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Relation between perceived direction of a sound image and the behavior of the precedence effect

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ABSTRACT

When similar sounds come to a listener from two different directions with the same level and small time difference (0–2 ms), he/she perceives a single sound image and its position changes from the middle of two sound sources for no time difference between two sounds to the direction of the leading sound with increasing time difference. This phenomenon is well known as a change from the summing localization to the precedence effect, but the process for such a change has not been sufficiently elucidated. In order to make use of the precedence effect for designing a public address system, the effect needs to be quantified.

In this paper, we describe two hearing experiments carried out with the same subjects and conditions. We then analyzed the relation between the perception of a sound image and the behavior of the summing localization and the precedence effect. The difference between two experiments was in the instruction that the subjects were asked to answer. The instruction in the first experiment was the perceived direction of the sound image, while in the second experiment the instruction was the position of the sound source nearest to the perceived sound image. The boundary time difference separating the summing localization from the localization based on the precedence effect was calculated from the results of both experiments. Consequently we found that: (a) the absolute value of the boundary time difference varies in the range of 0.4–0.8 ms with the small level difference (0,+3 dB) between two sound sources and (b) the perceived image at the boundary time difference is localized around 10° from the left/right-side sound source to the middle of two sound sources.

1. Introduction

When sound is emitted in a room, some reflected sound waves follow the direct one to the position of the listener. The listener perceives the position of the sound source based on the relation of the reflected sound to the direct one. Simplifying this relation to the occasion that the similar sound from each of two sound sources in the free field, sound image with these sound sources are known to be synthesized in the following manners [1,2]:

1. When the sound from two sound sources reaches the listener almost at the same time and with the similar level, one sound image is perceived in between the sources. This phenomenon is called the summing localization [1].
2. When the time difference between two sound sources is greater than several times of 10 ms, two individual sound images are perceived corresponding to the positions of two sound sources, i.e., echo is perceived in this condition.
3. When value of the time difference is sufficiently small around 1 ms, a single sound image is perceived almost at the position of the sound source emitting the leading sound, and the contribution of the sound source emitting with a lag to the sound localization becomes ineffective. This phenomenon is called the "precedence effect" [3–6].

Behavior of the precedence effect has been widely investigated previously. For example, it is affected by not only the time difference between the sound sources but also factors such as the level difference and the location of the sources [1]. The time difference for which the perceived sound image changes from a single position of the leading source to two separated ones, usually termed "echo threshold," has been investigated in detail with various time and level differences, and various kinds of stimuli. However, the relation of the sound localization to the perceptual phenomena is still unclear when the time difference between two sound sources is varied between 0 and 2 ms. In other words, previous researches

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have not elucidated exactly how a single perceived sound image moves from between the two sources to the leading source as the time difference between the sources is increased. It is also unclear that how much such behavior is affected by the other factors, such as the level difference. In order to elucidate these effects, previous studies conducted surveys regarding summing localization and/or the precedence effect. For example, Wallach asked the following to the subjects in his experiment: whether the perceived sound image was to the left or not [4–6]. If the synthesized sound image(s) with multiple sound sources have to be investigated in detail, such questions are no longer sufficient.

This limitation causes problem for constructing systems which utilize the precedence effect. A typical example is a public address (PA) system installed in a room; some products related to this application already exist. Steinke has introduced the Delta Stereophony as the PA system in concert halls [7]. Nakajima et al. put their product named OZ-T100 to practical use, as the compact and flexible version of Delta Stereophony using digital signal processing technology [8]. These systems or products aim to have the audiences perceive the sound image at the position of the sound source (or the speaker) by arranging the time differences among multiple sound sources so as to bring about the precedence effect. The above references stated that the sound image agrees well with the practical position of the sound source obtained in both visual and auditory senses. However, we argue that such agreement has not been evaluated quantitatively. Moreover, the effectiveness of these systems may not be uniform in the specific room, because the behavior of the precedence effect is likely to be affected by various differences among the sound sources. With the specific locations of sound sources and the specific time and level differences among them, the point where the perceived sound image is desirable may be spatially restricted within the room. The influence of various factors upon the precedence effect, such as the sound source location, time and level differences among sound sources and the reflections within the room, has not yet been established.

From the above statements, the investigation on the relation between the perceived sound image and the occurence of the summing localization and/or the precedence effect is essential, in order to obtain the fundamental findings for the appropriate construction of the PA system applying the precedence effect. In this paper, we investigate the following two points:

1. To quantitatively obtain the change of perceived sound image position with the time and level differences between two sound sources.
2. To clarify the relation of the perceived sound image to the perceptual phenomena such as the summing localization and the precedence effect.

In order to clarify these points, two listening experiments were carried out in light of our previous researches [9,10]. In the first experiment (termed Exp. I hereafter), we investigated the change of perceived sound image with the time and level differences between the sources. Exp. I corresponds to the first of the above items. In the second (termed Exp. II), the subjects were asked to pick the sound source nearest to the sound image out of three visible sources. Since all conditions (subjects, stimuli, and sound source positions) are as same as possible in both experiments, it is possible to directly compare the results obtained in each. This experiment clarified the second of the above items.

2. Experiments

In this paper, two experiments (Exps. I and II) were examined in order to discuss the relation between the perceived sound image and the perceptual phenomena such as the summing localization and the precedence effect. The difference of the condition of Exp. II from that of Exp. I is the instruction given to the subjects. The common conditions are explained first, then each experiment is mentioned.

2.1. Common conditions

2.1.1. Apparatus and sound source positions

Both experiments were carried out in an anechoic room. Configuration of the system is illustrated in Fig. 1a–c. Two sound sources are located in the direction of ±30° (called "Set A" hereafter), 0° and 60° (called "Set B"), and 0° and 90° corresponding to the direct front and right of the subject, respectively. In both sets, the distance from the sound sources to the center of the head of the subject was fixed at 1.5 m, and the height of all sound sources was 1.4 m. The head of each subject was lightly fixed by using a head-rest, and the subjects were asked not to move their heads while hearing the stimuli. The stimuli were output from the audio interface connected to a personal computer, and fed to the loudspeaker via an audio amplifier. The details of Fig. 1a–c are described in more detail in Sections 2.2 and 2.3.

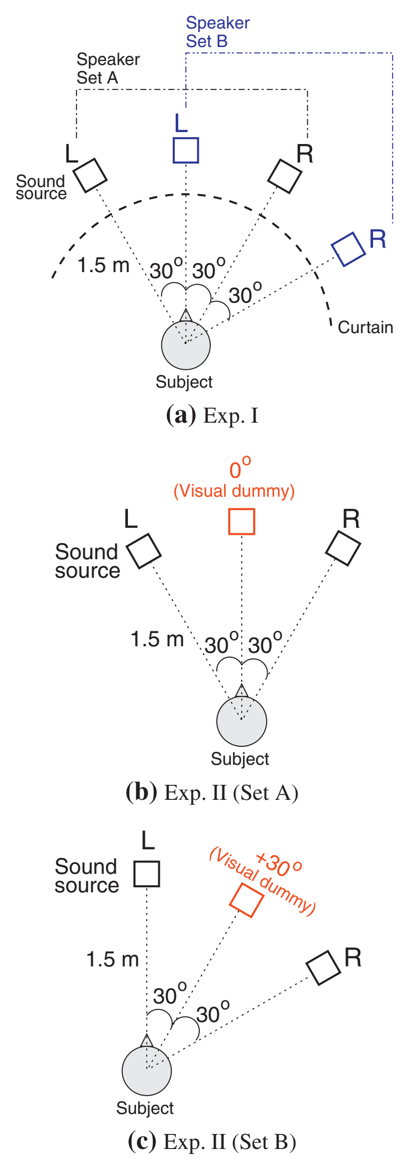

Fig. 1. Sound source position set at each experiment.