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Effects of dividing frequency in filtering for dichotic presentation to reduce masking to a consonant by the preceding vowel

Atsunobu Murase[1,3,*], Shuichi Sakamoto[1,†], Yôiti Suzuki[1,‡], Tetsuaki Kawase[2] and Toshimitsu Kobayashi[2]

[1]*Research Institute of Electrical Communication and Graduate School of Information Sciences, Tohoku University*
[2]*Department of Otolaryngology, Tohoku University Graduate School of Medicine*
[3]*Matsushita Electric Industrial Co., Ltd.*

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1. Introduction

Sensorineural hearing loss is typically characterized by increased hearing thresholds, a reduced dynamic range of hearing, a degraded temporal resolution, an increase in temporal masking and a reduced frequency selectivity. Among them, the reduction in frequency selectivity engenders remarkable disadvantages through large and extensive masking, particularly the masking of middle- and high-frequency components by intense low-frequency components, that is, the so-called upward spread of masking.

Several researchers have examined the effects of dichotic listening to discover techniques for coping with the upward spread of masking [1–6]. Dichotic listening generally means listening to a different signal in each ear; however, in this context, it means listening to complementarily filtered speech sounds in each ear. That is, the speech signal is divided into two complementary parts in terms of frequency spectra to reduce masking between contiguous frequency bands. Previous studies have suggested that dichotic listening is fundamentally effective in improving speech intelligibility [1,2,4–6].

We previously proposed a dividing method for dichotic listening, in which sound stimuli were divided into two frequency bands to reduce the masking to a consonant by a preceding vowel. Dividing frequencies were selected by considering the formant frequencies of Japanese vowels. An experimental evaluation using nonsense vowel/u/-consonant-vowel (VCV) syllables was conducted, involving hearing-impaired listeners. The results demonstrated an improvement in intelligibility scores [7].

In this study, we performed intelligibility tests using the first three vowels /a/, /i/ and /u/ in nonsense VCV syllables. We then examined the relationship between the effective dividing frequency and the difference of preceding vowels.

2. Experimental procedure

The listening test was conducted in a soundproof room of the Research Institute of Electrical Communication, Tohoku University. Speech stimuli were presented to listeners through headphones (HDA-200; Sennheiser Electronic GmbH & Co. KG). Speech stimuli were nonsense VCV syllables uttered by a native Japanese female vocalist with experience of training in narration. The first vowel in each VCV syllable was one of the three Japanese vowels /a/, /i/ and /u/; the subsequent CV was one of the possible Japanese syllables except a contracted sound (67 CVs).

For a dichotic condition, the speech signal was split into two bands using a low-pass filter (LPF) and a high-pass filter (HPF). Considering the frequency characteristics of Japanese vowels [8], the boundary frequency was set around that of the second formant. For the diotic listening condition, an all-pass filter (APF) was used instead of LPF and HPF. Table 1 shows a summary of the dividing conditions. Diotic stimuli with an amplitude of -6 dB (diotic-6 dB) were also prepared because, in terms of binaural summation of loudness, loudness under the dichotic condition was estimated to be about 6 dB lower than that under the diotic condition at a moderate sound level [9]. Therefore, if a dichotic hearing aid is effective for the listener, the resultant intelligibility score under the dichotic condition will be higher than that obtained under the diotic-6 dB condition. The speech signal level was maintained at the listener's most comfortable level (MCL), which was determined under the diotic condition. The interval between stimuli was set to be 3 s. Listeners were three elderly persons with sensorineural hearing losses. Table 2 shows MCLs for the respective listeners. Figure 1 shows their audiograms. Listeners were asked to write the perceived syllables as they heard them.

3. Results and discussion

Intelligibility scores averaged over all listeners and listener B are shown respectively in Figs. 2 and 3.

Figure 2 shows that the intelligibility scores obtained under the dichotic 0.8 and dichotic 1.0 conditions are higher than that obtained under the diotic-6 dB condition. On the other hand, when the dividing frequency is higher than 1.2 kHz, most scores become lower than that obtained under the diotic-6 dB condition. These scores were tested using a two-way repeated-measure ANOVA for the two experimental variables: the dividing condition (8) and vowel (3). The results show that the interaction between the vowel and the dividing condition is not statistically significant ($F(14, 28) = 1.12$, n.s.), although the main effect of the dividing condition is statistically significant ($F(7, 14) = 4.71, p < .01$). Tukey's

*e-mail: murase.atsunobu@jp.panasonic.com
†e-mail: saka@ais.riec.tohoku.ac.jp
‡e-mail: yoh@ais.riec.tohoku.ac.jp

Table 1 Frequency dividing conditions.

Condition	Left channel	Right channel	Cross over [kHz]
Diotic	APF	APF	—
Diotic−6 dB	APF	APF	—
Dichotic 0.8	LPF	HPF	0.8
Dichotic 1.0	LPF	HPF	1.0
Dichotic 1.2	LPF	HPF	1.2
Dichotic 1.6	LPF	HPF	1.6
Dichotic 2.0	LPF	HPF	2.0
Dichotic 2.4	LPF	HPF	2.4

Table 2 Age and most comfortable level of each listener in intelligibility tests.

Subject	Age	MCL [dB SPL]
Listener A	69	60.0
Listener B	66	76.0
Listener C	59	60.0

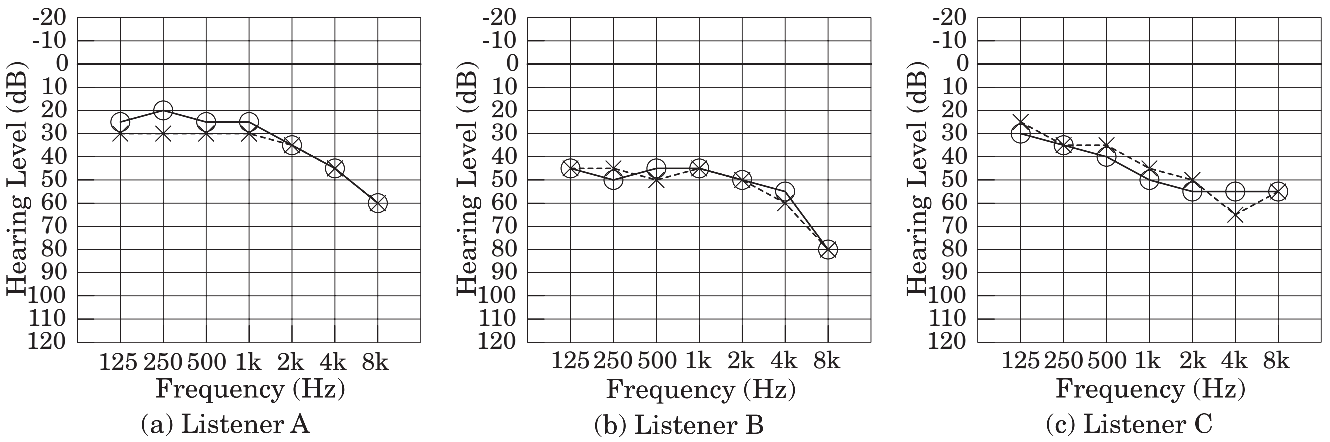

Fig. 1 Audiograms of participating listeners.

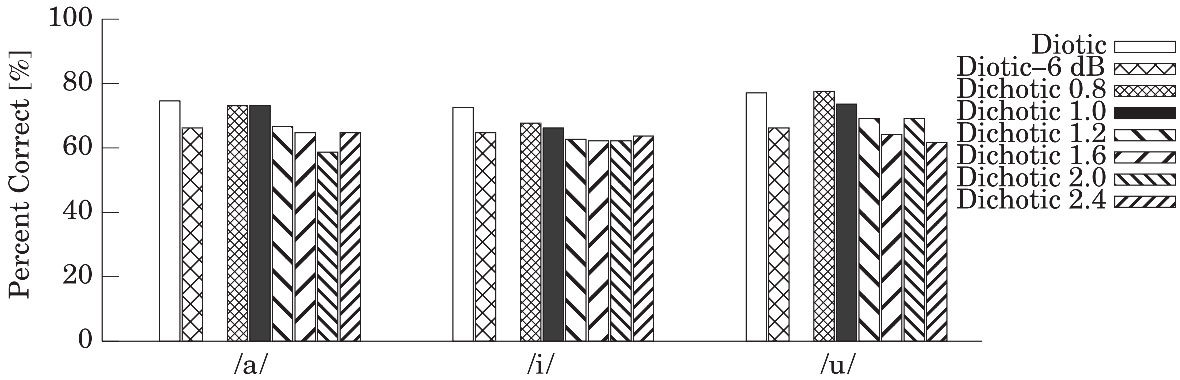

Fig. 2 Percentage of correct responses averaged over all listeners.

multiple comparison tests show that the intelligibility scores obtained under the dichotic 1.6, dichotic 2.0 and dichotic 2.4 conditions are significantly lower than that obtained under the diotic condition ($p < .05$). There is no statistical significance in other combinations of conditions.

Depending on dichotic dividing conditions, a case exists, in which the intelligibility score is almost equal to that under the diotic condition, though loudness is lower than that under the diotic condition. This result suggests that dichotic listening is effective as previous studies.

Figure 3 shows results for listener B, indicating different tendencies among preceding vowels. In the case of preceding vowel /a/, the score under the dichotic 1.0 condition is the highest among dividing conditions; the score is higher than both the scores obtained under the diotic−6 dB and diotic conditions, even though loudness under the diotic condition is higher than that under the dichotic 1.0 condition. In the case of preceding vowel /i/, score improvement is not apparent under the dichotic conditions even when the dividing frequency changes; the scores are almost equal to that under the

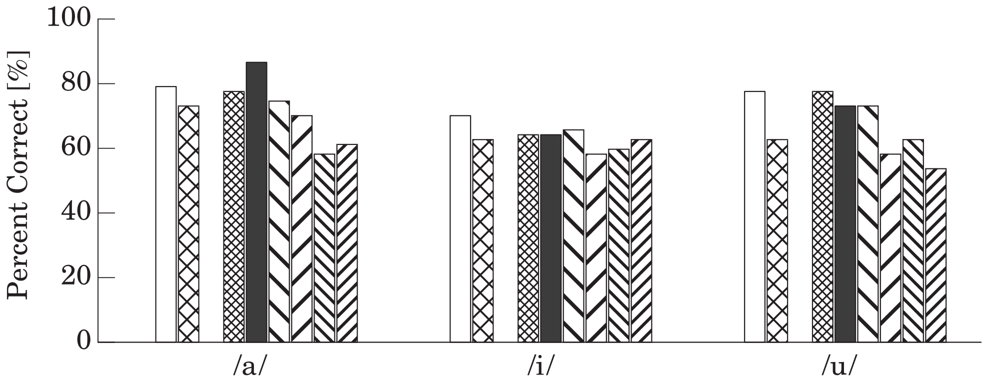

Fig. 3 Percentage of correct responses for listener B.

diotic−6 dB condition. Results for preceding vowel /u/ show that the score under the dichotic 0.8 condition is the highest among dichotic conditions. The higher the dividing frequency becomes, the more the score declines.

These results suggest that varying the dividing frequency is effective in improving the intelligibility score. Because the formant structure varies among vowels, the effect of masking induced by the concentration of energy around the first formant frequency is likely to be different. Therefore, different tendencies for preceding vowels might be attributable to the difference in formant frequency.

In the present study, the number of listeners was very limited. Therefore, further investigations with more listeners are required to confirm how the most effective dividing frequency for a dichotic presentation depends on masking preceding vowels, masked consonants and listeners' hearing characteristics.

4. Conclusion

In this study, to develop effective signal processing for sensorineural hearing impairment, we examined the effects of dichotic presentation to reduce masking to a consonant by the preceding vowel among elderly persons. The results of speech intelligibility tests show that, for all three preceding vowel conditions, a two-band dichotic presentation with a dividing frequency higher than 1.6 kHz is not effective in improving intelligibility for hearing-impaired listeners. The results also suggest that the effective dividing frequency for a dichotic presentation might vary with the preceding vowel, at least for certain listeners.

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