Asymmetrical mismatch negativity as determined by phonetic but not physical difference

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Abstract

A two-tone oddball procedure was employed to examine the effect of a phonemic category on the mismatch negativity (MMN). One of the stimuli was a phoneme prototype of Japanese /e/, and the other, [e/ö], which was perceived by Japanese participants as showing deviance from typicality but is nonetheless included in the category /e/. As control stimuli, a pair of pure tones (1940 and 1794 Hz), corresponding to the F2 frequencies of /e/ and [e/ö] respectively, was presented within the same oddball procedure. The MMN for deviant [e/ö] revealed greater amplitude than that of deviant /e/, although there was no significant difference in amplitude between the pure tones. The results suggest that a phonemic category determines the auditory sensory memory.

Keywords: Event-related potential; Mismatch negativity; Phoneme; Prototype; Sensory memory; Category

A linguistic representation on the sensory memory stage in the brain has recently been explored as indexed by the mismatch negativity (MMN) [1,3,5,8,10,11]. The MMN is an event-related potential reflecting an automatic change-detection response of the brain [7]. Under an oddball procedure the MMN is elicited by infrequent tones (deviant stimuli), showing a mismatch with the neuronal model formed by frequent tones (standard stimuli). In general, the responsiveness of the MMN increases in the order of increasing the physical difference between standard and deviant stimuli [2,7]. Since the neuronal model depends on perceptual properties of stimuli [9], however, some exceptions exist in the relationship between the MMN and stimulus difference. For instance, the MMN to a native phoneme contrast reportedly tended to be greater than that to foreign-language phonemes, although the physical difference between the contrasts was identical [3,5,8,11]. Other paradigms have also shown the inconsistency of the MMN by phonetic contrasts with the physical magnitude of stimulus differences [1,10].

In a reversed oddball paradigm, standard and deviant stimuli are reversed between two sessions of a two-tone oddball procedure [1,2]. Thus, one of the two stimuli is presented as standard and the other as deviant in the first session. In the second session, the probability of both stimuli is reversed. In line with the assumption that the MMN reflects purely the physical difference between two stimuli, the MMN should demonstrate identical outcomes between the two sessions [2]. Considering a perceptual magnet effect [6], however, the MMN of phonemic stimuli may indicate asymmetrical outcomes for deviants in the reversed paradigm. A perceptual magnet effect means that the prototype of a vowel category functions as a perceptual magnet for other category members, assimilating neighboring stimuli and effectively pulling them toward the prototype [6]. Therefore, if the prototype and non-prototype of a vowel category are used as stimuli in the reversed oddball paradigm, perceptual deviance from the prototype standard might be less than that from the non-prototype one.

The phonetic continuum from /e/ to /o/ can be established by decreasing only the frequency of the second formant (F2). Finnish and Estonian subjects distinguish three to four vowel categories within the continuum [3,8]. In contrast, Japanese speakers perceive only two categories, /e/ and /o/, among the continuum. Based on the perceptual ability for Japanese speakers, we intended to test the symmetry of the MMN during the reversed oddball procedure of phonetic stimuli. In this study, a phoneme prototype of Japanese /e/ and its neighboring stimulus were used as stimuli. Based on the idea of perceptual magnet effects, it was expected that perceptual deviance reflected by the MMN would be less for the /e/ standard and deviant of the neighboring stimulus, in comparison with the reversed case.

This study consisted of a two-part experiment, the first of which was vowel stimulus discrimination experiments and the second the MMN recording experiments. In the vowel stimulus discrimination experiments, eight healthy Japanese adults (4 women and 4 men, aged 21-46 years old, mean 34.13 years) participated. Similar to a previous study [8], the synthetic vowel stimuli, /e/, [e/ö], /ö/, /õ/ and /o/, were used. The stimuli were synthesized using a KAY Analysis-Synthesis Laboratory Model 4304. The formant values for all stimuli were constant except for the F2 (F0 = 105, F1 = 450, F3 = 2540, F4 = 3500 Hz). The F2 values were 1940 Hz for /e/, 1794 Hz for [e/ö], 1533 Hz for /ö/, 1311 Hz for /õ/ and 851 Hz for /o/. Duration and intensity of the stimuli were 400 ms (rise and fall times 10 ms each) and approximately 70 dB SPL at each participant’s head, respectively. The stimuli were presented through a loudspeaker located approximately 100 cm behind the head. In the first session, participants were required to categorize each sound as either /e/ or /o/. In the second session, they rated each stimulus according to the following scale. A rating of 5 denoted a typical percept of category /e/, -5 denoted a typical percept of category /o/ and zero denoted equal contributions of both. This is because a Japanese speaker perceives only the two categories within the above continuum of stimuli. For both sessions, participants underwent 150 trials, 30 each of the five vowel stimuli. The 150-trial series was divided into blocks of 5 trials with the five vowel stimuli presented in random order within each block. Participants were warned of an upcoming trial, and asked to report the category or rating to us in a self-paced manner. If participants requested a second presentation, it was given, but requirements for repeat presentations were rare.

Eight healthy Japanese adults (3 women and 5 men, aged 22-46 years old, mean 36.63 years) participated in the MMN recording experiments. Half of them were also participants in the vowel stimulus discrimination experiments. A pair of pure tones (1940 and 1794 Hz sinusoidal waves, corresponding to the F2 frequencies of /e/ and [e/ö], respectively [8]), and a pair of synthetic vowels (/e/ and [e/ö]) were used as stimuli. Duration and intensity of all stimuli were identical to those used in the vowel stimulus discrimination experiments. Two sessions were carried out for each pair of stimuli. In the first session, one of the two stimuli was presented as standard (probability 0.86) and the other as deviant (probability 0.14). The probability of both stimuli was reversed in the second session. The order of reversing the stimuli was counterbalanced across participants. In one session, 703 trials were presented with 1000 ms stimulus onset asynchronies. The first three trials consisted of the standard stimuli. The sessions using pure tones always preceded those using the vowel stimuli. To allow participants to ignore stimuli, they were asked to read books during the experiments.

Electroencephalogram (EEG) was recorded from scalp sites Fz, Cz and Pz (10-20 system) with reference to the right earlobe. Electro-oculogram

(EOG) was derived from a bipolar montage (supraorbital to lateral canthus of the right eye). Band pass of the indices was 0.1-30 Hz. Epochs of 450 ms with a 50 ms pre-stimulus baseline were averaged separately for each stimulus category. The first three trials and those with a change of either EEG exceeding 100 μV or EOG exceeding 150 μV were excluded from the averaging. All participants had at least 70 artifact-free EEG epochs for the deviant stimuli. To examine the MMN, the potential measured for the standards was subtracted from that measured for the deviants. In addition, the MMN was only determined from the Fz electrode, since the most reliable results are found at that site [7,8]. For the grand-average difference waveforms, the time window for measuring the peak latency and amplitude of the MMN was between 80 and 200 ms for the pure tones, and between 110 and 250 ms for the vowel stimuli (Fig. 2). A repeated measure analysis of variance was used to assess significant differences in the latency and amplitude of the MMN. The analysis resulted in no violation of sphericity. Thus, the epsilon correction was not applied for degrees of freedom. In addition, to correct the type II error, Cohen's power analysis [4] was applied to a probability of less than 0.10 but greater than 0.05.

Figure 1 shows results of the vowel discrimination experiments. The mean percentage categorization for each stimulus was calculated from the first sessions (Fig. 1, top). The percentage of /e/ categorizations was maximum for stimulus /e/ and minimum for stimulus /o/, whereas the percentage of /o/ categorizations was just the opposite. In particular, the former percentage for stimulus /e/ (100 %) was slightly greater than that for stimulus [e/ö] (98 %). Comparison of the two values using a paired t-test revealed no significant difference ($t(7) = 1.00$, $P > 0.30$). The results of the second sessions showed that, as the F2 frequency of the stimuli reduced, the averaged ratings decreased linearly (Fig. 1, bottom). Thus, the averaged rating for stimulus /e/ was more than 4 while that for stimulus /o/ was less than –4. Comparison of the mean values for stimuli /e/ (4.33) and [e/ö] (3.68) demonstrated the difference to be significant ($t(7) = 3.22$, $P < 0.02$).

Figure 2 illustrates grand-average waveforms at the Fz electrode obtained from both pairs of pure tones and vowel stimuli. Grand-average difference waveforms, obtained from the pairs of pure tones, revealed similar peak amplitudes and latencies of the MMN for the deviants 1940 and 1794 Hz (Fig. 2, top). In contrast, the difference waveforms for the pairs of vowel stimuli demonstrated asymmetrical amplitudes and latencies for the MMN between the deviants (Fig. 2, bottom). Figure 3 depicts averaged peak amplitudes and latencies of the MMN for the deviants of pure tones and vowel stimuli. Comparison between the pairs of amplitudes was insignificant for the pure tones ($F(1, 7) = 0.65$, $P > 0.40$), although it was significant for the vowel stimuli ($F(1, 7) = 9.12$, $P < 0.02$). Moreover, the difference for the latencies was insignificant for the pure tones ($F(1, 7) = 0.00$, $P > 0.90$) whereas it was significant for the vowel stimuli ($F(1, 7) = 5.29$, $P = 0.06$, *Power* < 0.51, *ES* = 0.43). The latencies to the non-prototype deviant were shorter than that to the prototype deviant.

The vowel discrimination experiments demonstrated an insignificant difference of categorization between the stimuli /e/ and [e/ö], whereas they simultaneously showed a significant difference between those for typicality. These results suggest that the stimulus [e/ö] was included in the category /e/, while it demonstrated deviance from typicality within that category. The MMN revealed greater amplitude and shorter latency for the non-prototype deviant ([e/ö]) than for the prototype one (/e/). The results for the pure tones suggest that the asymmetry cannot be explained by a difference in the F2 frequency between the vowel stimuli [8]. The perceptual magnet effect asserts that a prototype of a vowel category, serving as the referent, demonstrates greater generalization to other members of the category [6]. The perceptual deviance from the prototype should thus be weaker than that from a neighbouring stimulus within the same category. That anticipation seems to be inconsistent with the present results of the MMN. An alternative explanation is that the participants in our study were inclined to rely on abstract representations of the vowels [1], that is, representations of a phonemic category (e.g., category /e/), as distinct from a prototype (e.g., the sound /e/). The neuronal activity elicited by the deviant /e/ might be incorporated in a set of neuronal activity representing the category /e/, which should be triggered by the standard [e/ö].

At the same time, we are aware of the differences in experimental procedures between the earlier [1,6] and the present studies. In the experiments examining the perceptual magnet effect, a prototype and a non-prototype vowel /i/ were both used as the standard [1] or referent stimuli [6]. The deviant [1] or comparison [6] stimuli in those studies were the neighbouring variants of the standard or referent vowels. Thus, the prototype and non-prototype vowels had large distance (120 mel or greater) in those studies (The mel scale is a metric to equate the psychophysical distance in pitch [6]). On the other hand, the non-prototype as used in the present study ([e/ö]) had relatively small distance (approximately 60 mel) from the prototypical vowel (/e/). Therefore, if a non-prototype having greater distance from the stimulus /e/ (such as /ö/ for Japanese speakers) and its variant are compared, the MMN for these stimuli may be symmetrical. Depending on this consideration, the present results of the asymmetrical MMN could rather show evidence supporting the perceptual magnet effect.

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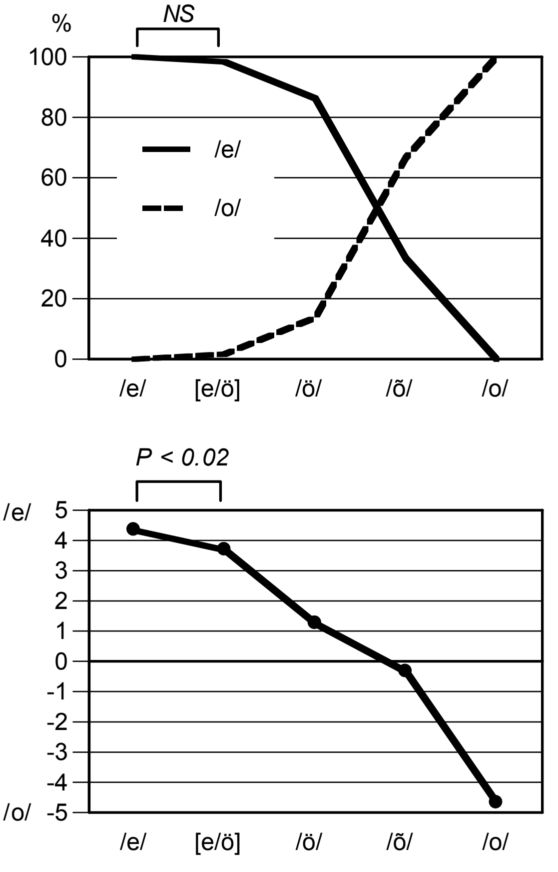
Legends

Fig. 1. Mean percentages of categorization by making a forced choice with categories /e/ versus /o/ (top) and mean ratings depending on the vowel typicality for /e/ and /o/ (bottom). Statistical significances for comparison between stimuli /e/ and [e/ö] are shown (n = 8).

Fig. 2. Grand-average waveforms for the pairs of pure tones (top) and the pairs of vowel stimuli (bottom) at electrode site Fz (n = 8). Grand-average difference waveforms are depicted at right.

Fig. 3. Mean peak amplitudes and latencies of the MMN for the deviants of pure tones (left) and of vowel stimuli (right). Statistical significances are shown for comparison between each pair of outcomes.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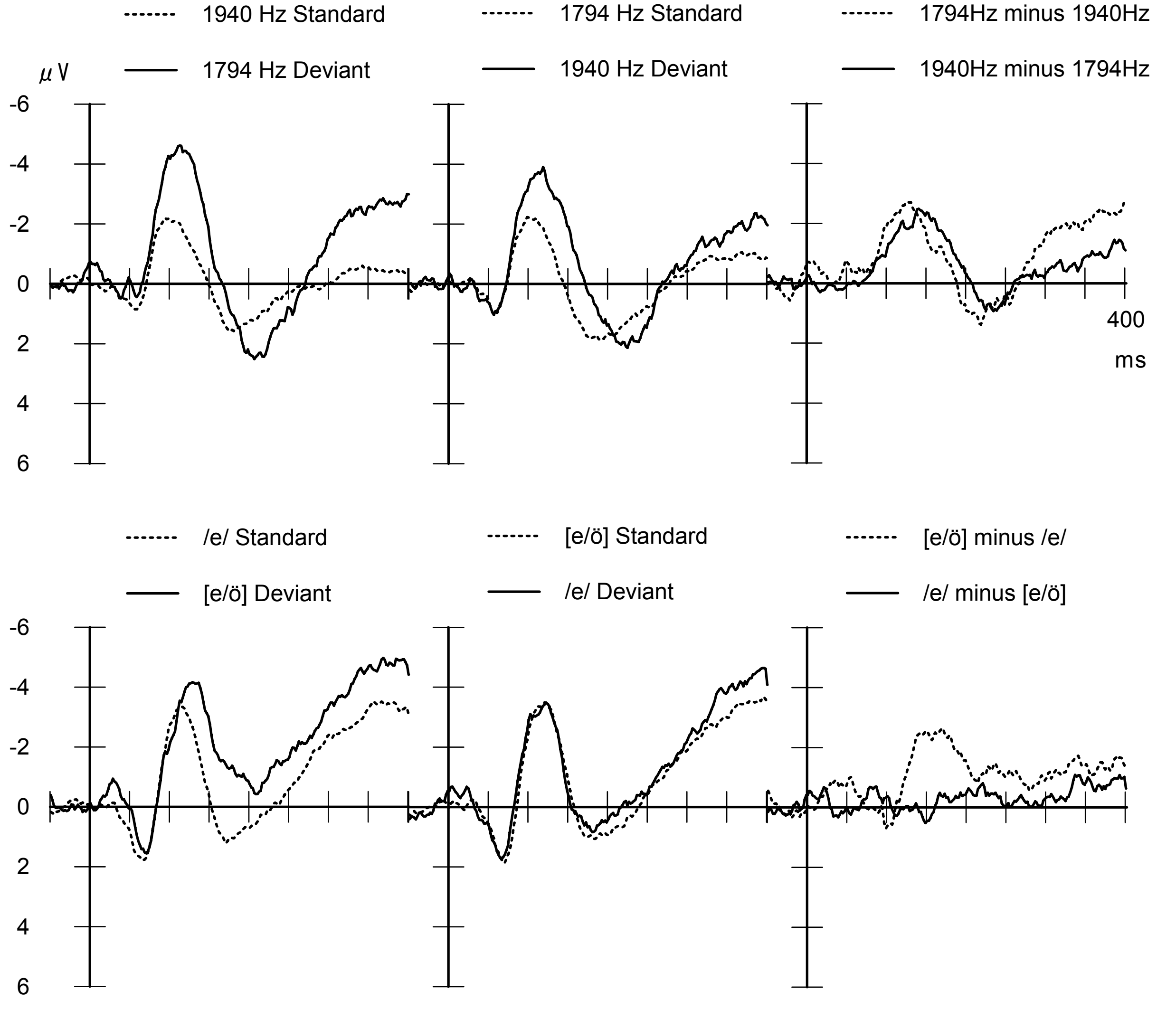

1940 Hz Standard
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1794 Hz Standard
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1940Hz minus 1794Hz
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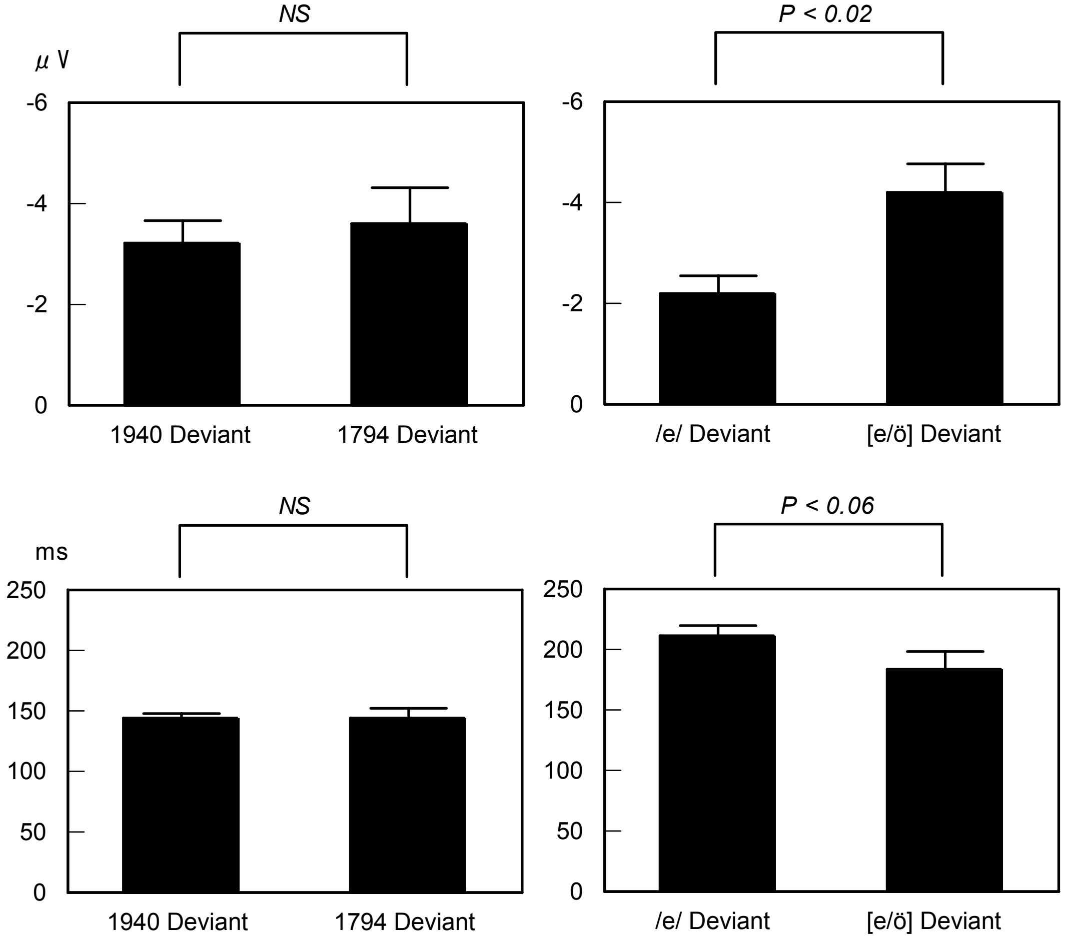
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