Auditory reinforcement at the absolute threshold of hearing and its SPL dependency

Junji Yoshida, Shinya Sagawa, Hiroshi Hasegawa, Masao Kasuga
Graduate School of Engineering, Utsunomiya University, 7-1-2 Yoto, Utsunomiya-shi, Tochigi, 321-8585, Japan,
yoshida@vibra.is.utsunomiya.ac.jp

The present study investigated the change of the absolute threshold of hearing when a pure tone preceded the test tone in the measurement of the absolute threshold. The preceding tone was presented first to one ear followed by the test tone to the contralateral or ipsilateral ear at an interval of 0.5 s. Both the preceding and test tones had the same frequency of 500 Hz and the same duration of 3 s. The sound pressure level (SPL) of the preceding tone was set at between 40 and 80 dB. The change of the absolute threshold of hearing was obtained from the difference between the thresholds with and without the preceding tone. As results, the absolute threshold of hearing decreased significantly about 2 dB when the preceding tone was presented in the contralateral ear, i.e., the loudness was increased by perceiving the preceding tone. This phenomenon is referred to as "auditory reinforcement." On the other hand, in the ipsilateral ear, the absolute threshold did not change significantly. Furthermore, the dependence of the auditory reinforcement on the SPL of the preceding tone was investigated. Consequently, it is noted that the effect level of the auditory reinforcement became large as the SPL of the preceding tone became large.

1 Introduction

It is known that the loudness of a sound is affected by another sound presented previously. Many studies focusing on this previous sound effect have been done, such as induced loudness reduction (ILR) [1]–[4], auditory fatigue [5]–[7], and loudness enhancement [8]–[10]. ILR, that is sometimes called as "loudness recalibration," is a phenomenon that a later presented sound is felt softer by the other sound presented previously [1]–[4]. The auditory fatigue is a phenomenon that the absolute threshold of hearing becomes higher when a loud sound is presented before the test tone for the measurement of the threshold [5]–[7]. And the loudness enhancement was reported as a phenomenon that the loudness of a sound is increased [8]–[10]. However, Scharf *et al.* and Marks *et al.* reported that the loudness enhancement does not actually increase the loudness, and it is a by-product of ILR by reconsidering the experimental method [4, 11]. There are, therefore, few reports on the actual effect of increasing the loudness in the previous sound effects at present.

In this paper, to investigate whether there is an effect of increasing the loudness at the absolute threshold of hearing, we measured the change of the threshold by presenting a previous sound in the contralateral or ipsilateral ear. Furthermore, we investigated the dependence of the threshold change on the sound pressure level (SPL) of the previous sound.

2 Experiment

2.1 Apparatus and Stimuli

A digital audio tape (DAT) player (SONY TCD-08) and an audiometer (GN Otometrics A/S ITERA) were used as the test apparatus. Pure tones at -15 to 20 dB SPL were used as the test sounds for measurement of the absolute threshold of hearing. And pure tones at 40, 60, and 80 dB SPL were used as the previous sounds. Both test and previous sounds had the same frequency of 500 Hz and the same duration of 3 s. The interstimulus interval (ISI) between the previous and test sounds was set at 0.5 s [12]. These sounds were recorded to the DAT and their SPLs were arranged using the audiometer exactly.

2.2 Procedure

The absolute threshold of hearing was measured in the cases with and without the previous sound. In the normal measurement of the threshold (without the previous sound), the test sound was presented to the subject as an inaudible sound of -15 dB SPL at first. Then, the SPL was increased at 5 dB step to the level where the response of the subject changed from "inaudible" to "audible." Next, the SPL was decreased at the same step to the level where the response changed from "audible" to "inaudible." And then, the same upward procedure was performed again. When the response changed at the same SPL in the previous upward sequence, the level was determined as the absolute threshold of hearing. The experimental sequence is shown in Fig. 1.

In the measurement of the threshold in the case with the

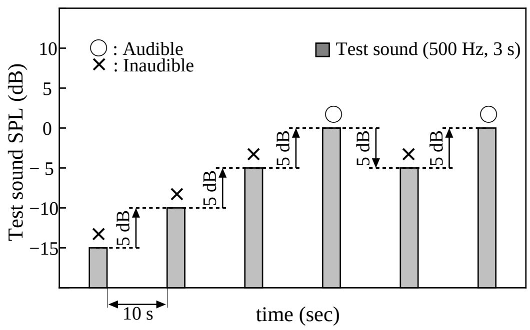

Figure 1: The experimental sequence for the measurement of the absolute threshold of hearing in the case without the previous sound. The gray bars indicate the test sounds for the measurement of the threshold. The SPL of the presented sound is changed at 5 dB step. When the response changes from "inaudible" to "audible" at the same SPL, the SPL is determined as the absolute threshold of hearing.

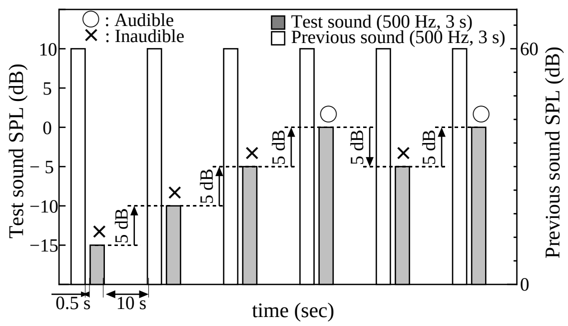

Figure 2: The experimental sequence for the measurement of the absolute threshold of hearing when the previous sound is presented at 60 dB SPL. The gray and white bars indicate the test and previous sounds, respectively.

previous sound, the previous sound was presented 0.5 s before the test tone. The measuring procedure was the same in the case without the previous sound. Figure 2 shows the measuring sequence in the case with the previous sound. The previous sound was presented either in the contralateral ear or in the ipsilateral ear.

These tests were performed in each session that took about 15 minutes. In one session, the subject was performed six tests of the threshold for each ear (left and right) in the cases without and with the previous sound in the contralateral and ipsilateral ear.

The change of the threshold by presenting the previous sound was calculated by subtracting the threshold with the previous sound from the threshold without the previous sound as follows:

$$E_{\mathrm{c}} = T_{\mathrm{n}} - T_{\mathrm{c}}, \quad (1)$$

$$E_{\mathrm{i}} = T_{\mathrm{n}} - T_{\mathrm{i}}. \quad (2)$$

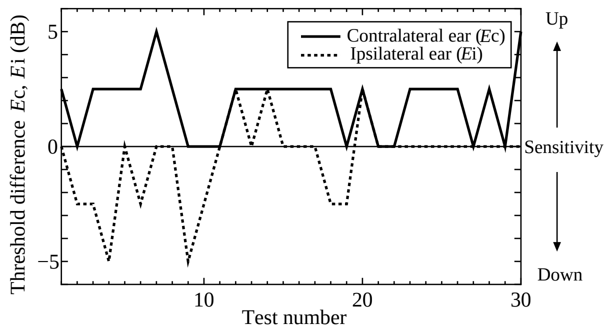

Figure 3: The differences of the absolute threshold of hearing averaged between the results at the left and right ear for each test in Subject A when the previous sound was 60 dB SPL. The solid and dotted lines denote the difference by presenting the previous sound in the contralateral ear (Ec) and in the ipsilateral ear (Ei), respectively.

T_{n} is the threshold in the case without the previous sound. T_{c} and T_{i} are the thresholds in the case with the previous sound in the contralateral and ipsilateral ear, respectively. Ec and Ei are the threshold differences when the previous sound was presented in the contralateral and ipsilateral ear, respectively. When the threshold differences (Ec, Ei) become positive, the absolute threshold of hearing is decreased, i.e., means that the loudness is increased by perceiving the previous sound. These threshold differences (Ec, Ei) were calculated in each session.

2.3 Subjects

Six male subjects at 20' s, who had normal hearing acuity, participated in this experiment. The subjects were named as Subject A to F, respectively. Each subject was performed 30 sessions in each previous sound (40, 60, 80 dB SPL). In one session, Six tests of the threshold were carried out. There were, therefore, 90 sessions (540 tests) in each subject. In total, 540 sessions (3240 tests) were performed in the six subjects.

2.4 Results

Figure 3 shows the threshold differences (Ec, Ei) averaged between the thresholds at the left and right ear for each test in Subject A when the SPL of the previous sound was 60 dB. The solid line denotes the threshold difference when the previous sound was presented in the contralateral ear (Ec), and the dotted line denotes that in the ipsilateral ear (Ei). In this figure, Ec is generally positive ,i.e., the sensitivity to loudness was increased by perceiving the previous sound in the contralateral ear, while Ei does not have a characteristic tendency.

The averaged values of the threshold differences (Ec,

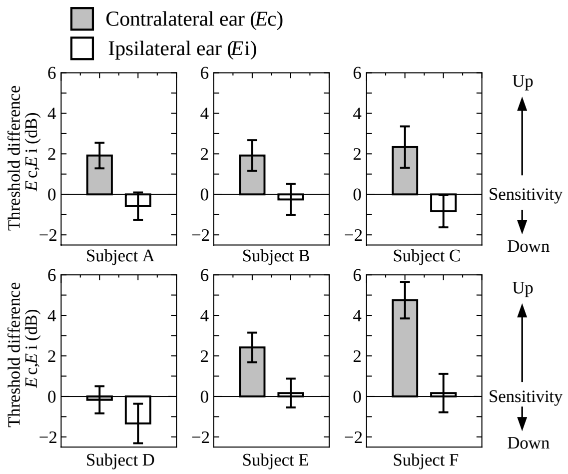

Figure 4: The averaged value of the threshold differences among all tests in each subject when the previous sound was 60 dB SPL. The gray and white bars indicate the threshold differences in the cases previous sound was presented in the contralateral (Ec) and ipsilateral ear (Ei), respectively. The error bars indicate the 95 % confidence intervals.

Ei) among all tests in each subject are shown in Fig. 4, and the averaged values among all subjects are shown in Fig. 5. Here, the gray and white bars indicate the threshold differences when the previous sound was presented in the contralateral ear (Ec) and ipsilateral ear (Ei), respectively. The error bars indicate the 95 % confidence intervals. In Fig. 4, Ec are positive significantly in most subjects, and the maximum level of Ec is 4.75 dB in Subject F. This result shows the loudness was significantly increased in most subjects by perceiving the previous sound in the contralateral ear. However, the effect was absent in Subject D. From the above, it is considered that the phenomenon in which the sensitivity to loudness is increased by the previous sound in the contralateral ear occurs in most people but absent in a few people.

In Fig. 5, the averaged value Ec is approximately 2 dB. On the other hand, Ei is almost zero. This means that the absolute threshold of hearing was hardly changed by perceiving the previous sound in the ipsilateral ear. From these results, in which the threshold difference Ec became positive only in the case of the contralateral ear, it could be considered that the effect does not occur mainly in the auditory peripheral nervous system.

Fig. 6 shows the averaged value of the threshold differences Ec and Ei when the SPL of the previous sound was 40, 60, and 80 dB. The horizontal axis indicates the SPL of the previous sound, and the vertical axis indicates the threshold difference. The filled and open circles are the threshold differences in the case of the contralateral (Ec) and ipsilateral ear (Ei), respectively. In this figure, Ec becomes large as the SPL of the previous sound in-

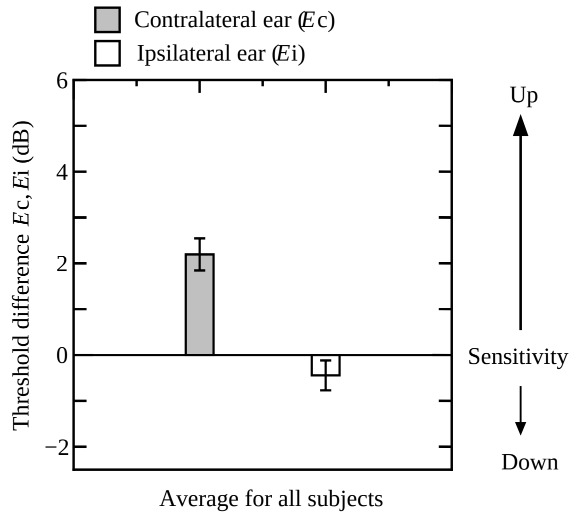

Figure 5: The averaged value of the threshold differences among all subjects when the SPL of the previous sound was 60 dB. The gray and white bars indicate the threshold differences in the cases previous sound was presented in the contralateral (Ec) and ipsilateral ear (Ei), respectively. The error bars indicate the 95 % confidence intervals.

creases. It shows that the effect of increasing the loudness at the threshold depends on the previous sound SPL. Also, Ei becomes large as the SPL of the previous sound increases. The changing tendency of Ei is similar with that of Ec. Therefore, the previous sound effect in the case of the ipsilateral ear may be affected by the effect in the case of the contralateral ear.

3 Discussion

In Sec. 2.4, it was clarified that the absolute threshold of hearing became lower significantly by presenting a previous sound in the contralateral ear. From this result, it could be considered that the loudness sensitivity at the absolute threshold of hearing was increased by perceiving the previous sound in the contralateral ear. We refer to this phenomenon as “auditory reinforcement.” Also, the effect of increasing loudness occurred when the previous sound was presented in the contralateral ear, while the effect did not appear in the case of the ipsilateral ear. Hence, it is considered that this effect does not occur mainly in the auditory peripheral system. Concerning with the result in which the threshold did not change by presenting the previous sound in the ipsilateral ear, it could be caused by the following phenomenon. When the previous sound was presented in the ipsilateral ear, the auditory peripheral nervous system was stimulated repeatedly. Then, in the peripheral nervous system, the sensitivity to loudness decreased by perceiving the pre-

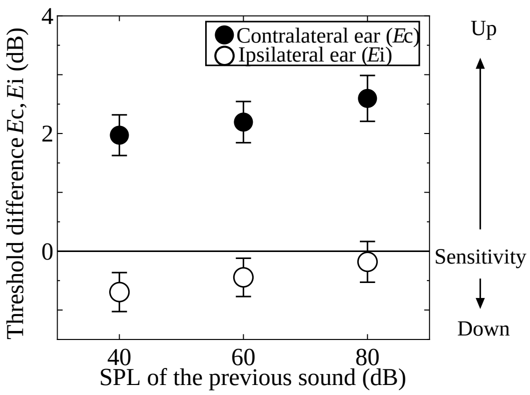

Figure 6: Dependence of the averaged threshold differences on the previous sound SPL. The horizontal axis indicates the SPL of the previous sound and the vertical axis indicates the threshold difference. The filled and open circles are the differences in the contralateral and ipsilateral, respectively. The error bars indicate the 95 % confidence interval in each value.

vious sound, that relates to the auditory fatigue [5]–[7]. The sensitivity to loudness was, however, increased by the loudness reinforcement at the same time. Hence, it is considered that the result in which the threshold did not change in the ipsilateral ear originated from the offset between the effects of the decreasing loudness and the increasing loudness.

4 Conclusion

We investigated the change of the absolute threshold of hearing by presenting the previous sound in the ipsilateral or contralateral ear. We also showed the dependence of the threshold change on the previous sound SPL. As results, we obtained the followings:

(1) The absolute threshold of hearing significantly decreased approximately 2 dB by presenting the previous sound in the contralateral ear.

(2) The absolute threshold of hearing did not change when the previous sound was presented in the ipsilateral ear.

(3) The effect of increasing loudness at the absolute threshold of hearing changed depending on the SPL of the previous sound presented in the contralateral ear.

Acknowledgments

The authors gratefully acknowledge the partial support of this work from a Grant-in-Aid for Young Scientists (B) (No. 15700145) and a Grant-in-Aid for Scientific Research (C) (2) (No. 15500127) from the Japanese Ministry of Education, Culture, Sports, Science and Technology.

References

[1] L. E. Marks, ''Recalibrating' the Auditory System: The Perception of Loudness', *J. Exp. Psychol.*, Vol. 20. pp. 382-396. (1994)

[2] Y. Arieh, and L. E. Marks, 'Recalibrating the auditory system: a speed–accuracy analysis of intensity perception', *J. Exp. Psychol. Human Percept. Perform.*, Vol. 29. pp. 523-536. (2003)

[3] D. M. Riordan, and W. A. Yost, 'Loudness recalibration as a function of level', *J. Acoust. Soc. Am.*, Vol. 106. pp 3506-3511. (1999)

[4] Y. Arieh, and L. E. Marks, 'Time course of loudness recalibration: Implications for loudness enhancement', *J. Acoust. Soc. Am.*, Vol. 114. pp 1550-1556. (2003)

[5] I. J. Hirsh, and R. C. Bilger, 'Auditory–threshold recovery after exposures to pure tones', *J. Acoust. Soc. Am.*, Vol. 27. pp 1186-1194. (1955)

[6] I. J. Hirsh, and W. D. Ward, 'Recovery of the auditory threshold after strong acoustic stimulation', *J. Acoust. Soc. Am.*, Vol. 27. pp 131-141. (1952)

[7] M. C. Botte, S. Charron, and H. Bouayad, 'Temporary threshold and loudness shifts: Frequency patterns and correlations', *J. Acoust. Soc. Am.*, Vol. 93. pp 1524-1534. (1993)

[8] R. Elmasian, and R. Galambos, 'Loudness enhancement: monaural, binaural, and dichotic', *J. Acoust. Soc. Am.*, Vol. 58. pp 229-234. (1975)

[9] R. Elmasian, R. Galambos, and A. Bernheim, 'Loudness enhancement and decrement in four paradigms', *J. Acoust. Soc. Am.*, Vol. 67. pp 601-607. (1980)

[10] F. -G. Zeng, 'Loudness growth in forward masking: Relation to intensity discrimination', *J. Acoust. Soc. Am.* Vol. 96. pp 2127-2132. (1994)

[11] B. Scharf, S. Buus, and B. Nieder, 'Loudness enhancement: Induced loudness reduction in disguise?', *J. Acoust. Soc. Am.*, Vol. 112. pp 807-810. (1992)

[12] J. Yoshida, T. Suzuki, H. Hasegawa, M. Kasuga, 'Auditory reinforcement and fatigue in the central and peripheral nervous systems'. *Proc. Int. Conf. on Acoustics* 2004, Kyoto, Japan, Vol. 2. pp. 1829-1832 (2004)