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1pPPb2. Study on effects of presence of cue-tone on psychophysical tuning curves
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Our previous study indicated that tunings of the auditory filter were sharpened by the presence of a cue-tone [Kidani, Miyauchi, & Unoki (2012), ISH2012]. It is unclear, however, whether the modification of the auditory filter due to the cue-tone is caused by excitation or suppression, because tip of the filter is normalized at 0 dB. Psychophysical tuning curves (PTCs) can show that the detection threshold is decreased at the probe frequency or increased around the probe by the presence of cue-tone, indicating excitation and suppression respectively. PTCs, because, are measured as masked threshold of probe by narrow-band noise. This study aims to consider the effect of the presence of cue-tone by measuring of PTCs. In present study, PTCs were measured in simultaneous masking in the absence and presence of cue-tone for four probe frequencies. The probes were presented at 10 dB above each absolute threshold. The frequency and level of the cue-tone were same as the probe. The result revealed that filter-Q, as regarded as the sharpness of tuning, was increased by the presence of cue-tone when the probe frequencies were 1.0 and 2.0 kHz, while the filter-Q was not changed when the probe frequencies were 0.5 and 4.0 kHz.

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INTRODUCTION

Human can hear the target sound selectively from among various sounds. There have been many studies about mechanism of selective listening [1]. Our previous studies indicated that improvement of the frequency selectivity is one of the factors of the mechanism of the selective listening [2-4].

The masked thresholds had been measured by the simultaneous notched-noise masking experiment in the absence and presence of cue-tone in the previous studies. The frequency and level of the cue-tone were the same as the probe. Auditory filter shapes were estimated from measured masking data based on the power spectrum model of masking. The results showed that tunings of the auditory filter were sharpened by the presence of a cue-tone. This showed that the frequency selectivity could be improved by the presence of cue-tone. The auditory filter shapes that the tip of the filter was normalized at 0 dB had, however, been compared with the presence and absence of cue-tone. It is unclear whether the gain of the filter is changed by the presence of cue-tone, and whether the modification of the auditory filter is caused by excitatory or suppressive effect due to the cue-tone.

This study aims to clarify the above two questions by considering psychophysical tuning curves (PTCs) that are measured in the absence and presence of cue-tone. PTCs are often used to measure the characteristics of the human frequency selectivity. Investigation of PTCs can reveal that the detection threshold is decreased at the probe frequency or increased around the probe by the presence of cue-tone, indicating excitation or suppression of neural activity.

SIMULTANEOUS MASKING EXPERIMENT

This section describes how the masked thresholds are measured to draw the PTCs. The masked thresholds are measured by simultaneous masking experiment.

Time conditions of stimuli

Figure 1 shows the layout for the time conditions used in the masking experiment. The durations of each masker, probe, and cue tone were 300 ms (15-ms raised-cosine ramps and a 270-ms steady state). Figures 1(a) and 1(b) show the conditions without and with the cue-tone (non-CT and CT conditions), respectively. Two maskers were sequentially presented with a 1300-ms inter-stimulus interval in each trial. A probe was simultaneously presented in either masker section. In the CT condition, a cue tone was presented 500-ms before presenting each masker. The inter-stimulus interval between cue tone and masker was decided to avoid the overlap of excitation patterns evoked by the cue tone and masker.

Stimuli conditions

The probe frequencies ($f_c$) were 0.5, 1.0, 2.0, and 4.0 kHz. The cue tone frequencies were the same as the $f_c$. Here, band noise was used as masker instead of the sinusoidal masker because of elimination of the beating effect that occurred in which the masker frequency is close to the probe frequency [5]. The bandwidth of masker was fixed at 80 Hz.

The probe level ($P_s$) was fixed to 10 dB above an absolute threshold of each participant. The cue-tone level was also fixed to the same value as the $P_s$. Nine masker levels separated by 2-dB steps for each masker condition were prepared. The average masker level was decided by reference to the past PTCs experiment [6].

Participants

Eight normal-hearing listeners, aged from 23 to 29, participated in the experiments. The absolute thresholds for all participants, measured through a standard audiometric tone test using a RION AA-72B audiometer, were at 15 dB hearing level or less for both ears at octave frequencies between 0.125 and 8.0 kHz. The scrutiny ear was an ear with a good characteristic. To set up the probe level (10 dB above each absolute threshold), hearing thresholds of all participants were measured for 0.5, 1.0, 2.0, and 4.0 kHz. All participants were given enough time to practice.
FIGURE 1. Time courses of stimulus pattern in trial for (a) without and (b) with CT.

The participants’ task was to choose the masker section included the probe from the two masker sections. The number of stimulus patterns was 756 (2 cue-tone conditions (absence or presence) × 42 masker conditions × 9 masker levels). Those stimuli were presented at random. Feedback was provided by LEDs that lighted up corresponding to the correct interval on the response box after each trial.

Experiment equipment

All stimuli were generated digitally at the sampling frequency of 48 kHz. The stimuli were presented monaurally to the subjects in a double-walled sound-attenuating booth (background noise level was 21 dB) via a Tucker-Davis Technologies (TDT) system III and an Etymotic Research ER2 insert earphone. The levels of the stimuli were calibrated using an Artificial Ear Simulator (B&K 4152) with a 2-cm³ coupler (B&K DB 0138) and a Modular Precision Sound Level Meter (B&K 2250).

RESULT

14,742 points data were obtained from experiments for all participants. The percentages of correct responses were derived from the results. The sigmoid functions were fitted to the response distributions as a function of masker level under all conditions. The masked threshold was defined as the masker level that estimates the 75% point on the sigmoid function. Thus, a larger masked threshold indicates that a probe will not be masked over a louder masker.

Figure 2 shows the measured PTCs. Solid line with black symbol shows the results of the CT conditions, and dash with white symbol line shows the results of the non-CT conditions. The general shapes of the PTCs in absence of cue-tone are similar to the general shape of the PTCs in presence of cue-tone.

The presentation effect is assumed to be local change, because the tip of PTCs changed by the presence of cue-tone. Figure 3 shows the tip of the PTCs in more detail. Figure caption is the same as Figure 2. The results indicate that the masker levels at masked threshold are increased around the probe frequencies in which the probe frequencies are 1.0 and 2.0 kHz. For the 0.5 kHz probe frequency, the CT condition reduced the masker level at the masked threshold on high frequency side and augmented the masker level on low frequency side. For the 4.0 kHz probe frequency, the CT condition reduced the masker level at the masked threshold on low frequency side and augmented the masker level on high frequency side. The Q₃ dB value, as sharpness of tuning, is measured to examine changes in the frequency selectivity in detail.

Figure 4 shows the measured the Q₃ dB value. Black symbol indicate the results of the CT conditions, and white symbol indicate the results of the non-CT conditions. These results indicate that the Q₃ dB value is increased by the presence of cue-tone in which the probe frequencies were 1.0 and 2.0 kHz. On the other hand, the Q₃ dB value is not changed in which the probe frequency was 0.5 kHz, and the Q₃ dB value is decreased by the presence of cue-tone in which the probe frequency was 4.0 kHz.
FIGURE 2. PTCs were measured for four signal frequencies. The horizontal axis is center frequency of the masker, the vertical axis is the level of the masked threshold. Solid line with black symbol shows the results of the CT conditions, and dash line with white symbol shows the results of the non-CT conditions.

FIGURE 3. The tips of the PTCs in more detail. Figure caption is the same as Figure 2.

FIGURE 4. $Q_{3\,\text{dB}}$ values were measured from PTCs. The horizontal axis is the signal frequency, the vertical axis is the $Q_{3\,\text{dB}}$ value. Black symbol indicates the CT conditions, and white symbol indicates the non-CT conditions.


DISCUSS

PTCs at lower probe level can be considered as the frequency selectivity in the peripheral auditory system [7]. The PTCs became sharp by the presence of cue-tone. This result suggests that the peripheral auditory system has a function of improving the ability of frequency decomposition corresponding to the presented cue. This section discusses the mechanism what changes the frequency selectivity by the presence of cue-tone.

For the 1.0 kHz and 2.0 kHz, the PTCs were improved by the presence of cue-tone, and were not improved in which the probe frequencies were 0.5 kHz and 4.0 kHz. This result is the same as the tendency of our previous study [4]. It has been suggested that the frequency selectivity was affected according to efferent pathway [6, 8, 9]. These papers reported that the PTCs change by the presence of noise to the contralateral ear. These results have shown that the characteristics of the peripheral auditory system changes by the contralateral stimulation. The mechanism of the changed PTCs is considered the activity of the olivocochlear bundle (OCB) and the variation of the cochlea characteristics by the activity of the OCB. The OCB is the efferent pathway to the cochlea from superior olivary nucleus. Effect of the activity of the OCB is considered in two ways [10]. The first way is the effect for hair cells are hyperpolarized. It might be affected that the characteristics of the peripheral auditory system are changed by the presence of cue-tone. The second way is the effect for the afferent pathway that the input-output characteristics of the outer hair cells are changed. It might be affected that the output from the peripheral auditory system are changed. The auditory nerve might account nicely for which effect of the OCB activity. It has been known that the number of the auditory nerve varies with the signal frequency [11]. There are a lot of auditory nerves in the range of 1.0 kHz from 2.0 kHz. There is the presentation effect of cue-tone in which a lot of auditory nerves. On the other hand, there is not the presentation effect in which low auditory nerves. The auditory nerves are involved in the workings of the afferent pathway. Therefore, the work of the OCB in which CT condition is considered for the afferent pathway. The work of the auditory nerve might be considered that the PTCs are not changed by the presence of cue-tone for the 0.5 kHz and 4.0 kHz.

Scharf et al. reported that the peripheral auditory system was affected supressive by the presence of cue-tone [12, 13]. Scharf et al. had carried out the detection experiment of probe from noise for participants who have the severed OCB on one side ear. The ear that was severed the OCB did not suppress the frequency around the cue-tone frequency compared with the normal ear. When the PTCs were sharpened, the masker levels at the masked threshold of frequencies around the probe frequency were increased in which the probe frequencies are 1.0 kHz and 2.0 kHz. Since louder masker level is required in order to mask the same probe, there results indicate that the neural activity corresponding to the frequencies around the probe frequency were suppression. Therefore, it suggested that PTCs has sharpened by this suppression effect of frequencies around the probe frequency.

SUMMARY

This paper investigated whether the PTCs are how changed by the presence of cue-tone. The following four conclusions are derived from this study.

- The Q values of the PTCs are increased by the presence of cue-tone.
- The presentation effect of cue-tone varies with the probe frequency.
- The masker levels at the masked threshold of frequencies around the probe frequency are increased in which the probe frequencies are 1.0 kHz and 2.0 kHz.
- The masker levels at the masked threshold vary with low- and high-frequency sides in which the probe frequencies are 0.5 kHz and 4.0 kHz.

These conclusions suggest that the frequency selectivity is improved by the presence of cue-tone. The presentation effect of cue-tone for the frequency selectivity occurred in which the masker levels at the masked threshold around the probe frequency are increased by the presence of cue-tone.

Our future work is to investigate that the PTCs are measured by the presence of cue-tone to contralateral ear. Since the OCB is connected to the contralateral ear as well as the ipsilateral ear [12], the activity of the OCB which is the efferent pathway to the peripheral auditory system could be studied by the future work.
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