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Auditory Evoked Magnetic Fields to Stimuli Causing Backward Masking

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Abstract—**When a masker tone is presented following a small signal tone, the threshold for the signal becomes higher than in quiet (backward masking). We presented to subjects pairs of signal and masker tones which caused backward masking and investigated the auditory evoked magnetic fields, varying the masker intensity. The responses to the paired stimuli had an N1m which became closer in shape to the N1m in response to masker without the signal as masker intensity increased. However, N1m peak amplitude showed a different behavior, which may reflect some underlying process in the center.**
Keywords—**auditory backward masking, auditory evoked magnetic field, N1m peak amplitude and latency**

Ⅰ. INTRODUCTION

There are three temporal conditions in which auditory masking occurs [1]: Simultaneous masking occurs when the signal tone is presented at the same time with the masker, forward masking when the signal follows the masker, backward masking when the signal precedes the masker. Backward masking is much less effective than simultaneous and forward masking, and thus has attracted less attention of researchers.

However, it has been found recently that backward masking improves (becomes less) over quite a long (roughly 10 years) period of development from infancy and that language-impaired children have excess backward masking [2]. These findings have aroused interest in the mechanism of backward masking and of auditory masking in general. There is also the question whether masking takes place in the periphery or the center [3].

MEG was used to investigate the mechanism of auditory masking, for example in [4]. AEF (auditory evoked field) to a pair of tones was studied [5] although the objective was not to investigate auditory masking itself. However, at least to our knowledge, there has been little work on backward masking using EEG or MEG.

Previously, we measured AEF's to stimuli designed to cause backward masking; a tone burst of 10 ms duration (signal) followed by another burst of 100 ms (masker), varying the interval between them and the signal intensity [6].

In the present paper, we investigated N1m components at around 100 ms after the stimulus onset, varying masker intensity. Stimuli consisted either of signal and masker or of masker alone. The dependencies of AEFs on stimulus conditions may correlate to behavioral result of auditory masking, and reflect some underlying process in the center.

Ⅱ. METHODS

The subjects were six males (22-34 years) without histories of hearing loss or neurological disorder. For each subject, we measured just noticeable level of the signal tone in quiet and defined its amplitude as 0 dB. The signal was a 1 kHz tone burst with 10 ms duration including 3 ms linear rise and fall time. The masker was also a 1 kHz burst but with 100 ms duration including 10 ms linear rise and fall time. The masker intensity was 0, 20, 40, or 60 dB and the signal was either 0 or 20 dB. Each stimulus consisted either of a pair of signal and masker or of masker alone. The onset time of each stimulus was designated $t = 0$ ms. The onset of signal tone was at $t = 0$ ms and that of masker was at $t = 30$ ms. ISI (inter stimulus interval) between the signal offset and the masker onset was then 20 ms. Fig.1 shows a typical auditory stimulus. The interval between consecutive stimuli varied randomly between 1.5 and 3 s. The stimulus sound was presented to the left ear through a plastic tube. The subjects were instructed to ignore the sound by concentrating on reading a self-chosen book. MEG was measured from $t = -100$ ms to $t = 800$ ms producing one sample process. More than 80 sample processes were averaged for each stimulus condition to give an AEF. N1m peak and latency were obta-

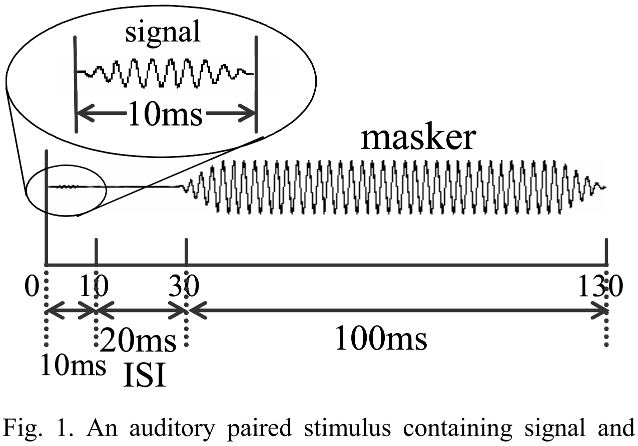

Fig. 1. An auditory paired stimulus containing signal and masker.

ined using Bp waveform where Bp is the modulus of the vector $(\partial B_z / \partial x, \partial B_z / \partial y)$.

Measurement was done with the 122-channel whole-cortex neuromagnetometer (Neuromag-122, Neuromag Ltd., Finland) in a magnetically shielded room. The vertical electro-oculogram (EOG) was recorded simultaneously and epochs in which its activity exceeded 150 μV were rejected from the on-line averaging. The MEG signal was sampled at 997 Hz and bandpass filtered between 0.03 and 100 Hz.

III. RESULTS

Fig. 2 shows AEFs to the stimuli measured from one subject at one site in the right hemisphere where the largest responses were observed. Each panel shows a response to a paired stimulus (thick line) and to masker alone (thin line). The signal intensity was 0 dB and the masker intensity varied from 0 dB (top panel) to 60 dB (bottom panel) with 20 dB steps. A single N1m peak was observed in all the cases whether the stimulus contained a signal tone or not. As the masker intensity became larger, the N1m peak amplitude had a tendency to increase and its latency had one to decrease. Furthermore, the AEF to paired stimuli became similar in shape to the AEF to masker as the masker intensity increased. These tendencies were generally seen among the subjects we measured.

Fig.3 shows correlation coefficients between the responses to paired stimuli and to masker averaged over the six subjects. They were obtained using the two Bp waveforms of the AEF during the period from 0 to 300 ms which included an N1m peak. There was a tendency for the correlation coefficient to increase gradually as the masker intensity increased. The Bp waveform for paired stimuli with 0 dB signal had higher correlation coefficients than those with 20 dB signal for all the masker intensities.

Fig. 4 shows the mean value of N1m peak latency (measured from the Bp waveform) averaged over all the subjects. The latency became shorter as the masker intensity increased in all stimulus conditions. The traces for stimuli of masker and paired stimuli with 0 dB signal tone are almost indistinguishable at the higher masker intensities. The trace for a paired stimuli with 20dB signal lies considerably lower than these two traces.

Fig.5 shows the mean value of N1m peak amplitude (in terms of Bp value) averaged over all the subjects plotted against the masker intensity. When the stimulus was of masker alone or contained signal tone of 0 dB, the N1m peak amplitude increased with the masker intensity. When the signal intensity was 20 dB, the change in N1m amplitude was not so significant as the other two traces. N1m peak was higher than the other two traces at 0 dB, but lower at 60 dB.

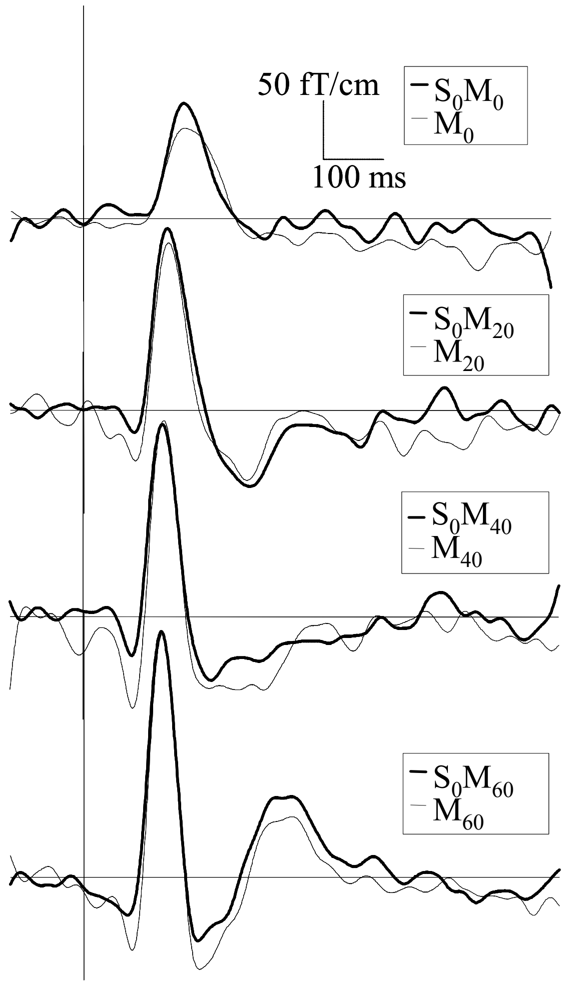

Fig. 2. AEFs to paired stimuli (thick line) and to masker (thin line) measured from one subject. The signal intensity was 0 dB, and the masker intensity increased from 0 dB (top) to 60 dB (bottom) with 20 dB steps. S_yM_x stands for *y* dB signal followed by *x* dB masker.

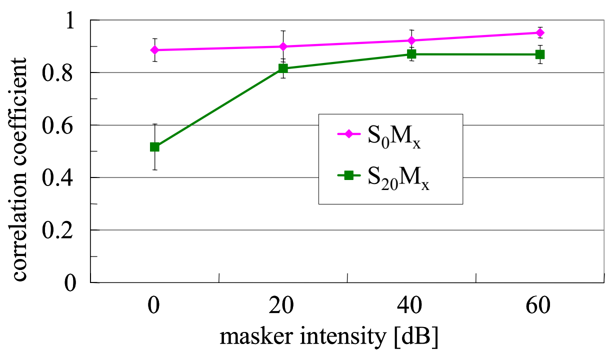

Fig. 3. Correlation coefficients between the responses (Bp waveform, see text) to paired stimuli and to masker plotted against masker intensity, signal intensity being 0 and 20 dB.

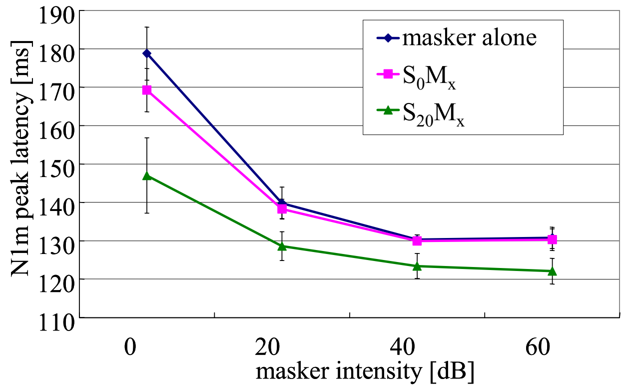

Fig. 4. N1m peak latency (Bp waveform) plotted against masker intensity, with no signal, 0dB and 20 dB signal.

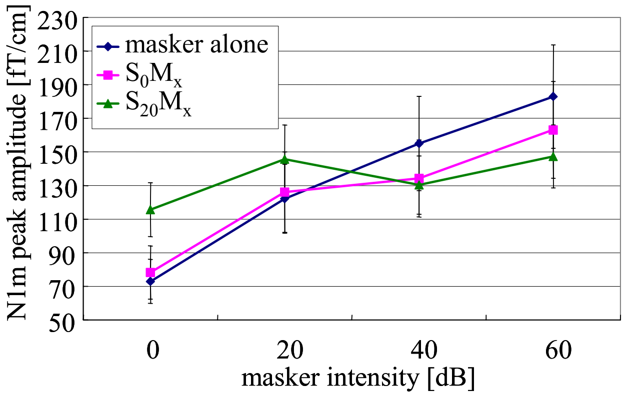

Fig. 5. N1m peak amplitudes (Bp value) plotted against masker intensity, with no signal, 0dB and 20 dB signal.

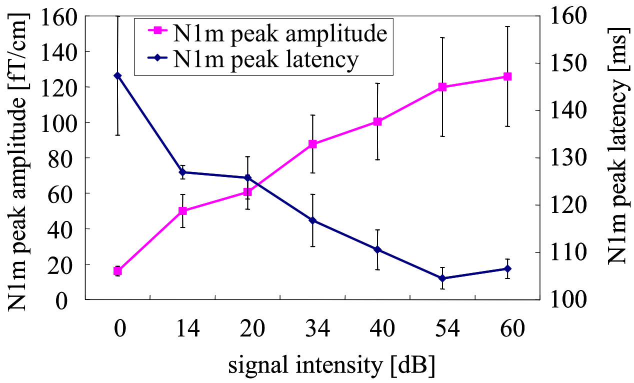

Fig. 6. N1m peak amplitude and latency to a signal tone burst plotted against its intensity.

IV. DISCUSSION

We measured AEFs to stimuli consisting of a signal and a masker with varying masker intensity, and compared them with AEFs to stimulus consisting of masker alone. In the following, we use a simplified expression S_yM_x to represent a category of paired stimulus having y dB signal and *x* dB masker. M_x is a stimulus of masker alone.

Fig.6 is a summary of our previous results on effects of signal intensity on N1m peak amplitude and latency without masker. It shows that latency of N1m to signal of intensity 0 dB was about 147 ms whereas Fig.4 shows that that of N1m to 20 dB masker was about 140 ms. If these signal and masker are combined as in our experiment, the response to the masker may well overtake that to the signal. Then the response to the paired stimulus will become similar to the responses to masker when masker intensity increases. Indeed, results shown in Figs. 3 and 4 are in agreement with this expectation, especially when signal was weak (0 dB). One may argue that this result is only natural, considering that the stimulus gets closer to the masker as the masker intensity increases. However, behavioral masking is exactly the approach of sensation of the paired stimuli towards that of the masker. Therefore, our question is how N1m's approach compares with the behavioral approach. We cannot answer this question now, because no behavioral results for the same stimulus condition are available.

N1m peak amplitude in response to $S_{20}M_0$ or $S_{20}M_{20}$ was larger than amplitudes to M_0 and M_{20} (Fig.5). It was also larger than the corresponding responses to the signal in quiet shown in Fig.6. N1m peak latency in response to the first two categories of stimulus was shorter than to the latter two categories (Fig.4). It was larger than the corresponding latency for the signal in quiet (Fig.6). Therefore, N1m to the paired stimuli with weaker masker intensity seems to reflect both response to signal and response to masker.

N1m peak amplitude in response to $S_{20}M_{60}$ was smaller than the amplitude to M_{60}. However, as we have seen from Figs.3, 4 and 6, this N1m peak should mostly represent response to the masker and not to the signal.

These tendencies can be seen already for paired stimuli with stimulus intensity 0 dB. It is surprising that a signal of the just noticeable level (0 dB) can influence the response to 60 dB masker. We have the following tentative explanation for this, using hypothetical underlying responses to signal and masker in the CNS (central nervous system). See Fig.7. When the masker is weak, N1m to a paired stimulus will be some function of a linear sum of responses to signal and to masker. In this situation, there will be no masking because both responses to signal and masker are too weak to interfere with each other, being separated by an interval of 20 ms. On the other hand, when the masker intensity is larger than 40 dB, the hypothetical response to masker in the CNS will advance in time to approach the response to signal, as suggested by the N1m latency shown in Fig.4. Now the interval between these two hypothetical responses in the CNS is short enough for them to interfere with each other. Then the response to signal suffers backward masking from the response to masker. Also the response to masker suffers forward masking from the response to signal. Thus, the resulting N1m will reflect mostly the response to the masker sup-

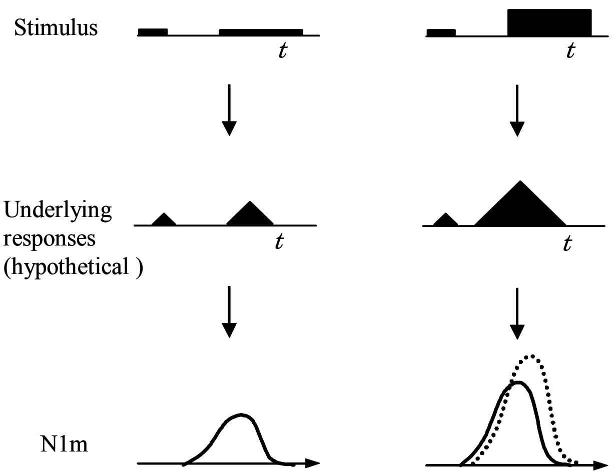

Fig. 7 Schematic drawing for an explanation of N1m to stimuli S_0M_0 (left) and S_0M_{60} (right). The top panels show the stimuli and the bottom panels show the N1m. The dotted N1m is the one obtained for masker alone. In the middle, hypothetical responses to the stimuli are shown. The time origin for each panel is shifted so that the responses may be seen. See text.

pressed by that to the signal. This explanation will be valid only if masking takes place in the CNS as was claimed in [3].

V. CONCLUSION

We investigated N1m components in AEFs to find possible correlates between AEFs and behavioral response to stimuli causing backward masking. Stimuli consisted either of masker and signal or of masker alone. AEFs to paired stmuli became closer in shape to those to masker with increasing masker intensity. However, N1m peak amplitude to paired stimuli changed differently from that to masker. There may be a clue here to understanding of the mechanism of auditory backward masking using MEG, as is discussed in the present paper.

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