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Technical note

Individual differences in directional bands in median plane localization

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Abstract

Blauert and other researchers demonstrated that the direction of a sound image for a narrow-band noise is perceived according to the center frequency of the stimuli. Blauert referred to the frequency band by which the direction of sound image is determined as the directional band. However, it has not yet been clarified if individual differences exist in the directional bands. It is also unestablished whether the directional band changes according to the bandwidth of the stimuli. In this study, 1/3 and 1/6 octave band noises were presented from the front, above and behind the subject in the median plane, and the responses to the stimuli were analyzed individually. The results show that (1) individual differences in directional bands exist; (2) there is no remarkable difference between directional bands for 1/3 and 1/6 octave band noises; (3) for some subjects, a directional band occurs in the direction in which they could not localize wide-band noise.

Keywords: Directional bands; Stimuli

1. Introduction

Blauert [1] reported that the direction of a sound image for a narrow-band noise with a bandwidth of less than about 2/3 octave depends not on the direction of the sound source, but only on the frequency of the signal. He further examined this psychoacoustic

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phenomenon for 1/3 octave band noise, and referred to the frequency band by which the direction of the sound image is determined as the directional band [2]. Morimoto and Aokata [3] clarified that the same directional bands observed on the median plane occur in any sagittal plane. Middlebrooks [4] obtained similar results; he showed that the angle around the interaural axis of subjects' responses tended to cluster within restricted spatial ranges that were specific to each center frequency.

In addition, some researchers have discussed the relationship between the direction of a sound image and the head-related transfer function (HRTF). Blauert [2] inferred that the direction of a sound image for a broad-band stimulus is perceived according to the directional band, which corresponds to the frequency components boosted in the amplitude spectrum of the HRTF. Middlebrooks [4] proposed a vertical angle perception model, in which a sound image is localized in the direction in which the correlation coefficient between the spectrum of the input signal to the ears and the spectrum of the subject's HRTF is a maximum.

However, two questions arise regarding the directional bands of the studies mentioned above. One question concerns the individual differences in directional bands. Blauert [2] conducted an additional experiment in which he examined the individual variations of directional bands, and reported that "... the limits of the directional bands of the individual observers underlie inter-individual variations; however, in the center parts of the directional bands, inter-individual agreement is quite good." Middlebrooks [4] showed the individual differences in the perceived angle around the interaural axis for each 1/6 octave band noise. It has not yet been clarified, from those results, if individual differences exist in the directional bands.

The other question concerns the effect of the stimulus bandwidth in directional bands for each subject. Neither Blauert [1,2] nor Middlebrooks [4] reported if the directional band changes according to the change in the bandwidth of the stimuli for each subject.

In this study, two localization tests were performed in order to clarify these points. In localization test I, a wide-band noise was presented in the median plane; this test was performed in order to evaluate the accuracy of median plane localization of each subject. In localization test II, 1/3 or 1/6 octave band noises were presented in the median plane. The experimental results were analyzed and discussed individually.

2. Localization test I

In localization test I, a wide-band noise was presented in the median plane.

2.1. Experimental method

2.1.1. Subjects

Subjects were six males and one female, aged from 26 to 42 years, with normal hearing sensitivity. All were experienced in this type of localization test, with the exception of Subject E.

2.1.2. Apparatus

The localization test was conducted in an anechoic chamber. For stimulus presentation, an audio interface (Layla 24/96) connected to a desktop PC, power amplifier (YAMAHA P2040), and seven cylindrical loudspeakers (diameter: 108 mm, length: 350 mm) were used.

The loudspeakers were located every 30° in the upper median plane, from the front (0°) to the rear (180°). The distance from the loudspeaker positions to the center of the subject's head was 1.5 m. The frequency characteristics of the loudspeakers were flattened to within ±2.0 dB in the frequency range of the stimulus using a frequency equalizer (Technics SH-8065). A laptop PC (Panasonic CF-R3) was supplied to the subjects to input their response.

2.1.3. Stimulus

The source signal was a wide-band white noise ranging from 280 Hz to 11.2 kHz, shaped by a linear phase filter (−192 dB/Oct) designed on MATLAB. The signal was presented from one of seven loudspeakers in the median plane. The stimuli were delivered at 60 dB (A) for 1.2 s, including 0.1 s onset and offset ramps, followed by an interval of 4.8 s.

2.1.4. Procedure

Each subject was tested individually while seated, with the head fixed in a stationary position, in a darkened anechoic chamber. A circle and an arrow, which indicated the median and horizontal planes, respectively, were shown on the display of the laptop PC. The subject's task was to plot the perceived elevation on the circle on the computer display, by clicking the mouse, during the interval of 4.8 s. Each stimulus set contained seven stimuli arranged in random order. Fifteen such sets were prepared for the test. The order of presentation of stimulus depended on the set. Prior to the test, a practice session with five stimulus sets was performed. After that, ten sets were presented in one session, completed in approximately 8 min.

2.2. Experimental results and discussion

Fig. 1 shows the responses to the wide-band noise stimuli. The diameter of each circle plotted is proportional to the number of responses within 5°. The ordinate of each panel is the perceived direction, and the abscissa is the target direction.

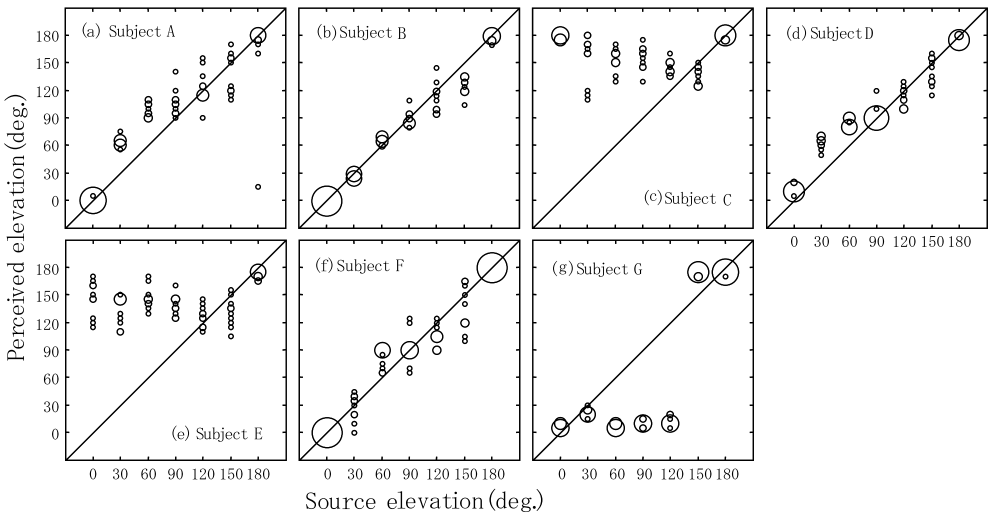

Fig. 1. Responses to the wide-band noise stimuli.

The responses of each subject can be categorized into three types: (1) For subjects A, B, D and F, the responses are distributed along a diagonal line; in other words, perceived elevations closely agreed with the target ones. (2) For subjects C and E, the sound images are localized in the rear for all target directions. (3) For subject G, the sound images are localized in the front when the stimuli are presented from above (60°, 90° and 120°).

3. Localization test II

In localization test II, the 1/3 and 1/6 octave band noises were presented in the median plane.

3.1. Experimental method

The source signals were 1/3 and 1/6 octave band noises. The center frequency of each noise was in the range from 800 Hz to 12.5 kHz, in 1/3 and 1/6 octave steps, respectively. The signal was presented from one of three loudspeakers located in front (0°), above (90°) and behind (180°) the subject.

The numbers of 1/3 and 1/6 octave band noise stimuli were 39 (13 center frequencies × three directions) and 75 (25 center frequencies × three directions), respectively. Each stimulus set contained 114 different stimuli arranged in random order. Ten such sets were prepared for the test, and each set was presented in a separate session. Each session was completed in approximately 11 min. The other experimental conditions were the same as for localization test I.

3.2. Results and discussion

3.2.1. Distribution of responses

Fig. 2 shows the responses to the 1/3 and 1/6 octave band noise stimuli. The area of each circle plotted is proportional to the number of responses within 5°. The ordinate of each panel is the perceived direction, and the abscissa is the center frequency of the stimuli. For each panel, the upper and the lower row are the responses to the 1/3 and 1/6 octave noise stimuli, respectively. Note that all responses to the stimuli presented from three loudspeakers are drawn in each panel.

Blauert [2] divided the responses into three sectors, that is, front, above and behind; the boundaries of them were 45° and 135°. In contrast, more detailed distribution of the responses according to the center frequency can be observed in Fig. 2.

For the center frequencies of approximately 0.8–2.0 kHz, the responses of subjects D and E to the 1/3 octave band noise stimuli (upper row of each panel) mostly concentrated to the rear and in front, respectively. This means that different directional bands occurred for these subjects. On the other hand, the responses of subjects B, C and G were separated into the front and rear, and the responses of subjects A and F were distributed over all directions.

For the center frequencies of approximately 2.5–6.3 kHz, the responses of subjects A, B, D, and F shift from the front to above as the center frequency becomes higher. The responses of subject G were mostly concentrated in front. For subject E, the responses were separated into the front and rear, and for subject C, the responses were distributed over all directions.

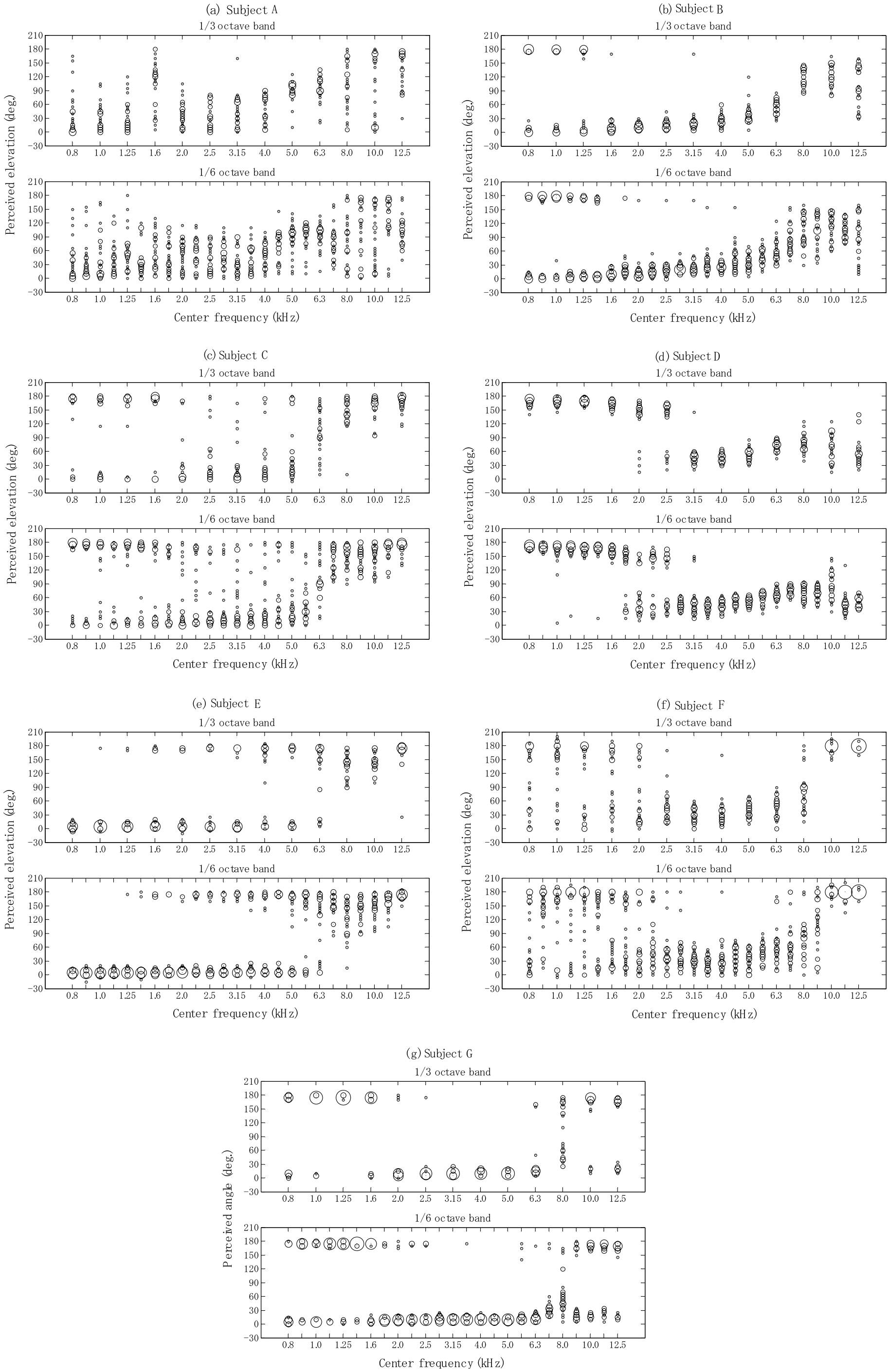

Fig. 2. Responses to the narrow-band noise stimuli.

For the center frequencies of approximately 8.0–12.5 kHz, the responses of subjects B, C, E, and F were distributed above and behind, and for subject D, around the front and above. For subject G, the responses were separated into the front and rear, and for subject A, responses were distributed over all directions.

Upon comparing the responses to 1/6 octave band stimuli (lower row of each panel) with those to 1/3 octave band stimuli, no distinct differences were observed, although the responses were somewhat scattered for 1/6 octave band stimuli.

As mentioned in Section 2.2, subject E localized sound images to the rear for wide-band noise stimuli presented from the front. However, further inspection revealed that the responses of the subject for 1/3 and 1/6 octave band stimuli were mostly concentrated in front for center frequencies of 0.8–1.25 kHz. This means that a directional band occurred in the direction in which the subject could not localize the wide-band noise. A similar result was observed for subject C.

These results can be summarized as follows: (1) individual differences in directional bands exist; (2) there was no distinct difference between responses to the 1/3 and 1/6 octave band noise stimuli and (3) for some subjects, directional bands occurred in the direction in which they could not localize a wide-band noise.

3.2.2. Analysis of directional bands

Next, directional bands were statistically derived, after the method of Blauert [2], as follows. (1) Each subject's responses were classified into three categories, that is, front ($\phi \leqslant 45$), above ($45 < \phi \leqslant 135$) and behind ($\phi < 135$), where ϕ is the perceived elevation. (2) A frequency band is regarded as the directional band if the number of responses in one category is significantly ($p < 0.05$) larger than the sum of the others. The statistical method used for the test was the binominal test.

Fig. 3 shows the directional bands for each subject. The directional bands for all subjects derived by summing the results ('All' in Fig. 3), and the ones by Blauert [2] ('Blauert' in Fig. 3), are also shown in the lower row in each panel.

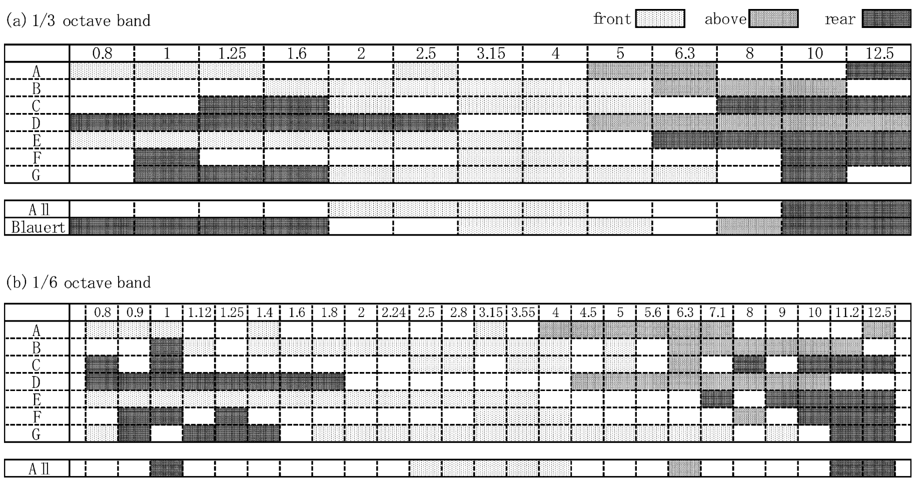

Fig. 3. Directional bands derived after the method of Blauert [2].

The comparisons of the results for all subjects for 1/3 and 1/6 octave band noise with the results of Blauert indicate that fewer frequency bands were determined as directional bands in this study. Nevertheless, the same tendency is observed in both sets of results, that is, the directional bands occur to the rear for the center frequencies of 0.8–1.6 kHz, to the front for the center frequencies of 2–5 kHz, above for the center frequencies of 6.3–8 kHz, and again to the rear for the center frequencies of 10–12.5 kHz.

On the other hand, the directional bands of each subject have different tendencies, and there is no directional bands common for all subject. Therefore, it is regarded that individual differences in directional bands exist.

Upon comparing the directional bands for 1/3 octave band noise with the ones for 1/6 octave band noise, different directional bands are not apparent between the two types of band noise, with the exception of 12.5 kHz for subject A. Therefore, it can be regarded that no remarkable difference exists between directional bands of 1/3 and 1/6 octave band.

Furthermore, frontal directional bands occurred for subjects C and E for the center frequencies of 2–5 kHz and 0.8–3.55 kHz, respectively; in other words, a directional band occurs in the direction in which the subject cannot localize the wide-band noise, as mentioned above.

4. Conclusions

Localization tests were performed in order to examine the individual difference and the effect of the stimulus bandwidth in directional bands. In these tests, 1/3 and 1/6 octave band noises were presented in the median plane. The results indicate that (1) individual differences in directional bands exist; (2) there is no remarkable difference between directional bands for 1/3 and 1/6 octave band noises; (3) for some subjects, a directional band occurs in the direction in which they cannot localize a wide-band noise.

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References

[1] Blauert J. A contribution to the theory of the front–back impression in hearing. In: Proceedings of 6th international congress on acoustics, 1968, A–3–10. In: Blauert J, editor. Spatial Hearing. MIT Press; 1997. p. 45.

[2] Blauert J. Sound localization in the median plane. Acustica 1969/1970;22:205–13.

[3] Morimoto M, Aokata H. Localization cues of sound sources in the upper hemisphere. J Acoust Soc Japan (E) 1984;5(3):165–73.

[4] Middlebrooks JC. Narrow-band sound localization related to external ear acoustics. J Acoust Soc Am 1992;92(5):2607–24.