordinary space, this problem can be solved. But there are few studies comparing the behavior of the precedence effect in anechoic chamber with that in ordinary room. In this study, the similar sound sources were installed both in the lecture room and in the anechoic chamber, and the behavior of the precedence effect was compared each other with the given time and level difference among sound sources.

EXPERIMENT

EXPERIMENT IN ORDINARY ROOM

As an ordinary space used for the experiment, the lecture room (in Akita Prefectural University) has been selected. Figure 1 shows a two-dimensional plan of this room. Right-hand side of Fig. 1 is the platform, audiences are seated facing right. In order to propagate a clear voice throughout this room, the amplifiers are required. Three loudspeakers are installed as the sound source. The loudspeaker (Front Sp.) is placed on the platform in front of the lecture room, assuming a human speaker. Two loudspeakers (Left Sp. and Right Sp.) simulating the equipment of the PA system are placed at the center near both sidewall of this room facing inside. The stimulus is the male’s announcement with a duration of about 3 s.

Six listening positions were picked up in this experiment as shown in Fig. 1 (P1 - P6 ). Considering the symmetry of this lecture room, all positions were in the right side of the room. Based on the positions of the equipments, the arrival time from each loudspeaker to each listening position was calculated as shown in Table 1. When the sound stimulus is presented at the same time from all loudspeakers, the sound from the Front Sp. is preceding about 5 to 12 ms at P1 and P4, and the sound from the Left or Right Sps. is preceding at P2, P3, P5 and P6. From these data, we made three conditions related to the time difference. Under three conditions, presentation from Front Sp. precedes that from Left and Right Sps., and the sound from the Left and Right Sps. are presented simultaneously. The time difference in the first condition is 10 ms. In this condition, the sound stimulus presented from Front Sp. arrives first at the points P1 and P4. The second condition has a time difference of 20ms. In this condition, sound from each loudspeaker arrives at approximately the same time at the center of lecture room (P5). The last condition of time difference is 40 ms. Under this condition, the stimulus emitted from Front Sp. is preceding at all listening positions.

Two relative level difference conditions between the sound stimuli presented from Front Sp. and Left/Right Sp. were set. One is that the level of the sound presented from Front Sp. equal to that of Left/Right Sp.. This is called “0 dB condition”. Another is that the level of the sound presented from Left/Right Sp. is 4 dB larger than that of Front Sp.. This is referred to as “+4 dB condition”. This condition is intended to ensure sufficient volume at the back of the lecture room. The A-weighted sound pressure level of sound presented from Front Sp. is 60 dBA at P4.

Four untrained young college students participated in this experiment. All subjects has normal hearing. Subjects were asked to answer the perceived direction of the fused image produced by the loudspeakers.

EXPERIMENT IN ANECOIC CHAMBER

First of all, in order to simulate the listening environment in the ordinary room, the impulse responses from each loudspeaker to each listening position was measured in the lecture room. Three loudspeakers are arranged on a circle of radius 1.5m in anechoic chamber with its dimensions as: W:7.5 m × D: 6.0 m × H:4.5 m. The subject seated in the
shown in Table 2. Other conditions are almost the same as the experiment in ordinary room. Level difference given for each loudspeaker with reference to 60 dBA is determined based on the impulse response. Level difference was calculated theoretically as shown in Table 1. Time difference was determined based on the impulse response. Level difference given for each loudspeaker with reference to 60 dBA is shown in Table 2. Other conditions are almost the same as the experiment in ordinary room.

RESULT AND DISCUSSION

The result of perceived sound images obtained from the listening test in each room is shown on the 2-dimensional plan of the lecture room in Figure 3. In this figure, the condition of time difference is 10 ms, and the level difference condition is 0 dB. Figure 3 (a) is the result of experiment on the lecture room, and Figure 3 (b) is that on the anechoic room. A rectangle in each panel represents the shape of the lecture room. The small squares in each panel show the loudspeakers, the positions of circles indicate the listening position. The gray fan-shape in these circles indicates the result of subject’s response. The center line of the fan-shape is the average of the perceived sound image, and the internal angle is twice the standard deviation. In Figure 3 (b), the result obtained for the anechoic chamber are shown in the corresponding position in the lecture room. Comparing with Fig. 3 (a) and (b), the perceived sound image is almost the same at P1, P2, P4 and P6. Moreover, the perceived sound images are almost localized in the direction of the Front Sp. except P2. On the other hand, there are the different tendency between the perceived sound image of ordinary room and anechoic chamber at P3 and P5, and the direction of the perceived image is not the direction of Front Sp.

All experimental results are shown in Figure 4. Fig. 4 (a) - (f) represent the result at P1 – P6, respectively. The left panel shows the direction of perceived sound image for the lecture room, and the right panel shows that for the anechoic room. The horizontal axis is the time difference condition, the vertical axis is the direction of the perceived sound image. The front direction of subject corresponds to 0 degrees, and the clockwise direction is positive. The solid line corresponds to the 0 dB condition, the dashed line corresponds to the +4 dB condition. The upper horizontal line is the direction of Right Sp., the middle horizontal line is that of Front Sp., and the lower horizontal line is that of Left Sp.

From Fig. 4 (a), (d) and (f), in both ordinary room and anechoic chamber, the direction of perceived sound image corresponds to the direction of Front Sp. under all level and time difference conditions. For P1 and P4, the sound
stimulus of Front Sp. precedes to that of Left/Right Sps. under all time difference conditions. In addition, the sound pressure level of sound presented by Front Sp. is also larger than that of Left/Right Sps.. Therefore, this result is predictable. In case of P6, the sound stimulus from Front Sp. follows that from Left/Right Sps. in the 10 ms condition. However, since the position of Left and Right Sp. is almost symmetrical, the composite sound generated by these loudspeakers may occur in the front. Therefore, in even the condition that the precedence effect does not occur, perceived sound image may be observed in the front direction.

On P2, the direction of the perceived sound image is that of Right Sp. under all condition, although slight variations are observed in the 40 ms condition. P2 is very close to the installation position of Right Sp., thus, the level of the sound stimulus emitted from Right Sp. is 12 – 17 dB larger than that of the other loudspeakers. This large level difference negates occurrence of a precedence effect. As a result, the clear sound image was generated in the direction of Right Sp.,

On P3 and P5, there are difference in the behavior of precedence effect between the ordinary room and the anechoic chamber. In order to examine the statistical difference between the experimental environments, a three-way analysis of variance (ANOVA), in which we adopted the place (lecture room and anechoic chamber), the time difference (10 ms, 20 ms and 40 ms) and the level difference (0 dB and +4 dB) as sources of variance, was performed for each listening position. As a result, the main effect of the place is significant on P3 ( F(1, 131)=132.5, p < 0.01 ). On P5, under the 10 ms condition, there are significant difference about the place ( F(2, 131)=6.78, p < 0.01 ). As shown in Table 1, the sound stimulus presented by Right Sp. precedes on the 10/20 ms conditions for P3. If the precedence effect occurs, the sound image should be perceived in the direction of Right Sp.. The panel corresponding the lecture room in Fig. 4 (c) shows that the perceived sound image is generated in the direction of Right Sp. in the 10/20 ms conditions, and it is direction of Front Sp. in the 40ms condition. However, for experiment in anechoic chamber, the direction of the perceived sound image is the front under all time difference conditions. In addition, since the standard deviation of the sound image is larger than that of other listening positions, the width of sound image may become broad. The arrangement of loudspeakers for P5 is almost symmetrical, but the perceived direction of sound image approaches in the direction of Left Sp. when time difference is short. In contrast, in an anechoic chamber, the sound image is localized in the front direction although the ambiguity of sound image may be wide. As shown in Fig. 1, the lecture room used in this experiment is not strictly symmetrical. The distance from P5 to the Left Sp. is a little

\[ \text{FIGURE 2.} \text{ Example loudspeaker arrangement in anechoic chamber simulating the environment of P1.} \]

\[ \text{TABLE 2.} \text{ Relative level at the subject’s position in anechoic chamber.} \]

(Unit: dB, Level difference condition: 0 dB, Reference level: 60dBA)

<table>
<thead>
<tr>
<th>Sound Source</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front loudspeaker</td>
<td>2.0</td>
<td>−12.2</td>
<td>−16.5</td>
<td>0.0</td>
<td>−12.4</td>
<td>−16.8</td>
</tr>
<tr>
<td>Left loudspeaker</td>
<td>−7.2</td>
<td>−8.4</td>
<td>−12.8</td>
<td>−9.5</td>
<td>−6.7</td>
<td>−14.4</td>
</tr>
<tr>
<td>Right loudspeaker</td>
<td>−7.6</td>
<td>4.5</td>
<td>−15.4</td>
<td>−9.0</td>
<td>−5.9</td>
<td>−15.9</td>
</tr>
</tbody>
</table>
farther than the distance to the Right Sp.. Therefore, if the perceptual direction is determined depending on arrival time difference, the sound image is perceived in the direction of a Right Sp.. This fact means that the direction of the perceived sound image was not in agreement with the prediction from physical data. If there are loudspeakers on position lateral and close to the listener and both loudspeakers are symmetrical, the asymmetry of the lecture room may bring about influence on sound localization.

CONCLUSION

In order to clarify the difference in behavior of precedence effect between in ordinary room and anechoic chamber, the similar sound sources were installed both in the lecture room and in the anechoic chamber, and the behavior of the precedence effect was compared each other with the given time and level difference among sound sources. As a result, there are no difference at the most of the listening positions. This fact suggest that the knowledge obtained by investigation in anechoic chamber can be used to design the public address system in ordinary space. However, when the loudspeaker is located at position lateral and close to the listener, there was a difference in the behavior of the precedence effect between both environments. As one of the future works, effect of physical properties, such as reverberation must be examined more in detail.

REFERENCES

FIGURE 4. The perceived direction of sound image for each listening position. The front direction of subject corresponds to 0 degrees, and the clockwise direction is positive.