Effects of the preceding and following tone on laterality threshold of the tone with interaural intensity difference

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ABSTRACT
In this paper, the thresholds of detection and laterality are explored using a tone with interaural intensity difference (IID) and a diotic tone masker in the stimulus configurations of simultaneous and temporal masking paradigms. On the forward masking condition, the results show that the laterality thresholds are almost the same as detection ones when the frequency of a signal tone is not the same as the masker frequency, and the laterality thresholds are about 10 dB higher than those of the detection. However, it is interesting to note that the results obtaind on the backward masking condition that the frequencies of signal and masker are equal, show that laterality thresholds are 25 dB to 40 dB higher than the detection thresholds.

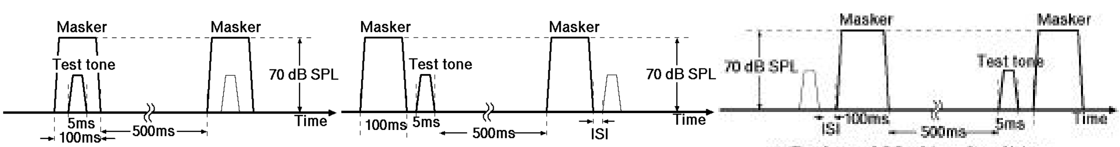
1. Introduction

Studies have been made over a long time to investigate the principles of sound lateralization and the data obtained from such studies have greatly extended our knowledge of this subject. The effect of a preceding tone on the lateralization of a following tone is well known as the precedence effect and many studies of this effect have been made. It is also evident that a following tone also affects the lateralization of a preceding tone in the backward masking condition. However, the number of studies which focus on the effects of a following tone is small, compared with studies of the effects of a preceding tone. Using a short pulse of 20 microseconds, Gaskell(1983)(1) conducted experiments using temporal masking conditions and demonstrated that a following tone has much smaller effect on the laterality of a preceding tone in the backward masking condition than it does in the forward masking condition. Litovsky et al.(1994)(2) conducted laterality judgment experiments using temporal masking conditions. He showed that in the backward masking condition, the accuracy of laterality judgments is nearly equal to that of laterality judgments by a single test tone, while in the forward masking condition, the accuracy of laterality judgments decreases due to the precedence effect. Tollin and Henning (1998)(3) studied the effect of the preceding and following tones on laterality by using a short click of 20 microsseconds. Their results show that the effects are only minimal in the backward masking condition if the interval of two clicks is less than 10 ms and show that the laterality threshold increases markedly in the forward masking condition. In most studies conducted using headphones, the interaural time difference (hereafter called ITD) has been used to lateralize the sound image. Although the interaural intensity difference (hereafter called IID) is considered equally important in lateralization, the number of studies made with a focus on the IID is very small. Gaskell(1983)(1) conducted experiments using tones with IID and gathered data on precedence effects. She found that a preceding tone affects the laterality of a pair of pulses, one having an intensity 6dB larger than the other, if these are generated within an interval of a few milliseconds i.e. this is manifestation of the precedence effect. Gaskell also found that a following tone has almost no effect on laterality in the backward masking condition. Tollin and Henning(1999)(4) studied laterality by observing the center stimulus tone of triple pulses having an IID of 6dB. The results show that the laterality becomes unclear due to the effects of preceding and succeeding pulses if these are generated within an interval of a few milliseconds. Ebata et al.(5) have systematically clarified the laterality threshold of tone bursts with ITD in simultaneous and temporal masking conditions. In current study, we have examined the laterality threshold using the IID. In most studies to explore the precedence effect, the tones with IID have been scarcely used. In this paper, we will compare the results of our study based on the IID method, specifically the frequency characteristics of the laterality threshold, with those of other studies conducted using the ITD method.

2. Methods

2.1Stimuli and Stimulus Configurations

Figure 1 shows the stimulus time patterns used in the detection experiment. A test tone is a 5 ms tone burst with a rise / fall time of 1 ms . The test tone frequencies are 0.5, 1, 2, and 4 kHz. The masker is a tone burst having a duration of 100ms with a rise / fall time of 1ms and a frequency of 1 or 4 kHz. The steady-state level of the masker is set to 70 dB SPL. In the simultaneous masking condition, as shown in Figure 1(a), a test tone appears in the center of a masker. In the forward masking condition, as shown in Figure 1(b), a masker was appears before a test tone. In the backward masking condition, as shown in Figure 1(c), a masker was appears after a test tone. In the forward masking condition, the inter-stimulus interval (hereafter called ISI) between a masker and a test tone is defined as the time from the fall of a masker to the rise of a test tone. In the backward masking condition, the ISI is defined as the time from the fall of the test tone to the rise of a masker. In the signal detection experiment, the level of masker is 70 dB SPL and presented with the same level to both ears, in such a way that each masker is lateralized at the center. A test tone with the IID of 5 dB is generated concurrently with either the first or the second masker. The test tone is generated randomly. A two-interval, two-alternative, forced-choice procedure is used in the experiments and subjects are asked to identify the period at which they perceive the test tone. Figure 2 shows the stimulus time patterns used in the laterality experiment. In the laterality experiment, a masker is lateralized at center and a test tone is appended to the masker so that the test tone is lateralized at either the right or left side of the masker. The IID of a test tone is made 5 dB. The subjects are asked to identify laterality of a test tone.



(a)Simultaneous Masking Condition (b) Forward Masking Condition (c)Backward Masking Condition

Fig.1 Stimulus time pattern used in the experiment of detection

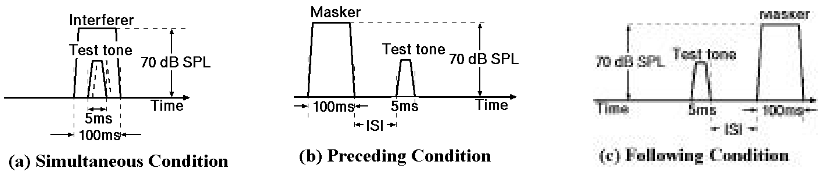


Fig.2 Stimulus time pattern used in the experiment of laterality

2.2Experimental Procedure

In the experiments, the detection and laterality thresholds are measured in three different conditions: simultaneous, forward and backward masking conditions. In both signal detection and laterality experiments, each subject is put into an anechoic room and asked to wear headphones(STAX-Pro) on both ears and to listen to stimulus tones. The ISI in a temporal masking condition is set to 2, 5, 10, 20 and 50 ms. The 3-down 1-up adaptive procedure was used in the experiments. The measurements start from the intensity where a subject can clearly identify a test tone or lateralize test tone. For the first two reversals, the step width of intensity level change is set to 4 dB. For the second two reversals, it is set to 2 dB. After the following reversals, it is set to 1 dB. Right after the twelfth reversals the threshold is obtaind from the last eight reversals. This session is repeated four times and the average of four session thresholds adopts as the threshold. The subjects A, B and C are three males in their twenties and they had normal hearing ability. Prior to the experiments, they received a training for a period of one month.

3. Results of Laterality Experiments Conducted Using Test Tones(Preceding and Following Tones)

Figures 3 and 4 show the results of the experiments. The case in which a masker or an interferer is at 1 kHz is shown in Figure 3. The case in which a masker or an interferer is at 4 kHz is shown in Figure 4. In both figures, the abscissa represents the ISI and the ordinate represents detction thresholds (or laterality thresholds). A shaded zone in the center of each figure includes the results of experiments in the simultaneous masking condition. The right hand side of the zone corresponds the results in the forward masking condition and that the left hand side represents the results in the backward masking condition. The results obtained from three subjects are indicated by A, B and C, respectively. Similar tendencies are observed in all three subjects. In both forward and backward masking conditions, both the detection and laterality thresholds decreased in proportion to ISI. If the frequency of a test tone is sufficiently far away from that of a masker or an interferer, as shown in Figure 3(d) and Figure 4(a) and (b), both the detection and laterality thresholds are almost unaffected by the masker or the interferer and they are nearly constant despite a change in ISI. Furthermore, there are little differences between the laterality and detection thresholds. Note that the laterality thresholds become higher than the detection thresholds over a wide range of frequencies, particularly in the high-frequency range, when ITD is given as a basic laterality cue. If the frequency of a test tone is equal to that of an interferer, both the detection and laterality thresholds are varied. Particularly in the backward masking condition, the laterality threshold does not decrease even if ISI increases, and a following tone has an interfering effect on the laterality over a long interval compared with that of ordinary masking effect. Because this interval is much longer than 10 ms, this phenomenon is presumed to be associated with the difficulty for the subject to identifying laterality cues due to cognitive masking, not with the interaction between preceding and following tones. As shown in Figure 4 (d), the laterality threshold obtained from one of the three subjects decreases abruptly as ISI increases. This is thought to be associated with whether or not the subject can identify laterality cues accurately.

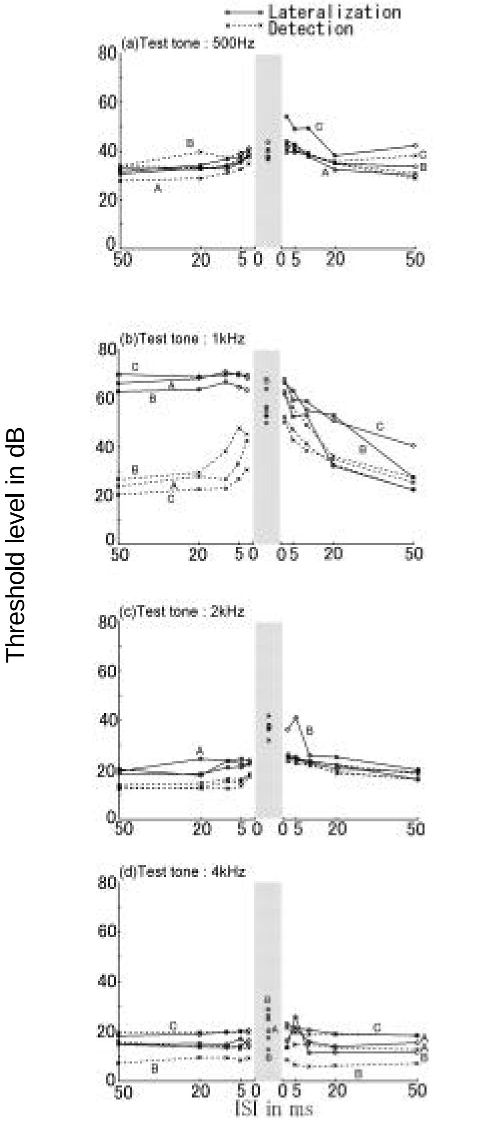


Fig.3 Threshold of detection and laterality

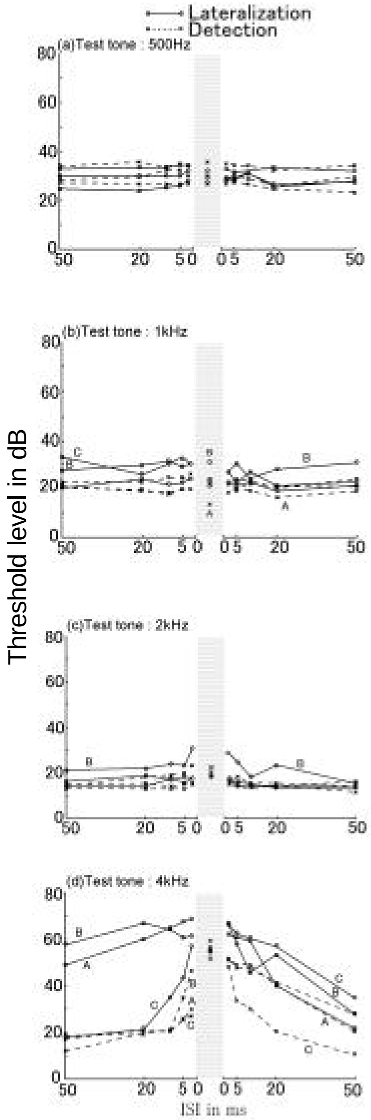


Fig.4 Threshold of detection and laterality

4. Discussion

Figures 5 and 6 show the characteristics of the detection and laterality thresholds, re-plotted based on the data in Figures 3 and 4. In these figures, only the results obtained with ISI set to 5 and 20 ms are shown, and each data point shows the average of measurements taken for three subjects. In both figures, the abscissa shows the frequency of a test tone, the ordinate shows the threshold level, the cross(X) shows the threshold of detection, the circle(O) shows the laterality threshold, and the ISI is used as a variable. The detection and laterality thresholds measured without an interferer are also shown as solid lines. Results in the forward masking condition are shown in Figure 5; interferers of 1 and 4 kHz are used in (a) and (b), respectively. Results in the backward masking condition are shown in Figure 6. Both detection and laterality thresholds obtained with an interfer whose frequency is equal to test tones, far exceed those obtaind without an interferer. In particular the laterality threshold increases markedly. When ISI is 5 ms, it increases by 30 to 40 dB; about 10 dB larger than the detection threshold. If the frequency of a test tone is different from that of an interferer, the thresholds remain almost unaffected by the interferer, except at 0.5 and 2 kHz, as shown in Figure 5(a). Although similar results are observed for the case of the backward masking condition as shown in Figure 6, a difference should be noted: if the frequency of the test tone is equal to that of an interferer, the laterality threshold increases greatly and it becomes approximately 30dB higher than the detection threshold.

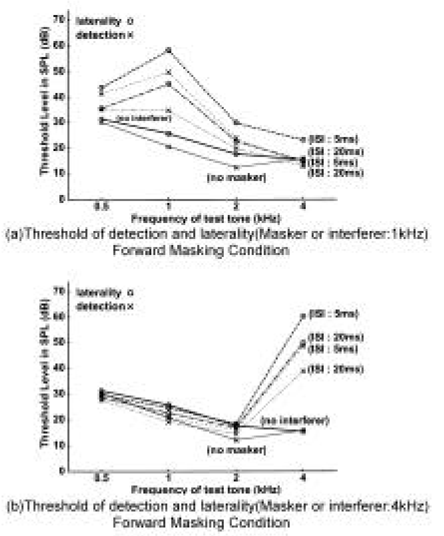


Fig.5 Threshold of detection and laterality

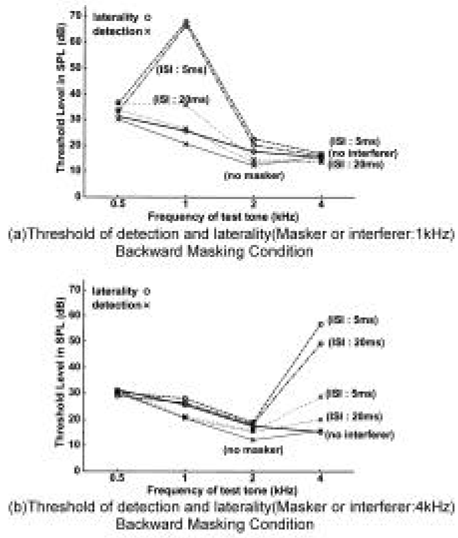


Fig.6 Threshold of detection and laterality

As is clear from the above discussion, if the frequency of the test tone is equal to that of the interferer in the forward and backward masking conditions, the laterality cannot be clearly identified although a test tone can be detected. In this case, the sound pressure must be increased by more than 10dB to enable subjects to identify laterality.This evidence shows that if the frequency of the test tone is different from that of the interferer, the test tone can be easily detected and lateralized. It is interesting to note that if the ITD is used as a laterality cue, different results are obtained, that is, the widespread effect of the interferer on laterality over a wide range of frequencies is observed. Figures 7 and 8 show a comparison between the laterality threshold shown in Figures 5 and 6 and those measured in experiments using the ITD. Figure 7 shows the results in the forward masking condition while Figure 8 shows the results in the backward masking condition. An interferer of 1 kHz and 4 kHz are used in (a) and (b), respectively. If an interferer is not used, the laterality threshold measured using the IID is markedly different from the threshold measured using the ITD. When the ITD is used, the laterality threshold increases in proportion to frequency and it is about 30 dB higher than the detection threshold at 4 kHz. When the IID is used, however, the difference between the laterality and detection thresholds is 5 dB or smaller over the whole range of frequencies. Furthermore, the IID has a very large interfering effect when the frequency of the test tone is equal to that of an interferer while the ITD has a relatively small interfering effect over a wide range frequencies. This difference becomes particularly conspicuous in the backward masking condition; specifically, the interfering effect of the ITD is minimal in the backward masking condition, while the interfering effect of the IID is larger in the backward masking condition than one in the forward masking condition at specified interfering frequencies.

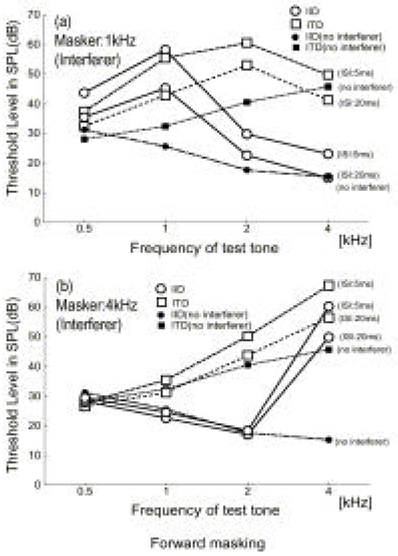


Fig.7 Difference between detection threshold and laterality one

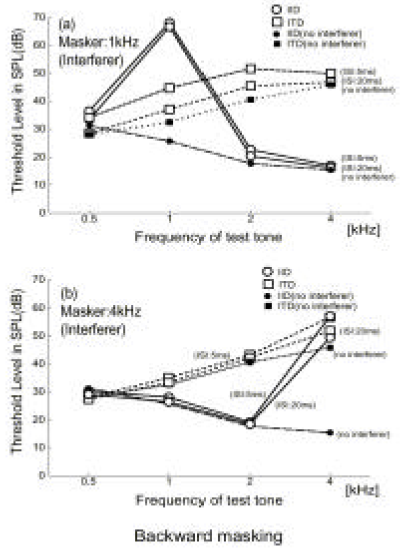


Fig.8 Difference between detection threshold and lateralitv one

5. Conclusions

In this study, the interaural intensity difference (IID) was used as a laterality cue and the results were compared with those of experiments using the interaural time difference (ITD). If the frequency of a test tone is equal to that of an interferer in the forward masking condition, the laterality threshold is approximately 10 dB higher than the detection threshold. If the frequency of a test tone is different from that of an interferer, the laterality threshold is nearly equal to the detection threshold. This is in marked contrast to the case in which the laterality threshold is higher than the detection threshold over a wide range of frequencies if the ITD is used as a laterality cue. Although the similar results were obtained in the backward masking condition, A difference should be noted: If the frequency of a test tone is equal to that of an interferer, the laterality threshold becomes markedly higher. This contrasts sharply with the case in which the relationship between the frequencies of a test tone and an interferer has a minimal effect on laterality overall in experiments using the ITD as a laterality cue. Based on all these results, we intend to conduct experiments using a free sound field and to further pursue a study of the characteristics of the laterality threshold.

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