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PERCEPTUAL MOVEMENT OF SOUNDS FED THROUGH MULTIWAY LOUDSPEAKERS SET UP PERPENDICULARLY

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ABSTRACT
Perceptual movement of sounds fed through eight multiway loudspeakers set up perpendicularly was investigated. The loudspeakers, which were mutually separated by 30 cm, were set up just in front of the observers or at the just side of them 4.5m apart from the observers. They were required to answer the start point of the loudspeaker through which they perceived that the sound was output at the start, and the end point of that loudspeaker. The results show that the ascension or descension of auditory images was perceived when 1/3 octave bands of noises with center frequencies of 1, 4, and 8 kHz were linearly moved up or moved down in the range of moving distances from 60 cm to 150 cm, both in the median plane and in the transverse direction. The results also show that the perceived moving distance depends on the moving speed of the sounds, becoming longer than the physical distance at the speeds of 10 and 20 cm/s, and converging to the physical distance concomitant with higher moving speed, irrespective of the center frequencies.

INTRODUCTION
Auditory images produced by a 5.1 channel sound system applied to DVD and Digital Broadcasting sounds may be controlled only in a horizontal plane. A future sound system such as a 3-Dimentional TV will require at least vertical movements of auditory images as well as horizontal movements.

K. Kurozumi researched the movement of a phantom sound image produced by white noise fed through two or three loudspeakers placed in a median plane [1][2]. The results show that smooth movements of sound images were perceived. S. Ferguson and D. Cabrera researched the vertical localization of sounds through multiway loudspeakers [3]. The results show that lower frequency bands of noises are localized below their physical positions whereas high-frequency sources are localized at their true positions.

The purpose of this paper is to investigate the vertical sound localization and the perceptual movements of auditory images through 8 multiway loudspeakers vertically setup in front of an observer and at the side of an observer, because these conditions are critical to sound localization.

EXPERIMENT-1: VERTICAL LOCALIZATION OF SOUNDS
The vertical localization of 1/3 octave bands of noises with the center frequencies of 1, 4, and 8 kHz was investigated when the array of 8 multiway loudspeakers set up just in front of an observer or at the side of an observer. The results of sound localization put out from the vertical array setup in a median plane were compared with those of a transverse direction.

Procedure
Figure 1 shows the diagram of the experimental set up in a median plane and in a transverse direction. Each stimulus was presented through one of 8 loudspeakers (ALR/JORDAN “Entry S”) set up perpendicularly with 30 cm apart to each other. An observer was positioned 4.5m apart from two arrays, respectively. The loudspeaker at the bottom of the array was positioned

80 cm above the floor. Each stimulus was calibrated to 60 dBA at the observer's position. Each loudspeaker was named after 1 to 8 (the loudspeaker-1 was at the bottom) and a plate with its number was put at the side of each loudspeaker.

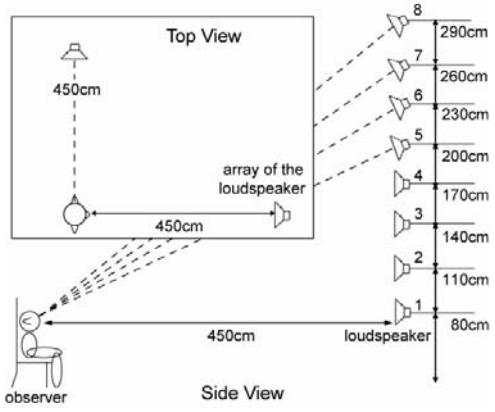

Figure 1.- Diagram of experimental setup. The loudspeakers were setup just in front of an observer and setup just at the side.

The duration of a stimulus was 1.5s with 50ms rise and decay times and 3s inter-stimulus intervals. 4 observers with normal hearing were required to point the number of the loudspeaker that they perceived where the stimulus was output. The experiment for each observer was repeated 5 times.

Results of the experiment

Figure 2 shows the relationship between the physical loudspeaker number that the stimulus was output and the perceived loudspeaker number that the observers answered where the stimulus was output. The stimulus was 4 kHz of bands of noises put out from the loudspeakers in front of an observer. The horizontal axis indicates the loudspeaker number where the stimulus was output, while the vertical axis indicates the loudspeaker number that an observer perceived where the stimulus was output. The figure in a circle indicates the number of the observers. For example, 11 observers perceived that the sounds were put out at the loudspeaker-2 when the stimulus was output at the loudspeaker-1. The dashed line shows the number of the observers who were able to answer the correct number of the loudspeaker where the stimulus was output.

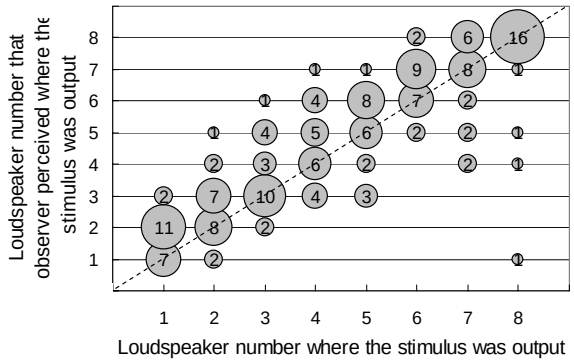

Figure 2.- Relationship between the physical loudspeaker number that the stimulus was output and the perceived loudspeaker number that the observers answered where the stimulus was output. Stimulus was 4 kHz of bands of noises put out from the median plane.

The results show that the observers fairly identified the correct number of the loudspeaker where the stimulus was output. Other results in the cases the center frequencies of 1 kHz and 8 kHz were same as those of 4 kHz.

Figure 3 shows the results in the case that the stimulus of 4 kHz of bands of noises was output from the loudspeakers at the side of an observer. The observers were much hard to identify the

correct number of the loudspeaker than the case when the stimulus was putout from the median plane.

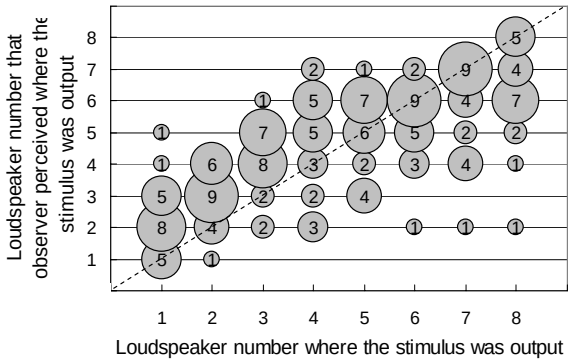

Figure 3.- Same as shown in Figure. 2 except for the case when the stimulus was put out in a transverse direction.

EXPERIMENT-2: PERCEPTUAL MOVEMENT OF SOUNDS

Effects of the moving speeds of sounds were investigated when they were moved upward or downward along the loudspeaker array. 1/3 octave bands of noises with the center frequencies of 1, 4, and 8 kHz were put out in a median plane.

Procedure

The same array of the loudspeakers used in the experiment 1 was used. The purpose was whether the observers perceived ascension or descension of auditory images when the stimuli were continuously moved up or moved down through the multiway loudspeakers in a median plane. In this experiment, the perceptual movement of sounds fed through loudspeakers vertically setup in a transverse direction was not investigated.

The loudness level of each stimulus was configured to 60dBA at the observer's position. Two patterns for the upward movement were used. The pattern-1was a stimulus that was moved from the loudspeaker-1 (80 cm above the floor) to the loudspeaker-4 (170 cm) and the pattern-2 was from the loudspeaker-1 to loudspeaker-5 (200 cm). Each pattern was put out with the five moving speeds of 10, 20, 30, 60, and 120 cm/s. These stimuli were randomly presented to 20 observers who were required to answer the perceived origin point of the loudspeaker number and the perceived end point of the auditory images.

Results of the experiment for sounds moved up

Figure 4 shows the relationship between the perceived origin point and the end point of auditory images in the case that the stimulus was moved up from the loudspeaker-1 to 5 (pattern-2), with the moving speed of 20 cm/s. The horizontal axis indicates the loudspeaker number of perceived origin point, while the vertical axis indicates the loudspeaker number of the perceived end point. Other parameters were same as Figure.3. For example, 3 observers perceived the sound moved up from loudspeaker-1 to 5 for the stimulus with the center frequency of 1 kHz, and 2 observers perceived the sound moved from loudspeaker-1 to 3 for the stimulus with the center frequency of 8 kHz. The results show 90% of the observers perceived ascension when the stimuli were moved up for all center frequencies of the bands of noises.

Figure 5 shows the effects of the moving speed of the sounds on the perceived moving distance in the case that the stimulus with the center frequency of 8 kHz was moved up from loudspeaker-1 to 4 (pattern-1). The negative values on the vertical axis show the percentages of the observers who perceived descension of the sounds, although the stimulus was moved up physically. The character "x" shown in Figure.5 shows the perceived moving distance of elevation. For example, the gray box shows the percentages of the number of the observers who perceived the moving distance over 120 cm ($x > 120$). At the moving speed of 10 cm/s, 50% of the observers perceived that the moving distance was over 120 cm when the physical moving distance was 90 cm. And also, when the moving speed becomes higher, the perceived moving distance of elevation becomes lower. The results obtained in Figure. 5 show that the

observers perceived ascension when the 1/3 bands of noises with the center frequency of 8 kHz were moved up linearly for all moving speeds. The results of the other center frequencies were same as the case of 8 kHz. Thus, the observers could perceive ascension when the stimulus moved up linearly, irrespective of the center frequencies and of the moving speeds.

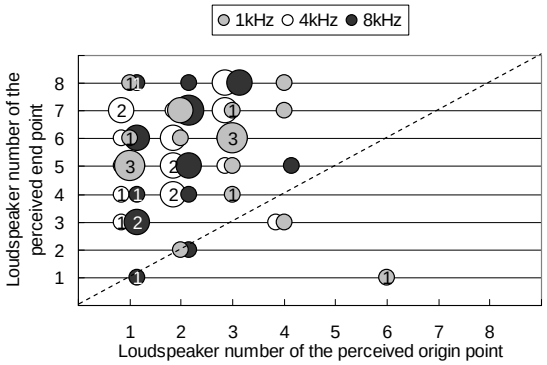

Figure 4.- Relationship between the perceived end point and the perceived origin point of auditory images in the case that the stimulus was moved up 120 cm from the loudspeaker-1 to 5, with the moving speed of 20 cm/s.

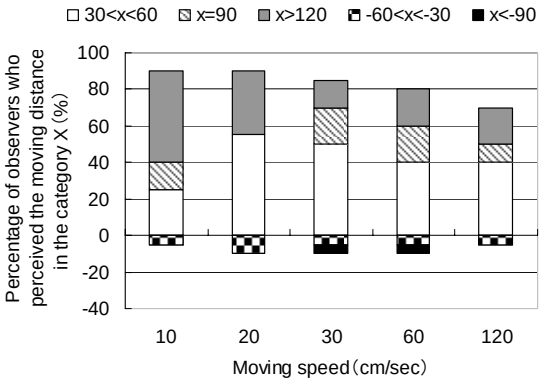

Figure 5.- Relationship between the percentage of the observers who perceived the moving distance in one of five categories (x) and the moving speed in the case that the bands of noises with the center frequency of 8 kHz was moved up 90 cm from the loudspeaker-1 to 4.

3.3. Results of the experiment for sounds moved down

Figure 6 shows the same as shown in Figure 4 except for the stimuli moved down 120 cm from the loudspeaker-6 to 2. The results show 85% of the observers perceived ascension when the stimuli were moved down, irrespectively of the center frequencies of the bands of noises.

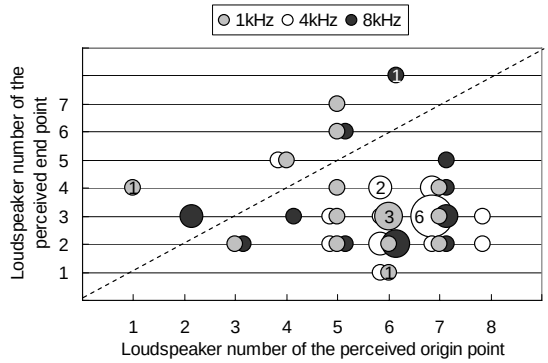

Figure 6.- Same as shown in Figure 4 except for the stimuli moved down 120 cm from the loudspeaker-6 to 2.

Figure 7 shows the same as shown in Figure 5 except for the stimuli moved down 90 cm from the loudspeaker-6 to 3. The positive values on the vertical axis show percentages of the observers who perceived ascension of auditory images whereas the stimulus was moved down

physically. The results show that over 60% of the observers perceived descension when the 1/3 bands of noises with the center frequency of 8 kHz were moved down linearly, irrespective of the moving speeds. The results of the other center frequencies were same as the case of 8 kHz.

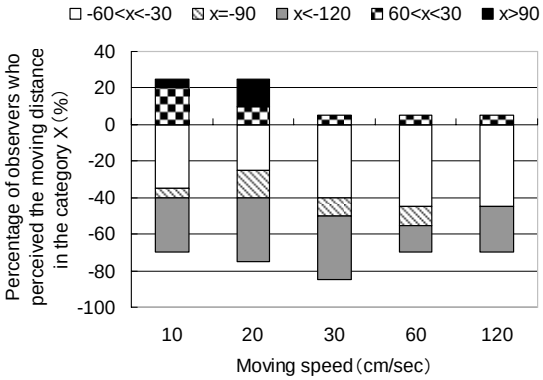

Figure 7.- Same as shown in Figure 5 except for the stimuli moved down 90 cm from the loudspeaker-6 to 3.

EXPERIMENT-3: PERCEPTUAL MOVEMENT OF SOUNDS IN A TRANSVERSE DIRECTION.
Perceptual movement of sounds fed through 8 loudspeakers vertically setup in a transverse direction was investigated. 1/3 octave bands of noises with the center frequencies of 1, 4, and 8 kHz were used at the stimuli.

Procedure
The same array of the loudspeakers as in the experiment 1 and 2 was used. The purpose was whether observers perceived ascension or descension of auditory images when the stimuli were continuously moved up or moved down through the multiway loudspeakers set up at the transverse direction. And also, the purpose was to compare the perceptual movement of sounds in a median plane with that of a transverse direction. The loudness level of each stimulus was configured to 60dBA at an observer's position. Eight patterns for the upward movement were used, where a stimulus was moved during 60 cm to 150 cm, at the fixed moving speed of 20 cm/s. These stimuli were randomly presented to 20 observers who were required to answer the perceived origin point of the loudspeaker number and perceived end point of auditory images.

Results of the experiment
Figure 8 shows the relationship between the percentages of the observers who perceived the moving distance in one of five categories (x) and the moving speed in the case that the bands of noise with the center frequency of 8 kHz was moved up 90 cm from the loudspeaker-2 to 5 and from the loudspeaker-4 to 7. The character "x" shows the perceived moving distance of elevation. The area on the right side shows the percentages of the observers perceived the sounds moved for the stimuli in a transverse direction, and the area on the left side shows the percentages of the observers perceived in a median plane. For example, when the stimulus with the center frequency of 1 kHz was moved up from the loudspeaker-2 to 5 in a transverse direction, 5% of the observers perceived 90 cm moving distance of elevation. On the other hand, in a median plane, 30% of the observers answered that perceived moving distance of elevation was same as a physical distance (90 cm). The results show that the observers could perceive ascension when the stimulus was moved up linearly in the transverse direction and in the median plane, irrespective of the center frequencies. Other results in the cases that the moving distances of elevation of 60, 120 and 150 cm were same as those of 90 cm.

Figure 9 shows the results in the case that the bands of noise with the center frequency of 8 kHz was moved down 90 cm from the loudspeaker-5 to 2 and from the loudspeaker-7 to 4. This figure also shows that the observers could perceive descension when the stimulus was moved up linearly in the transverse direction and in the median plane, irrespective of the center frequencies.

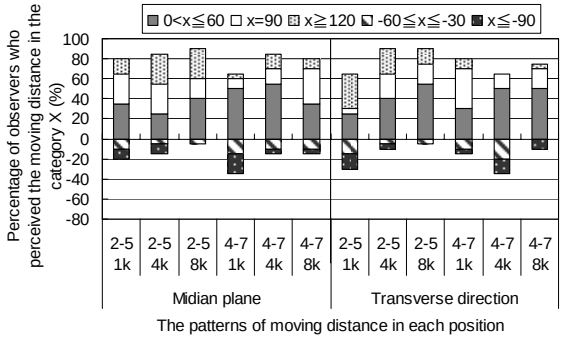

Figure 8.- Relationship between the percentage of the observers who perceived the moving distance in one of five categories (x) and the moving speed in the case that the bands of noises with the center frequency of 8 kHz was moved up 90 cm from the loudspeaker-2 to 5 and 4 to 7.

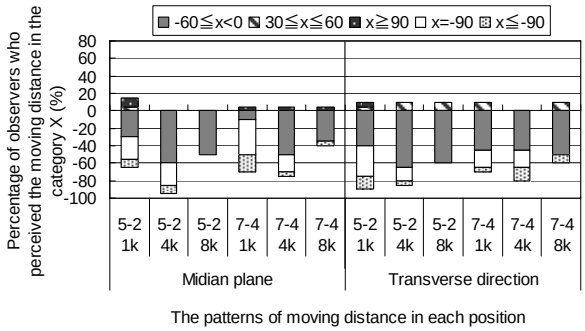

Figure 9.- Same as shown in Figure 8 except for the case when the stimulus was moved down 90 cm from the loudspeaker-5 to 2 and 7 to 3.

CONCLUSIONS

Localization of sounds fed through 8 mulitway loudspeakers set up just in front of an observer was fairly identified when 1/3 octave bands of noises were put out from one of these loudspeakers, while the localization of sounds fed through the loudspeakers set up just at the side of an observer was inferior to the median plane. When a sound moved vertically up or down, an observer perceived ascension or descension. The perceived moving distance of elevation becomes higher at the moving speed of 10 or 20 cm/sec than the physical moving distance. Moreover, there are few differences of perceptual movement of sounds between in a median plane and in a transverse direction when the sounds moved up linearly. There were such cases as some observers perceived descension whereas the physical sounds moved up or ascension when the sounds moved down. These tendencies could often be seen when the physical moving distance of 60 cm and the moving speed of 20 cm/sec, for all center frequencies.

Further studies will be necessary to investigate whether any differences will exist in each condition that the loudspeakers set up in front of, at the side of, and at the back of an observer.

ACKNOWLEDGMENT

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