ABSTRACT
The present study investigates the effects of a previous sound on loudness at the absolute threshold of hearing. Changes in the absolute threshold of hearing were measured when a previous sound was presented before presenting a test sound (pure tone: 500 Hz) in a measurement of the threshold. A pure tone (500 Hz), a band noise (central frequency: 500 Hz, band width: 100 Hz), or a white noise was used as the previous sound. All previous and test sounds had equal duration of 3 s in the measurement. A previous sound at 60 dB SPL was presented first in one ear, followed by presentation of the test sound in either the contralateral or ipsilateral ear at an interval of 0.5 s. As results, the threshold was decreased 2.4 dB by perceiving a previous sound in the contralateral ear when the previous sound was the pure tone or the white noise, and decreased 2.1 dB when the previous sound was the band noise. Conversely, the threshold change in the ipsilateral ear was little when the previous sound was the pure tone or the band noise, and decreased 2.1 dB when the previous sound was the white noise.

INTRODUCTION
It is known that loudness of a sound is affected by a sound presented previously as sequential effects in loudness [1]. Several studies have been reported the sequential effects such as auditory fatigue [2,3], loudness recalibration [4–6], and loudness enhancement [7–9]. Most of these studies investigated the sequential effects when a previous sound was presented in the ipsilateral ear and reported these phenomena mainly as deterioration effects on the loudness of a sound.

In these kinds of reports, Yoshida et al. reported a phenomenon that when a pair of sounds was compared in the contralateral ear, the second perceived sound was felt louder than the first perceived sound even if these sounds had the same sound pressure level (SPL), and this phenomenon referred to as "auditory reinforcement" [10]. They also reported a phenomenon that the absolute threshold of hearing decreased when a previous was presented in the contralateral ear as a kind of the auditory reinforcement [11].

In this paper, to investigate dependence of the kind of previous sounds on the auditory reinforcement, we measured changes in the absolute threshold of hearing by presenting various previous sounds in the contralateral or ipsilateral ear.

EXPERIMENT
Apparatus and stimuli
We measured absolute threshold of hearings using a compact disc (CD) player (VICTOR XL-V1) and an audiometer (GN Otometrics A/S ITERA). Figure 1 shows a schematic diagram of the experimental apparatus. We used 500-Hz pure tones at –15 to 20 dB SPL as the test sounds for measurement of the absolute threshold of hearing. All test sounds had the same duration of 3 s. We presented a pure tone (500 Hz), a band noise (central frequency: 500 Hz, band width: 100 Hz), or a white noise before presenting a test sound as the previous sound. All previous sounds had the same SPL of 60 dB and the same duration of 3 s. The interstimulus interval (ISI) between a previous and test sound was set at 0.5 s [10]. We recorded these previous and test sounds onto a CD and arranged their SPLs using the audiometer.
Procedure
We measured absolute threshold of hearing in cases with and without a previous sound. In the general measurement of thresholds, i.e., the case of without a previous sound, we first presented the test sound to the subject as an inaudible sound at –15 dB SPL. We then increased the SPL in a 5-dB step to the level at which the subject response changed from "inaudible" to "audible." Next, we decreased the SPL in a 5-dB step to the level at which the subject response changed from "audible" to "inaudible." We then performed the above-described procedure again. When the subject response changed at the same SPL in the previous upward sequence, we determined the level as the absolute threshold of hearing. Figure 2 shows a measurement sequence of the case without a previous sound.

Figure 1.-A schematic diagram of the experimental apparatus.

Figure 2.-A measurement sequence of the absolute threshold of hearing of the case without a previous sound. SPL of the test sound was changed in a 5-dB step. When the subject response changed from "inaudible" to "audible" at the same SPL in the upward sequence, the SPL was determined as the absolute threshold of hearing.
In the measurement of the thresholds for the case of with a previous sound, we presented a previous sound (pure tone, band noise, or white noise) 0.5 s before presenting the test sound. The measurement procedure was the same as the case without a previous sound. Figure 3 shows a measurement sequence of the case with a previous sound. We presented the previous sounds either in the contralateral ear or in the ipsilateral ear (test ear) of the subject.

Each measurement session involved six types of tests: threshold measurement in each ear (left and right) for cases without a previous sound, with a previous sound in the contralateral ear (left and right), and with a previous sound in the ipsilateral ear (left and right). And there are three types of previous sounds (pure tone, band noise, and white noise). Each session took around 15 minutes.

We calculated the change in the threshold originating from a previous sound presentation using following equations:

\[
E_c = T_g - T_c, \quad \text{(Eq. 1)}
\]
\[
E_i = T_g - T_i, \quad \text{(Eq. 2)}
\]

where \(T_g\) is the threshold in the case without a previous sound, \(T_c\) and \(T_i\) are the thresholds in the cases with a previous sound in the contralateral and ipsilateral ears, respectively. \(E_c\) and \(E_i\) are threshold differences when a previous sound was presented in the contralateral and ipsilateral ears, respectively. When the threshold difference (\(E_c\) or/and \(E_i\)) becomes positive, that means the absolute threshold of hearing has decreased.

Subjects and tests
We employed five male subjects in their 20's for this experiment. All subjects had normal hearing acuity. Each subject performed 30 sessions in each previous sound. Because each session consisted of six threshold tests and there are three kinds of previous sounds, each subject performed 540 tests. The five subjects thus performed 2700 tests in total.

RESULTS
Figure 4 shows the threshold differences (\(E_c\) and \(E_i\)) averaged among all subject at each previous sound. The white and gray bars denote the results of the cases a previous sound was presented in the contralateral and ipsilateral ears, respectively.
In Fig. 4, the threshold differences $E_c$ in the contralateral ear are 2.4, 2.1, and 2.4 dB when the previous sounds were the pure tone, band noise, and white noise, respectively. This result shows that the absolute threshold of hearing decreased in all cases when a previous sound was presented in the contralateral ear. The threshold decrease in the contralateral ear for the case of the band noise is small compared with those for the cases of the pure tone and white noise. The threshold differences $E_i$ in the ipsilateral ear hardly change when the previous sound was the pure tone or band noise. Conversely, for the case of the white noise, the threshold difference $E_i$ changes 2.1 dB, i.e., the absolute threshold of hearing decreased in the ipsilateral ear when the previous sound was the white noise.

**DISCUSSIONS**

In the above experiment, the absolute threshold of hearing was found to be decreased by presenting a previous sound (pure tone, band noise, or white noise) in the contralateral ear. In the comparison between the results ($E_c$) when the previous sound was the pure tone and was the band noise, magnitude of the threshold decrease for the case of pure tone was larger than that for the case of band noise. This phenomenon is considered to display a characteristic in which magnitude of the threshold decrease is enlarged according to similarity between the previous and test sound. Therefore, the threshold decrease in the contralateral ear must be maximized when the frequency of the previous sound was the same as that of the test sound. However, $E_c$ for the case the previous sound was the white noise is as large as that for the case of the pure tone, though the similarity to the test sound of the white noise is less than that of the band noise. This result shows that magnitude of the threshold decrease is not determined only by the similarity between the previous and test sound but also by other characteristics of auditory perception.

Thought the three kinds of previous sounds employed had the same SPL of 60 dB, considering that they had respectively different characteristics of auditory perception such as the equal-loudness, masking effects, and so on. Then we calculated loudnesses of the previous sounds according to the method standardized by ISO532B. Figure 5 shows the calculated loudnesses of the previous sounds of the pure tone, band noise, and white noise. In Fig. 5, loudness of the white noise is twice (or more) larger than those of the pure tone and band noise. Hence, the white noise was perceived louder than the other previous sounds. We reported previously that magnitude of the threshold decrease in the contralateral ear became large as the SPL of the previous sound increased [12]. In the report, we used the previous and test sounds, both of which had the same frequency of 500 Hz, thus increase in SPL of the previous sound means increase in the loudness. Therefore, considering that magnitude of the threshold decrease for
the case of white noise became as large as that for the case of the pure tone thought the white noise had the lowest similarity to the test sound among the previous sounds. From the above-mentioned results, noting that magnitude of the threshold decrease becomes large as the similarity between the previous and test sounds becomes high, and as the loudness of the previous sound increase.

![Loudness in each previous sound](chart.png)

Figure 5.-Loudness in each previous sound. The loudness of the white noise is twice (or more) larger than those of the pure tone and band noise.

On the other hand, in the case that a previous sound was presented in the ipsilateral ear, the absolute threshold of hearing hardly change when the previous sound was the pure tone or band noise. The threshold, however, decreased 2.1 dB when the previous sound was the white noise. This phenomenon is considered to occur by the mutual effect between the threshold decrease effect in the central nervous system and the threshold increase effect in the peripheral nervous system [11]. When the previous sound was the pure tone, the threshold was decreased by the decrease effect in the central nervous system but the threshold was increased by auditory fatigue in the peripheral nervous system. The threshold thus hardly changed.

When the previous sound was the band noise, the threshold increase effect was weakened by decrease in the same frequency component of the test sound (500 Hz), but the threshold decrease effect was also weakened since the similarity between the previous and test sound became low. The threshold thus also hardly changed.

When the previous sound was the white noise, the threshold increase effect was weakened more than that in the case of the band noise, and the threshold decrease effect was strengthened by increase in the loudness. The threshold then decreased when the white noise was presented in the ipsilateral ear.

CONCLUSIONS
In this study, we measured changes in the absolute threshold of hearing by presenting a previous sound in the contralateral or ipsilateral ear before presenting a test sound (pure tone: 500 Hz) for measurement of the threshold. We used various kinds of previous sounds: a pure tone (500 Hz), a band noise (central frequency: 500 Hz, band width: 100 Hz), and a white noise, all of which had the same SPL of 60 dB. As results, we obtained the following findings:

1. The absolute threshold of hearing decreased by presenting any previous sound in the contralateral ear.
2. Magnitude of the threshold decrease became large as the similarity between the previous and test sounds increased.
3. Magnitude of the threshold decrease become large as the loudness of previous sound increased.
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References: This text is not visible and cannot be provided.