

A modified oddball paradigm “cross-modal delayed response” and the research on mismatch negativity

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ABSTRACT: A modified oddball paradigm was developed to facilitate the focus of attention and to minimize target effects on deviant-related components of auditory and visual event-related potentials (ERPs) elicited with long interstimulus intervals. Subjects were required to focus on either the visual or auditory stimulus in each stimulus block. Deviant-related components were obtained by subtracting ERPs of the standard stimulus from that of the deviant stimulus for each modality with each stimulus condition. Results showed that auditory mismatch negativity (MMN) and a visual early deviant related negativity (DRN1) were elicited both when stimuli were attended and unattended. In contrast, N2b and P3 were produced only under the attended condition. In comparison of attended MMN and unattended MMN at three time windows (100–150 ms, 150–200 ms, and 200–250 ms) of MMN zone, different scalp distributions were shown, depending on the time windows. This result suggests that the attended auditory MMN is a mixed wave, consisting of genuine MMN, N2b, and possible P165. The effect of attention on MMN may stem from the contamination of these overlapping components. With the present paradigm, at least three sensory memory traces have to be maintained simultaneously in multiple sensory modalities to support automatic processing. © 2002 Elsevier Science Inc.

KEY WORDS: Event-related potentials (ERPs), Mismatch negativity (MMN), Selective attention, Cross-modal delayed response paradigm.

INTRODUCTION

The mismatch negativity (MMN) can be recorded from the scalp in response to rare, physically deviant sounds that are embedded within a train of more frequent standard sounds. This component is believed to reflect the result of a comparison process between the deviant stimulus and representations held in sensory memory of recently encountered (standard) stimuli. The MMN has attracted the attention of psychologists because it is thought to involve automatic processing of information in the brain. It may also signal an attention switch to an initially unattended channel due to a change in the environment [11,19,24]. Although it is clear that the MMN can be elicited in auditory modality in the absence of attention, there has been a long-standing controversy as to whether attention has any effect on MMN. Furthermore, it also remains

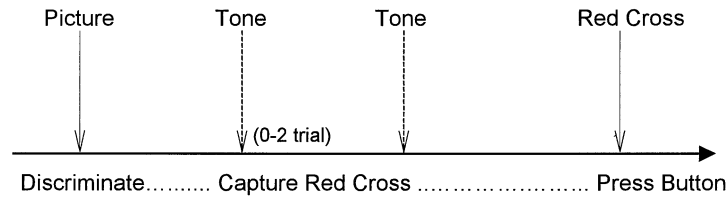
somewhat unclear whether there is an analogous automatic deviant-related negativity in the visual modality.

MMN in the auditory modality was first reported by Näätänen et al. [25,27]. Several studies found that MMN amplitudes were identical under attended and unattended conditions, suggesting that MMN is not influenced by attention. These authors concluded that MMN reflects automatic processing [25,26,35]. However, other authors [41] discovered that in the original experiments, the stimuli were presented at such slow rates that subjects were able to attend to both relevant and irrelevant inputs. They therefore presented dichotic stimuli at very fast rates (random interstimulus interval (ISIs): 65–320 ms) to force selective attention, as they had earlier used in studies investigating the effects of attention on the N1 component of the event-related potentials (ERP) [14,15,32]. With such fast rates of presentation, Woldorff et al. [41] found that the MMN elicited by unattended deviant stimuli was considerably smaller than that elicited by attended deviants, both when intensity and when frequency decrements were used to define the deviant feature. This was interpreted as evidence that the processing of stimuli in unattended channels can be attenuated at an early sensory level under conditions of highly focused auditory selective attention [42].

But in Woldorff et al.'s experiments, the MMN could be overlapped by N2b, a component affected by attention. The effect of attention may not be on the MMN itself [22,28]. The MMN scalp topography is usually considerably anterior to that of the N2b, and unlike N2b, the MMN reverses its polarity at recording sites below the Sylvian fissure when the nose is used as a reference [1,2,30,34,36]. Näätänen et al. [28] recorded from mastoids with a nose reference, and distinguished MMN from N2b according to whether the polarity was reversed or not. In their experiment, Näätänen et al. also used a very fast rate of stimulus presentation (random ISI: 70–200 ms) and enabled the determination of attention effects on the MMN [4]. They found that MMN elicited by a frequency change in the ignored input stream was very similar to the MMN elicited by equivalent stimuli in the attended input stream. In contrast, the MMN to an intensity deviation was clearly attenuated in the absence of attention. Näätänen et al. proposed that such modulation of the attention effect for intensity deviation was probably due to the influence of attention on the MMN

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Experiment 1: Attending To Visual Stimuli, Ignoring Auditory Stimuli.



Experiment 2: Attending To Auditory Stimuli, Ignoring Visual Stimuli.

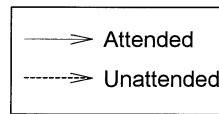
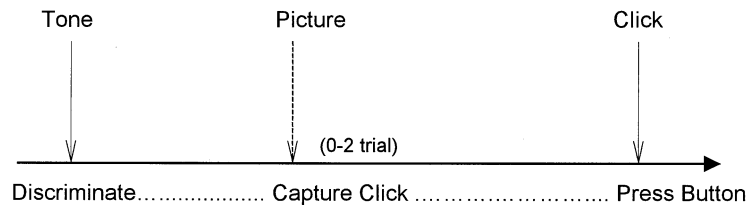


FIG. 1. The paradigm “cross-modal and delayed response.” Shows part of trials. The whole sequence consists of 433 trials. The pictures and tones were either standard or deviant stimuli.

generator itself, rather than the antecedent sensory-analysis and -storing functions.

Recently, corroborating evidence was obtained. Kropotov et al. [17] used implanted electrodes to record ERPs with long ISIs directly from the human cortex. This intracranially recorded MMN was attention independent. However, other studies of cross-modal attention [3,43] showed that the auditory frequency MMN using difficult-to-detect deviants and short ISIs was enlarged by attention. The same research group later [4] suggested that the effect of target-specific negativity is a considerable contamination factor in these MMN experiments. Although the target factor may be related to the effect of attention on MMN in these experiments, the impact of simultaneous memory traces in different modalities could also be considered. Trejo et al. [39] also examined the attentional sensitivity of the frequency MMN. When subjects listened to a demanding binaural mixture of a narrative and tone bursts, the MMN was modulated by attention. These findings are consistent with Näätänen’s [21] hypothesis that two types of neuronal populations generate MMN. Computational neurons specialized to respond to the slightest stimulus deviations are thought to generate the initial mismatch signal, and amplifying (modulating) neurons receive and strengthen that signal. In this view, attention affects the amplifying system but not the computational system. Accordingly, sensory information would be fully processed even in the absence of attention.

Another issue on MMN is whether MMN-like responses are elicited outside the auditory modality. On the basis of negative results from two studies, Näätänen [20] stated that “no MMN appears to occur in the visual modality.” However, Cammann [6] reported that color deviant was associated with a subtraction ERP in the “ignore” condition that clearly showed a widely distributed

MMN-like change between 150 and 350 ms, with a parietal maximum. Banquet et al. [5] claimed that evidence for a visual MMN was already provided by Simson et al. [38], and Renault and Lesevre [33]. However, Näätänen [20] pointed out that Simson and his colleagues used a discrimination condition which makes it difficult to disentangle a possible MMN among the overlapping ERP components of the “N2” time zone and that Renault and Lesevre’s result cannot rule out anticipatory potentials. Besides, there are other studies that did not observe a visual MMN [10,22, 29,31]. Nevertheless, Ciesielski et al. [8] obtained preliminary evidence suggesting that mismatch negativity may occur in the visual modality. Particularly, studies of cross-modal attention [3,43] revealed that deviant visual stimuli also elicited an MMN-like component, largest over the inferior temporal cortex. The visual MMN-like component increased in amplitude with attention, but it was also evident during inattention. However, as mentioned above, the effect of target-specific negativity is a considerable contamination factor. Further clarification of the existence and properties of visual MMN is important because it involves sequential and parallel visual processing [20] and speaks to the universality of mismatch across modalities.

In sum, discrepancies over previous experimental results for MMN are probably related to differences in the depth of attentional focus (e.g., due to long vs. short stimulation intervals) and to the overlap of MMN with N2b and target-related potentials. As Näätänen [23] indicated, if the sound sequence used for MMN elicitation is attended, the MMN is overlapped by other ERP components, such as the P165 and, most notably, the N2b, which makes the pure measurement of the MMN difficult or impossible. The present experiment used a modification of the usual oddball task, a cross-modal, delayed response paradigm (see Fig. 1) to

serve as a control for confounding factors and re-examine the effects of attention on MMN in both the visual and the auditory modalities. The basic design involved the presentation of a series of pictures and tones in random order, hence the term "cross-modal." The stimuli of the unattended modality were presented during the interval between a stimulus and a response imperative signal of the attended modality. For example, if the attended modality was visual, the auditory stimuli (tones) were interposed between visual stimulus (picture) and imperative signal (red cross). Subjects were required only to discriminate between the standard and deviant stimuli of the attended modality and to decide which hand (left or right) they would use to press the button when the attended stimulus was presented. Their responses were produced only after the response imperative signal had occurred, hence the term "delayed response." It was expected that the more pure unattended MMN and the attended MMN related to non-target in the present paradigm would provide more convincing result for the above unresolved questions.

MATERIALS AND METHODS

Subjects

Twelve undergraduates (7 male, 5 female), 19–22 years of age, were paid to serve as subjects in the experiment. All of them were right-handed as measured by the Reitan Test [7], with normal hearing and vision or corrected visual acuity. They did not have any history of neurological and mental diseases.

Procedure

The experimental instrument was the ERP workstation manufactured by Neuro Scan. Two experimental blocks, counterbalanced for order between subjects, were administered to each subject using a cross-modal delayed response oddball paradigm.

Block I: Attending visual modality. There were sequences of five events, including the standard and deviant stimuli in both the auditory and visual modalities and a visual response imperative signal. The visual standard stimulus was a color scenery photograph (4.3 cm × 2.8 cm). The deviant stimulus was the same picture with the degree of contrast increased. Every visual standard or deviant stimulus was followed by 0–2 auditory stimuli preceding a small red cross (0.5 cm × 0.5 cm) which served as the response imperative signal (see Fig. 1). Visual stimuli were presented at the center of a computer screen positioned 1.0 m in front of the subject. The auditory standard stimulus was an 800-Hz tone pip. The deviant stimulus was a 1000-Hz tone pip. Both had a duration of 30 ms (including 5 ms rise/fall time). Tone intensity was 60 dB SPL. In each modality, the standards were presented for 368 trials (85%), and the deviants for 65 trials (15%). The presentation order of the two modalities and of the standard and deviant stimuli in each modality was pseudo-random. The interstimulus intervals between adjacent standards varied from 250–700 ms in pseudo-random order, and the interstimulus intervals before and after deviants varied from 652–700 ms in pseudo-random order.

Subjects were seated at a table with a chinrest to inhibit head movements in a sound-attenuated room. Auditory stimuli were delivered to earplugs through air tubes (length: 50 cm, diameter: 2 cm) in order to mitigate electromagnetic stimulus artifacts. Subjects were instructed to pay attention to the pictures but not to the tones. They were asked to get ready with either their left or right thumb, depending on whether it was the standard or the deviant picture. That is, they only decided which hand to press the button when a picture was presented, looked for the response imperative signal that would appear at any time and got ready for pressing, but did not press until the imperative signal was presented. Once the

response imperative signal (red cross) appeared, they were asked to press the button as quickly and accurately as possible. Half the subjects responded to the standard stimuli with right thumb and to the deviants with left thumb, and other half responded with opposite thumbs.

Block II: Attending auditory modality. There were sequences of five events, including the standard and deviant stimuli in both the auditory and visual modality and an auditory response imperative signal. Every standard or deviant auditory stimulus was followed by 0–2 visual stimuli preceding a faint click (2 ms, 18 dB SPL), which served as the response imperative signal. Subjects were instructed to fixate on the central point of the screen but to attend to auditory signals rather than pictures. They were required to get ready with either their left or right thumb depending on whether it was the standard or the deviant tone. That is, they only decided which hand to press the button when a tone was presented, looked for the response imperative signal that would appear at any time and got ready for pressing, but did not press until the imperative signal was presented. Once the response imperative signal (click) appeared, they were asked to press the button as quickly and accurately as possible. The other details were the same as in block I.

Eye movements were monitored by vertical electrooculogram (VEOG) and horizontal electrooculogram (HEOG). Several practice trials were run until the subjects' eyes remained focused on the screen during testing with correct responses.

ERP Recording and Averaging

Electroencephalogram (EEG) was recorded using an electrode cap with 16 scalp electrodes of the international 10–20 system (Fz, F3, F4, F7, F8, Cz, C3, C4, T3, T4, Pz, T5, T6, Oz, O1, O2), left and right mastoids with a nose reference (see Fig. 3). VEOG and HEOG were recorded with two pairs of electrodes, one placed above and below right eyes, and another 10 mm from the lateral canthi. Electrode impedance was maintained below 5 k Ω . EEG and EOG were continuously sampled at 250 Hz, amplified with filter settings of 0.1–40 Hz and archived for off-line analysis.

The recording epoch was 652 ms, including a 52-ms prestimulus baseline. Because more standard stimuli were presented than deviants (368 vs. 65), 65 standard stimulus trials with ISI (onset to onset, hereinafter) of 652 ms or longer were selected for averaging to equalize the number of averaging deviants. The ISI of the other 303 (total 606 for two modalities) deleted standards were less than 652 ms (250 to 600 ms), in order to shorten the period of experiment, thus prevent the subject's fatigue.

EOG artifact was automatically corrected by Neuro Scan software [37]. Trials with contamination from amplifier clipping, bursts of electromyographic activity, or peak-to-peak deflection exceeding 100 μ v were excluded from averaging. The EEG evoked by standard/deviant stimuli, in the auditory/visual modalities under attention and inattention were averaged separately, and 8 ERP waveforms were obtained. The actual number of individual trials per waveform ranged from 53 to 65 (mean 58).

Data Reduction and Statistical Analysis

The deviant-related components (DRC) were obtained by subtracting ERPs of the standard stimuli from those of the deviant stimuli. In the present report, we focus on MMN.

Measurement. For original (raw) ERP components, the amplitude (baseline to peak) and peak latency were measured. The measurement windows were determined by visual inspection of grand average waveforms (see Figs. 3 and 4) and previous reports [22]. The mean amplitudes of subtraction-derived DRC, relative to

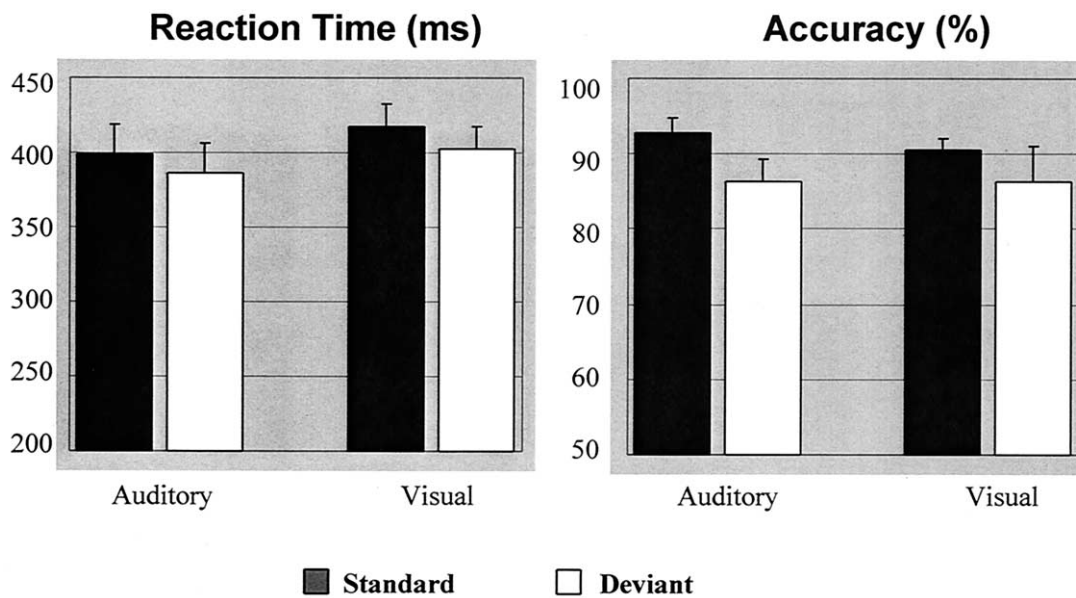


FIG. 2. Reaction time and correct rate of visual and auditory stimuli identification.

the prestimulus baseline, were measured separately across three 50 ms time windows: 100–150 ms, 150–200 ms, and 200–250 ms.

Statistics. ERP latencies and amplitudes were assessed via three-way analyses of variance (ANOVA) with repeated measurements (SPSS, 1993). The factors were condition (two levels: attention and inattention), modality (two levels: auditory and visual), and electrode site (16 levels). The p values were corrected by the Greenhouse-Geisser method. In comparing the scalp distributions of different components, the amplitude data were first normalized to control for component \times electrode interactions resulting simply from differences in overall component amplitude [18]. Simple effects tests were conducted at each electrode site when normalized interactions were significant.

RESULTS

Performance Data

Figure 2 displays the mean values (standard error in brackets) of reaction time (RT), and accuracy for standard and deviant stimuli in the auditory and visual modalities. The t -test did not show any significant differences between auditory and visual modalities and between standard and deviant stimuli. This suggests a consistent difficulty level in identification of standard and deviant stimuli in the two modalities.

Basic ERPs Components

The grand-average ERPs elicited by standard (dashed line) and deviant (solid line) stimuli in the auditory modality under attention and inattention conditions are shown in Fig. 3. The ERPs in the visual modality are shown in Fig. 4. In both auditory and visual modalities, the typical P1, N1, P2, and N2 components were elicited by standard and deviant stimuli under attention and inattention conditions. Only attended deviant stimuli evoked the P300. The maximum amplitudes and their peak latencies of basic ERP components are shown in Table 1. The ERP waveforms obtained with the present multimodal paradigm are seen to be similar to those elicited in the single modality paradigms in other laboratories.

DRC

DRC were obtained by subtracting ERPs of the standard stimuli from that of the deviant stimuli in the same modality and condition. Figure 5 presents the grand-average DRC under attention and inattention conditions in the auditory and visual modalities.

Table 2 presents the maximum amplitude of DRC and their locations for each of three 50-ms time windows in different modalities and attention conditions. To account for polarity reversal, the amplitudes at the ipsilateral mastoid are listed in the brackets. These data show that regardless of modality and condition, the early DRC was negative. Figure 5 shows that deviants in both modalities, when they were unattended, produced a single deviant-related negativity (DRN1), with maximum amplitudes at F4 between 100 and 200 ms. When attended, the deviant-related negativity was divided into an early DRN1 around 100–200 ms and a late DRN2 around 200–300 ms. Figure 5 and Table 2 indicate that DRN1 maximum amplitude was at T4 when attention was on the auditory modality, but at O2 when attention was on the visual modality. The auditory DRN1 reverses polarity at the mastoids under attention, seen clearly over the left mastoid recording, and under inattention, seen clearly over the right mastoid. In contrast, the auditory DRN2 and both visual DRNs do not reverse polarity at mastoids. Previous research shows that frequency MMN occurs between 100 to 250 ms [22]. In addition, the characteristics of DRN2 match with those of N2b [1,2,30,34,36]. Thus we associate DRN1 mainly with MMN, and DRN2 with a mixed wave of MMN and N2b. As illustrated in Fig. 5, there was also a late deviant-related positivity (DRP), peaking after 400 ms. DRP amplitudes were very large in attention, but very small in inattention regardless of modality. We associate the DRP with P300, and this will not be further discussed in this paper.

Amplitude. ANOVA shows that the interaction between attention and electrode site at 100–150 ms was significant [$F(15,165) = 2.18, p < 0.009$]. At 150–200 ms, significant levels were reached in the interactions between electrode site and modality [$F(15,165) = 3.09, p < 0.021$], and between electrode site and attention [$F(15,165) = 3.17, p < 0.020$]. At 200–250 ms, signif-

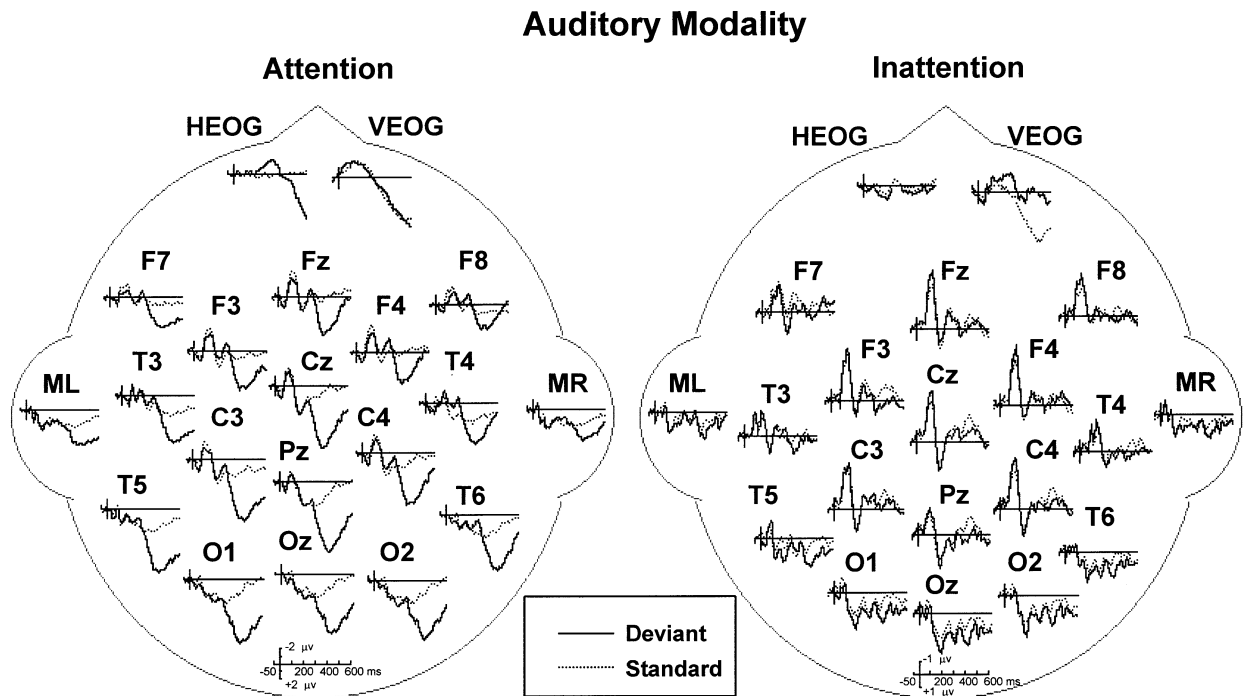


FIG. 3. Grand-average event-related potential to auditory deviant (solid line) and standard (dashed line) stimuli under attention (left) and inattention (right) conditions. Abbreviations: HEOG, horizontal electrooculogram; VEOG, vertical electrooculogram.

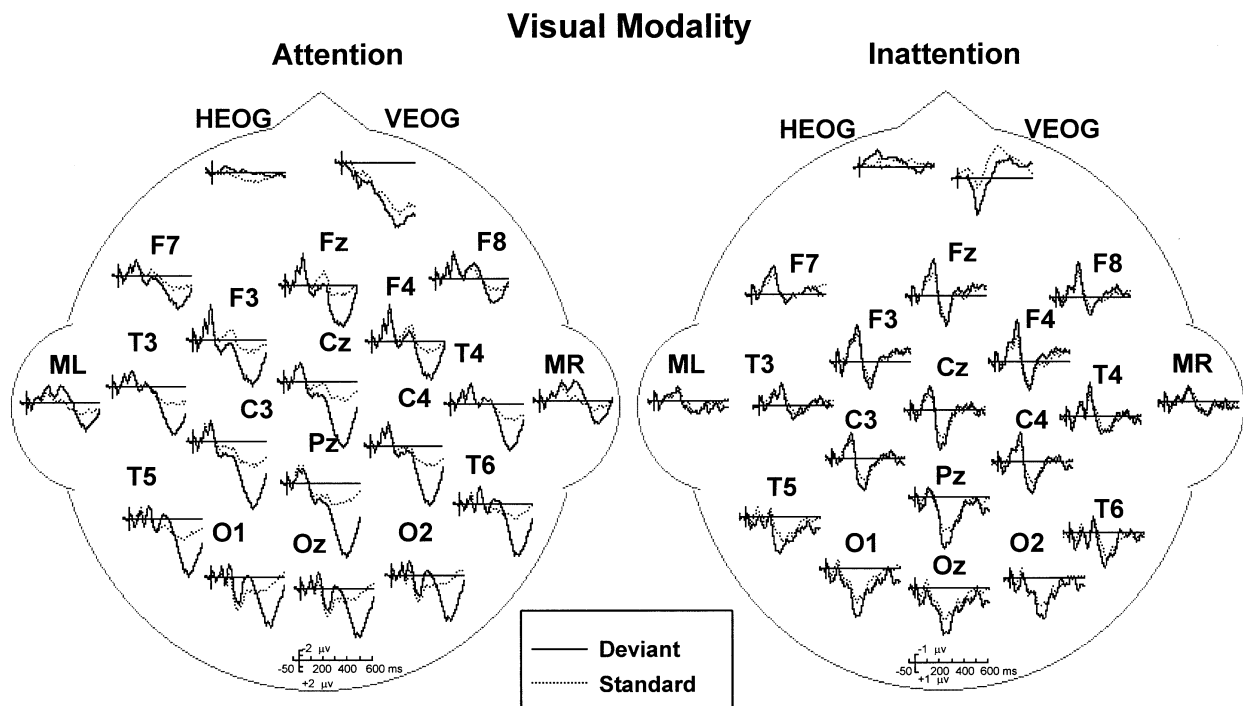


FIG. 4. Grand-average event-related potential to visual deviant (solid line) and standard (dashed line) stimuli under attention (left) and inattention (right) conditions. Abbreviations: HEOG, horizontal electrooculogram; VEOG, vertical electrooculogram.

TABLE 1
THE MAXIMUM AMPLITUDE (μV) OF BASIC COMPONENTS OF ERPS, THEIR PEAK LATENCY (ms) AND ELECTRODE SITES

Modality	Condition	Component	Standard Stimuli			Deviant Stimuli		
			Site	Amplitude	Latency	Site	Amplitude	Latency
Auditory	Attention	P1	Oz	1.38 \pm 0.34	67.0 \pm 7.02	O1	2.11 \pm 0.32	43.8 \pm 4.83
		N1	F4	-4.57 \pm 0.65	125.0 \pm 4.22	F4	-3.84 \pm 0.46	120.0 \pm 8.06
		P2	O1	3.78 \pm 0.55	201.7 \pm 13.15	O2	5.39 \pm 0.75	183.7 \pm 10.29
		N2	F4	-1.42 \pm 0.44	277.7 \pm 10.69	F4	-2.39 \pm 0.49	260.9 \pm 6.13
		P3				Pz	10.70 \pm 1.45	388.0 \pm 16.65
	Inattention	P1	T6	1.32 \pm 0.36	51.3 \pm 4.77	O1	1.37 \pm 0.50	44.0 \pm 4.39
		N1	F4	-4.62 \pm 0.46	115.3 \pm 5.69	F4	-5.80 \pm 0.63	126.3 \pm 5.46
		P2	O2	3.58 \pm 0.47	180.7 \pm 9.31	O2	4.33 \pm 0.55	177.7 \pm 6.88
		N2	F3	-2.42 \pm 0.34	277.7 \pm 8.41	F4	-2.59 \pm 0.74	291.0 \pm 7.69
Visual	Attention	P1	Oz	1.38 \pm 0.35	67.0 \pm 7.02	Cz	1.23 \pm 0.21	49.9 \pm 4.97
		N1	F4	-7.82 \pm 0.85	140.3 \pm 5.90	F4	-8.33 \pm 1.33	144.5 \pm 7.46
		P2	O1	7.90 \pm 1.41	202.4 \pm 7.60	O1	7.32 \pm 0.64	206.1 \pm 9.71
		N2	F4	-3.21 \pm 0.90	298.1 \pm 7.83	T6	-4.20 \pm 1.13	304.1 \pm 14.19
		P3				Pz	15.25 \pm 1.28	474.0 \pm 15.03
	Inattention	P1	T6	1.32 \pm 0.36	51.3 \pm 4.77	F3	0.84 \pm 0.40	49.1 \pm 5.26
		N1	F4	-4.77 \pm 0.60	169.3 \pm 8.44	F4	-6.65 \pm 1.00	160.7 \pm 7.72
		P2	O2	6.67 \pm 1.06	204.7 \pm 13.44	O1	8.30 \pm 1.32	241.3 \pm 11.68
		N2	F3	-1.18 \pm 1.05	325.5 \pm 14.48	Fz	-2.10 \pm 0.86	324.6 \pm 10.46

icant levels were reached in the interactions between electrode site and modality [$F(15,165) = 3.41, p < 0.013$], and between electrode site and attention [$F(15,165) = 3.47, p < 0.013$]. Also, there was a main effect of modality [$F(1,11) = 5.34, p < 0.041$]. Besides, comparisons of attention and inattention of all electrodes were conducted for the three time windows:

100–150 ms. Auditory DRN at Fz ($t = 2.75, p < 0.019$) and F4 ($t = 2.40, p < 0.035$) was significantly larger under inattention than attention. F3 ($t = 2.12, p < 0.057$) and Cz ($t = 2.13, p < 0.057$) nearly attained significant level. There was a similar tendency for the visual DRN at fronto-central scalp location, even if the difference did not reach a significant level.

150–200 ms. Auditory DRN was significantly larger when attended than unattended at T4 ($t = 2.23, p < 0.047$) and the same trend occurred at all other electrode sites except frontal area. Visual DRN was significantly larger under attention than inattention at Oz ($t = 2.22, p < 0.048$), and nearby posterior sites also showed this trend.

200–250 ms. Auditory DRN at F3, F7, F8, T4 ($t = 2.39$ – $2.99, p < 0.04$) and visual DRN at T5, O1, Oz, and O2 ($t = 2.31$ – $2.82, p < 0.045$) were significantly larger under attention than under inattention. The attended auditory DRN at Fz, F3, F4, F7, Cz, C3, C4, T3, and T4 were significantly larger than their counterparts of the visual modality ($t = 2.15$ – $5.09, p < 0.05$).

Figure 6 depicts the distribution of DRNs in auditory and visual modalities under attention and inattention. Each picture presents the topography of the mean amplitude in the labeled latency window. Under attention the auditory DRN1 was located at the right temporal regions with the subsequent DRN2 distributed broadly across the fronto-central, temporal, and parietal areas. The visual DRN1 and the DRN2 both peaked at occipital area, but the DRN2 had a broader distribution than that of the DRN1. Under inattention, both the auditory DRN1 and the visual DRN1 were largest in the frontal region.

DISCUSSION

Modified Paradigm

The present experiment used a modified oddball paradigm by integrating cross-modal presentation and delayed response to re-examine the effects of attention on MMN in both the visual and the auditory modalities. The basic design involved the presentation of a series of pictures and tones in random order, hence the term “cross-modal.” The stimuli of the unattended modality were presented during the interval between a stimulus and a response imperative signal of the attended modality. When the attended modality was visual, the auditory stimuli (tones) were interposed between visual stimulus (picture) and imperative signal (red cross). Subjects were required only to discriminate between the standard and deviant stimuli of the attended modality and decide with which hand (left or right) they would press the button when the attended stimulus was presented. Their response was produced only after the response imperative signal had occurred, hence the term “delayed response.” While waiting to press a button immediately as the imperative signal appear, subjects would fully engaged in the detection of the signal and would find it difficult to pay attention to irrelevant information of the unattended modality presented at this moment. This was so even though the ISI is relatively long in this paradigm. In other words, this paradigm forces attention that is normally only possible with the short-ISI paradigm. In addition, equivalent responses were required for both standard and deviant stimuli. Thus, deviant-related components (DRC), which were obtained by subtracting ERPs of the standards from those of the deviants, were less likely to be contaminated by target effects than in the usual oddball paradigm. This feature is particularly useful for exploring the possible effects of attention on the MMN when using long ISIs.

In this experiment, performing the relevant discrimination task was emphasized in instructions to the subjects. Furthermore, the

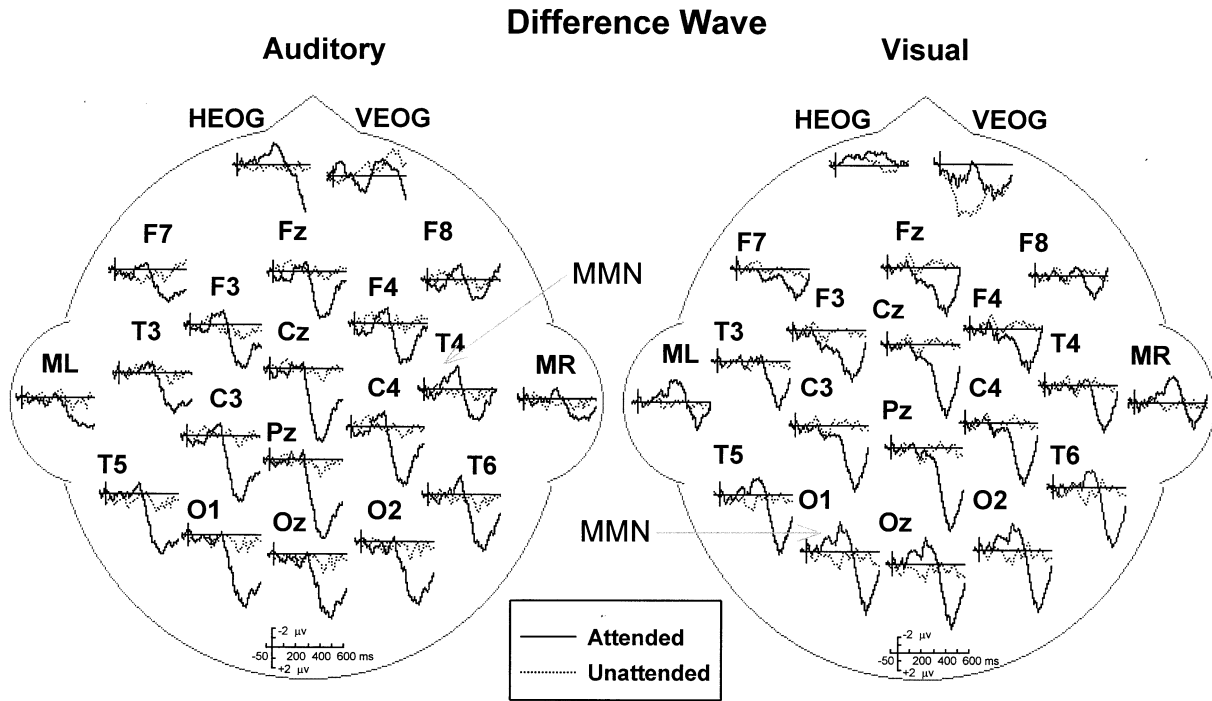


FIG. 5. Grand-average of the deviant-related components obtained by subtracting the event-related potential of standard stimuli from that of deviant stimuli under attention (solid line) and inattention (dashed line) conditions in auditory (left) and visual (right) modality. Abbreviations: HEOG, horizontal electrooculogram; VEOG, vertical electrooculogram.

response imperative signals were very small (for the visual modality), or faint (for the auditory modality), the number interposed unattended stimuli was pseudo-randomly assigned (0 to 2), and the interval between stimuli also was pseudo-randomly assigned (250 to 700 ms for standards, 652 to 700 ms for deviants). These controls were used so that subjects could not attend to irrelevant stimuli presented. As a result, we can both eliminate target effect (7) of attended MMN and obtain more pure unattended MMN.

Auditory MMN and Attention

Compatible with previous findings that there are separable brain generators in supratemporal and frontal cortex contributing

to the auditory MMN [12,22,27], we found the auditory maximum amplitude of attended auditory MMN at the temporal cortex and at the frontal cortex for unattended auditory MMN. Because both attended and unattended auditory MMN reversed their polarity at mastoids, the attended and unattended MMN should share these generators. As to the maximum amplitude of attended MMN was not present at frontal cortex, we speculated that it should be contaminated by N2b and possible P165. Even though we have eliminated the contamination of movement component in attended MMN by having the subjects to press buttons for both deviants and standards in the attention condition, the effects of attention specific components (N2b and possible P165) would play a remarkable

TABLE 2
THE MAXIMUM AMPLITUDES (μV) OF DEVIANT-RELATED COMPONENTS AND THEIR ELECTRODE SITES

Modality	Window (ms)	Attended		Unattended	
		Site	Amplitude	Site	Amplitude
Auditory	100–150	T4	-0.07 ± 0.29 (0.26 ± 0.30)	F4	-0.87 ± 0.63 (0.06 ± 0.52)
	150–200	T4	-0.95 ± 0.46 (0.37 ± 0.36)	F4	-0.37 ± 0.54 (0.42 ± 0.41)
	200–250	T4	-1.65 ± 0.51 (-0.21 ± 0.57)	F4	0.04 ± 0.68 (0.32 ± 0.49)
Visual	100–150	O2	-0.56 ± 1.00 (-0.17 ± 0.84)	F4	-0.68 ± 0.66 (-0.21 ± 0.38)
	150–200	O2	-1.20 ± 0.58 (-0.40 ± 0.56)	F4	-1.30 ± 0.68 (-0.25 ± 0.46)
	200–250	O2	-1.38 ± 0.68 (-1.00 ± 0.68)	F4	0.37 ± 0.72 (0.52 ± 0.26)

The amplitudes at mastoids of same side are showed in the parentheses.

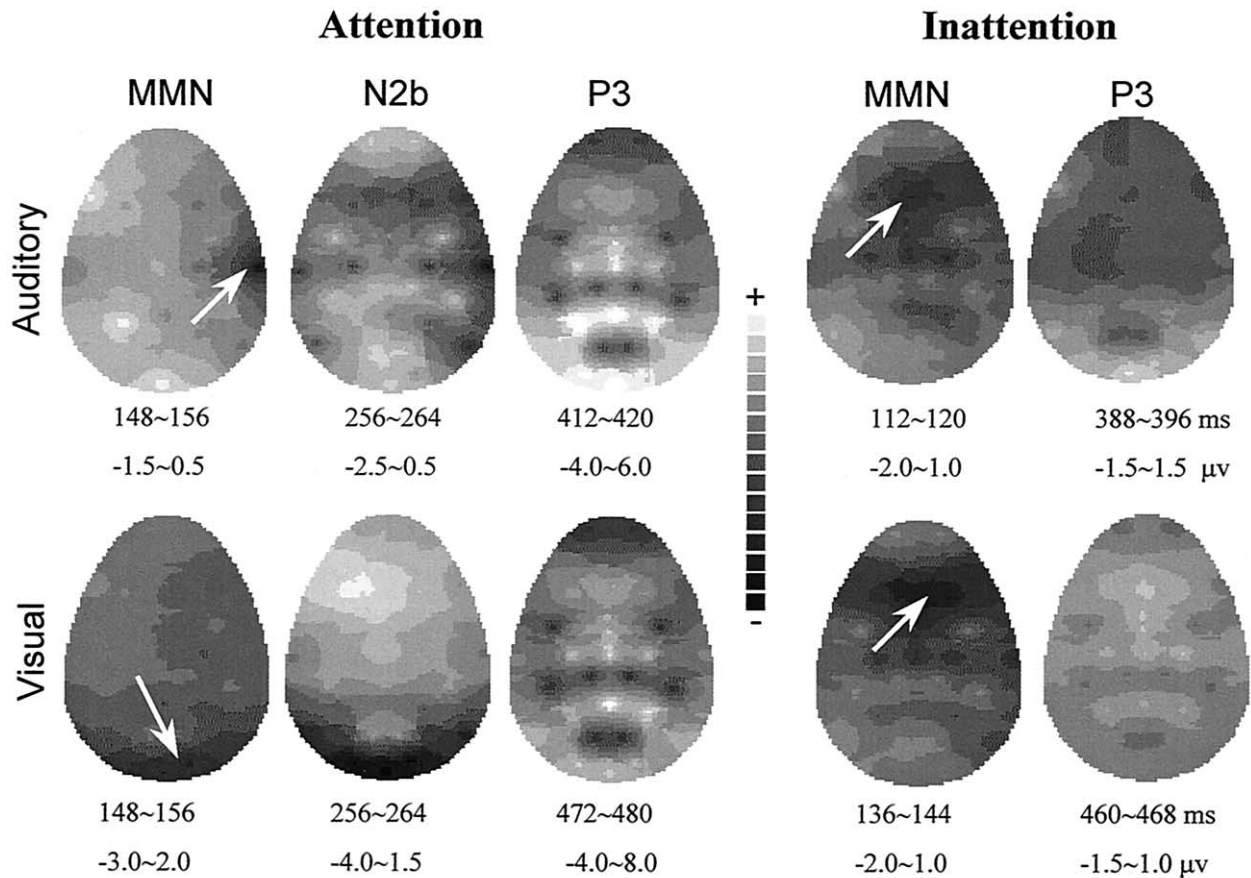


FIG. 6. The distribution of deviant-related components in auditory and visual modalities under the attended and unattended conditions. The numerals below every picture are the latency (ms) and amplitude (μV) range, respectively. Abbreviation: MMN, mismatch negativity.

role [22]. These components have different distributions on the scalp from MMN (e.g., N2b peaks at the central area) and would overlap with the attended MMN, altering its amplitude and thus its topography. In addition, in the comparison of attended and unattended MMNs at three time windows of MMN zone (100–150 ms, 150–200 ms, and 200–250 ms), the electrode sites at which the attended MMN was significantly larger than the unattended MMN, varied with the time window. This is an additional evidence suggesting that the attended MMN is not a pure component, but a mixed wave composed of genuine MMN, N2b and possible P165. The effect of attention on MMN may stem from the contamination of these overlapping components.

Auditory MMN and Visual MMN

As mentioned above, the present results suggest that for attended auditory stimuli, the deviant-related negativity (DRN) can be separated into an early DRN1 and a subsequent DRN2 component. Under inattention, only the DRN1 was elicited. The distributions of DRN1 and DRN2 differed, with DRN1 inverting at the mastoids regardless of attention, while DRN2 did not. Therefore, we associate DRN1 mainly with MMN, and DRN2 with a mixed wave of MMN and N2b [1,2,30,34,36].

DRNs in the visual modality shared some similarities to the auditory MMN components. Like the auditory DRN, the visual DRN was comprised of two components under attention, while

only the early deflection could be identified under inattention. Both the auditory DRN1 and the visual DRN1 reached maximal amplitudes over their respective primary sensory cortices or frontal regions. These common features between the visual DRN1 and the auditory MMN lead us to view the visual DRN1 as a possible analog of the MMN.

The Match Processing of Three Traces

The present cross-modal selective attention paradigm allows simultaneous recording of ERP effects of attention in the auditory and visual modalities. This provides more consistent background conditions, and thereby allowing ERP comparisons of different modalities to be more accurate. This sort of design has been explored in recent years [3,4,8,9,13,16,43,44]. In the present experiment, the DRNs were obtained under attention and inattention conditions in the two modalities. According to the match and mismatch principle [22], both the visual and auditory standard stimuli must maintain neural traces. In addition, the response imperative signal would also leave a trace, since it followed every attended standard or deviant stimulus and was repeated more frequently than the standard stimulus. Winkler et al. [40] addressed the possible simultaneous existence of two traces in the auditory modality. In order to make the current experiment work, at least three simultaneous multiple modality memory traces must be provided to support the automatic processing of MMN.

The limit to the number of active memory traces, and the issue of whether the traces of different modalities interact with each other will require further investigation.

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