Relation between frequency bandwidth of broadband noise and largeness of sound image

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1. Introduction

When we listen to sounds through our ears, we perceive sound images. Similar to visual images produced by visual sensation, the sound image has spatial characteristics such as spatial position, at which the sound image is localized, and largeness of the sound image.

It has been reported that the spatial position of the sound image is characterized by binaural and monaural cues, i.e. interaural time differences (ITD), interaural level differences (ILD), and spectral cues [1]. On the other hand, the largeness of sound image, often expressed as auditory source width (ASW) [2] or spatial impression (SI) [3], is known to be produced by early reflections especially from lateral directions. Research has been performed to provide physical measures relevant to ASW and SI, namely, lateral energy fraction ($L_f$) [4] or interaural cross correlation (IACC) [5–7]. Such physical measures are useful for analysis and design of room acoustics, whereas the discussion has been focused on the perceptual phenomenon in which reflected sounds affect the spatial extent of the sound image.

Even without reflections, or in an anechoic environment, a sound image is perceived with a certain largeness when we listen to a sound radiated from a sound source. A sound source located straight in front of the listener’s face in an anechoic environment leads to highly correlated binaural signals. Even in such a situation, the sound image would have a certain largeness that is no longer related to lateral reflections or IACC.

As for other physical factors that may affect the largeness of the sound image, Anazawa et al. indicated that the largeness, or “wideness,” of the sound image for 1/3 octave-band noise varies with its center frequency; a lower center frequency yields a larger sound image [7]. Although their experiment was not intended to explicitly assume a free field where IACC does not vary with reflections, the results imply that the largeness of sound image is affected by spectral characteristics of the source signal itself without reflections.

Although Anazawa’s results suggested that the center frequency of the broadband noise has an impact on the largeness of sound images, it is yet to be revealed whether and how other spectral characteristics such as frequency bandwidth affect the largeness of sound images. As for the frequency bandwidth, the authors’ previous experimental results employing the Scheffé’s paired comparison indicate that a broader bandwidth of broadband noise leads to a larger sound image [8], while the experiment was not designed to capture an absolute largeness of sound image and was performed for spatial extent only in a horizontal direction although the sound image would extend in other directions including a vertical direction.

In this work, in order to further explore the physical factors relevant to the largeness of sound images in a free field, subjective experiments are performed to investigate the relation between the frequency bandwidth of broadband noise signal and the absolute largeness of sound images in the horizontal and vertical directions.

2. Subjective experiments

Subjective experiments were conducted employing headphone and loudspeaker presentations.

2.1. Stimuli

Broadband noise signals were generated by convolving bandpass filters to a pink noise signal (sampling frequency: 44.1 kHz, 16-bit quantization). Twenty bandpass filters (Butterworth, 3 dB/oct. attenuation) whose center frequency is 1 kHz were prepared with bandwidths of 50, 70, 100, 120, 150, 180, 200, 250, 300, 360, 400, 500, 600, 720, 800, 1,000, 1,200, 1,440, 1,600, and 2,000 Hz.

For the headphone presentation, non-individualized HRTFs for a frontal source at 1-m distance from the center of a head were convolved with the broadband noise signals to generate binaural signals. For each of the binaural signals with various bandwidths, the sound pressure levels were adjusted to be 60 dB of A-weighted sound pressure level at the left ear.

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ear of a head and torso simulator (SAMRAI, Koken) when
they were presented through a set of headphones (HD598,
Sennheiser), which was used in the experiments.

2.2. Procedure

Participants were five males who reported no hearing
difficulties. The experiments were performed in an anechoic
chamber. The stimuli were presented through either a set
of headphones or a loudspeaker (LS603, Marantz). In the
headphone presentation, the stimuli were output from the
headphones via an audio interface (Duo Capture EX, Roland).
In the loudspeaker presentation, the stimuli were output from
the loudspeaker via the audio interface and a power amplifier
(1705II, BOSE). The loudspeaker was located in front of the
participant at 1-m distance. Figure 1 illustrates the exper-
imental system for the headphone and loudspeaker presenta-
tions. In order to remove effects of visual information, an
acoustically transparent blackout curtain was located in front
of the participant at 1-m distance. As depicted in Fig. 2(a),
six pairs of markers were displayed on the blackout curtain in
order to provide references for largeness of the sound image
in horizontal/vertical directions to a participant. The pair of
markers was arranged horizontally and vertically respectively
for trials for horizontal and vertical directions. The marker
intervals were 20, 40, and 80 cm both for the horizontal and
vertical directions, corresponding to visual angles of approx-
imately 12, 23, and 44 degrees.

Figure 2(b) illustrates the GUI (Graphical User Interface)
displayed on a tablet device (iPad, Apple), which was used by
the participants in the trials for both the horizontal and vertical
directions. The participants were asked to adjust the frequency
bandwidth of the broadband noise using a slider on the left
side so that the largeness of presented sound image match
with the marker interval in the horizontal or vertical direction.
After finishing adjustment of bandwidth for each trial, the
participants finalized their adjustment by pushing a button on
the right side, and then the selected bandwidth was recorded.
The trials were performed five times for each of the three
marker intervals (20, 40, and 80 cm), resulting in 15 trials in
total, for both horizontal and vertical directions. The trials for
horizontal and vertical directions were performed in different
sessions.

2.3. Results

Figure 3(a) demonstrates the observed bandwidths, aver-
aged among participants for each marker interval for the
headphone and loudspeaker presentations. The abscissa and
ordinate denote the marker interval in visual angle [deg.] in
the horizontal direction and frequency bandwidth [Hz],
respectively. Figure 3(b) demonstrates the corresponding
results for the vertical direction. The error bars indicate
standard errors. For each of four conditions (headphone/loudspeaker × horizontal/vertical), the multiple comparison test with the Bonferroni correction shows significant differences ($p < 0.05$) in frequency bandwidths among the three visual angles. The results indicate that, both for the headphone and loudspeaker presentations, the frequency bandwidth is greater as the marker interval in the horizontal and vertical directions increases. The frequency bandwidths are roughly proportional to the marker interval in the horizontal and vertical directions. Furthermore, the paired t-test shows no significant differences ($p > 0.05$) in the frequency bandwidths between the headphone and loudspeaker presentations.

3. Discussion

From the experimental results, it should be noted that, for the same visual angle, the corresponding frequency bandwidth is generally greater for the horizontal direction than for the vertical direction. This implies that the participants might perceive vertically long sound images. However, it may also be explained by the differences of localization blur in horizontal and vertical directions. Moreover, the participants’ response for the vertical direction might be biased because the slider used in the GUI for collecting the participants’ responses is vertically arranged as illustrated in Fig. 2(b). These issues including a use of other adjustment methods would be addressed in future works.

In addition, the current experiments employed a single center frequency, 1 kHz. It may be interesting to investigate how a simultaneous control of the center frequency and the bandwidth affect the sound image largeness. These issues should be also discussed in future works.

4. Summary

The subjective experiments were performed to explore how the frequency bandwidth of the broadband noise signal affect the largeness of the sound images.

The experimental results indicate that the largeness of sound image in the horizontal and vertical directions are greater as the frequency bandwidth increases; the largeness of sound image in visual angle both in the horizontal and vertical directions is roughly proportional to the frequency bandwidth. No prominent differences are found in the largeness of sound image between headphone and loudspeaker presentations.

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References

[1] J. Blauert, *Spatial Hearing: The Psychophysics of Human Sound Localization* (MIT Press, Cambridge, MA, 1997).
[2] W. V. Keet, “The influence of early lateral reflections on the spatial impression,” *Proc. 6th Int. Congr. Acoust.*, E-2-4, E-53-E-56 (1968).
[3] M. Barron, “The subjective effects of first reflections in concert halls—The need for lateral reflections,” *J. Sound Vib.*, 15, 475–494 (1971).
[4] M. Barron and A. H. Marshall, “Spatial impression due to the early reflections in concert halls: The deviation of a physical measure,” *J. Sound Vib.*, 77, 221–232 (1981).
[5] M. Morimoto, K. Iida and Y. Furue, “Relation between auditory source width in various sound fields and degree of interaural cross-correlation,” *Appl. Acoust.*, 38, 291–301 (1993).
[6] K. Kurozumi and K. Ohgushi, “Relation between cross-correlation coefficient of two channel acoustic signals and sound image quality,” *J. Acoust. Soc. Jpn. (J)*, 39, 253–260 (1983).
[7] T. Anazawa, H. Yanagawa and T. Ito, “On correlation coefficients of both ears and “Feeling of Wideness”,” *Tech. Rep. Inst. Electron. Commun. Eng. Jpn.*, EA70-13 (1970).
[8] K. Yamazaki, M. Otani, M. Toyoda, M. Hashimoto and M. Kayama, “Effects of frequency bandwidth on sound image size,” *Proc. Autumn Meet. Acoust. Soc. Jpn.*, pp. 761–762 (2014).