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Research report

Cross-modal selective attention to visual and auditory stimuli modulates endogenous ERP components

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Abstract

In two experiments event-related potentials (ERPs) to visual and auditory stimuli were measured in 12 healthy subjects. A cross-modal and delayed response paradigm was used that allows ERPs to be obtained separately to attended and unattended stimuli under conditions in which unattended stimuli are less likely to be covertly or randomly attended. The results showed: (1) N1 enhancement with attention for standard stimuli in auditory and visual modalities and for deviant stimuli in the visual modality; (2) The onset time and scalp distribution of both the N1 for attend condition and Nd1 were similar regardless of standard or deviant stimuli in the auditory and visual modality; the onset time of Nd1 elicited by auditory and visual deviant stimuli was earlier than that of the unattended N1, and their scalp distributions were different; and (3) The Nd1 components elicited by auditory and visual deviant stimuli were distributed over the respective primary sensory areas, but Nd1 components evoked by auditory and visual standard stimuli were distributed over the frontal scalp. These results suggest that the attended N1 enhancement is primarily caused by a component with endogenous origins and that the early attention effect occurs before the exogenous components. The results support the view that the cross-modal attention to deviant stimuli modulates modality-specific processing in the brain, whereas attention to standard stimuli affects modality-nonspecific or supramodal brain systems.

Keywords: Event-related potential; Selective attention; Modality specific processing; Supramodal brain system; Negativity difference; N1; Cross-modal and delayed response paradigm

1. Introduction

Several components of the event-related potential (ERP) occurring between 100 and 200 ms after a stimulus have been found to be associated with the process of selective attention. For example, in a pioneering study using a dichotic listening task, Hillyard and colleagues [13] observed an enhancement of the N1 component (peak latency of about 100–150 ms) for stimuli presented in the attended ear compared to those presented to the ignored ear. They suggested that the amplitude of the N1 reflects the early selection of information from a particular location. However, Näätänen et al. [24] proposed that the difference between the ERPs for attended and unattended channels cannot be considered only in terms of the amplitude variation of peak with a latency between 100–150 ms; rather, the difference reflects the superimposition of another negative component lasting several hundred milliseconds. This negative difference (Nd) wave was termed the ''processing negativity'' (PN). Among other factors the difficulty of the discrimination between attended and unattended channels affects PN amplitude and latency [11,21–23,25].

Näätänen et al. [21,22] argued that the ''N1 effect'' was caused by an endogenous PN component overlapping with exogenous ERP components. In their studies, they used a similar paradigm to that of Hillyard et al. [13] but with a longer interstimulus interval (ISI) of 800 ms. They found that the N1 amplitude was unaffected by attention and that the N1 peak was followed by a low-amplitude (1–2 μv) negative displacement beginning at 150 ms during the descending limb of the N1 deflection [22]. Woldorff and Hillyard [30] criticized Näätänen's interpretation on the grounds that the ISI was so long that subjects could, despite instructions, pay attention to the unattended stimuli. In fact, it could be argued that when single stimuli are

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separated by long intervals, it is difficult *not* to pay attention to a stimulus that one is instructed to ignore. Hence a long ISI may not be a reliable and pure manipulation of a subject's direction of attention, whereas a short ISI forces the subject into a mode of attending only to the relevant stimulus. But, as pointed out by Näätänen [20], the use of a short ISI creates another problem: any endogenous ERP component associated with selective attention can be masked by the exogenous component evoked by the same stimulus: Näätänen [20] argued that in Hillyard et al.'s studies, the use of a short ISI resulted in the overlap of the endogenous PN and the exogenous N1.

We are left with an impasse. The use of a long ISI allows for the separation of endogenous and exogenous components; this is desirable because the theoretical interpretation of selective attention effects in the brain depends importantly on which type of component is affected. On the other hand, only a short ISI allows selective attention to be manipulated reliably so that irrelevant stimuli are not attended.

Up to now, the problem of whether the early Nd attention effect reflects a N1 modulation or an endogenous PN component remains unresolved [1,18]. In the present study we attempted to resolve this problem by using a newly developed modification of the standard oddball task, a cross-modal, delayed response paradigm [29,17]. In this method, a long ISI is used to allow for separation of exogenous and endogenous ERP components. The basic design involves presentation of a series of stimuli-pictures and tones in two sensory modalities-in a random sequence; hence the term ''cross-modal''. Stimuli in an unattended channel are presented during the interval between a stimulus in the attended channel and a response imperative signal. The task of the subject is first discriminate between the standard and deviant stimuli in the attended channel, but only when the response imperative signal appears; hence the term ''delayed response''. The task was emphasized to subjects and response imperative signals were designed to be very small (for visual modality) or very weak (for auditory modality). Therefore, even though the ISI is long, subjects find it difficult to pay attention to the irrelevant stimuli, so that attention is effectively focused on the relevant stimulus.

2. Methods

2.1. Subjects

Twelve undergraduate students aged 19–22 (8 male, 4 female) were paid to serve as subjects in the experiment. All of them were right handed as measured by the Reitan's Test [5] with normal hearing and vision or corrected visual acuity and without history of neurological or mental disease.

2.2. Stimuli

The experimental instrument was an ERP workstation (STIM and SCAN 3.0, Neuro Scan, Herndon, VA, USA). The cross-modal, delayed-response task consisted of the following stimuli: standard and deviant stimuli in the attended modality; response imperative signal; and standard and deviant stimuli in the unattended modality. The visual standard stimulus was a color scenery photograph screen (4.3 cm $\times$ 2.8 cm). The visual deviant stimulus was the same picture with increased contrast. The imperative signal for attending to visual stimuli was a small red cross (0.5 cm $\times$ 0.5 cm). Every visual stimulus/signal was presented at the center of the computer screen. The auditory standard stimulus was an 800 Hz tone pip. The auditory deviant stimulus was a 1000 Hz tone pip. Both standard and deviant stimuli had a duration of 30 ms with 5 ms rise and 5 ms fall times. Tones were presented binaurally over earplugs at an intensity of 60 dB.SPL. The imperative signal for attending to auditory stimuli was a click (2 ms, 18 dB.SPL). For each modality of stimulus presentation, the standard stimuli were presented for 306 trials and the deviant stimuli for 65 trials (relative probabilities of 82.5% and 17.5%, respectively). For the attended modality, every attended standard or deviant stimulus followed a response imperative signal. In between every stimulus and the response imperative signal of the attended modality, 0–2 stimuli of the unattended modality were randomly inserted. The ISI was varied pseudo-randomly between 250 to 700 ms (onset to onset). Both the presentation order of the standard and deviant stimuli in each modality and the order of the stimuli of two modalities were pseudo-random (see Fig. 1).

2.3. Task and procedure

Subjects were seated in front of a table with a chinrest to inhibit head movements in a sound-attenuated room. Earplugs were inserted in the subject's ears. The distance from eyes to screen was 1.2 m. Each subject carried out two blocks of experiments and 5 min of rest separated the blocks. In the two blocks, the standard and deviant stimuli were similar but the modality attended and imperative signal were different. Subjects reacted to standard and deviant stimuli by pressing a button with the thumb of their left and right hands, respectively. The use of the left and right thumbs for standard and deviant stimuli alternated so that half the subjects responded to the standard stimuli with the right thumb, and half with the left thumb, and vice versa for the deviant stimuli. Thus there was no difference of target and non-target between standard and deviant stimuli.

2.3.1. Experiment 1, attend visual modality

As shown in Fig. 1 (top), the subjects were instructed to pay attention to the pictures rather than to the tones. They

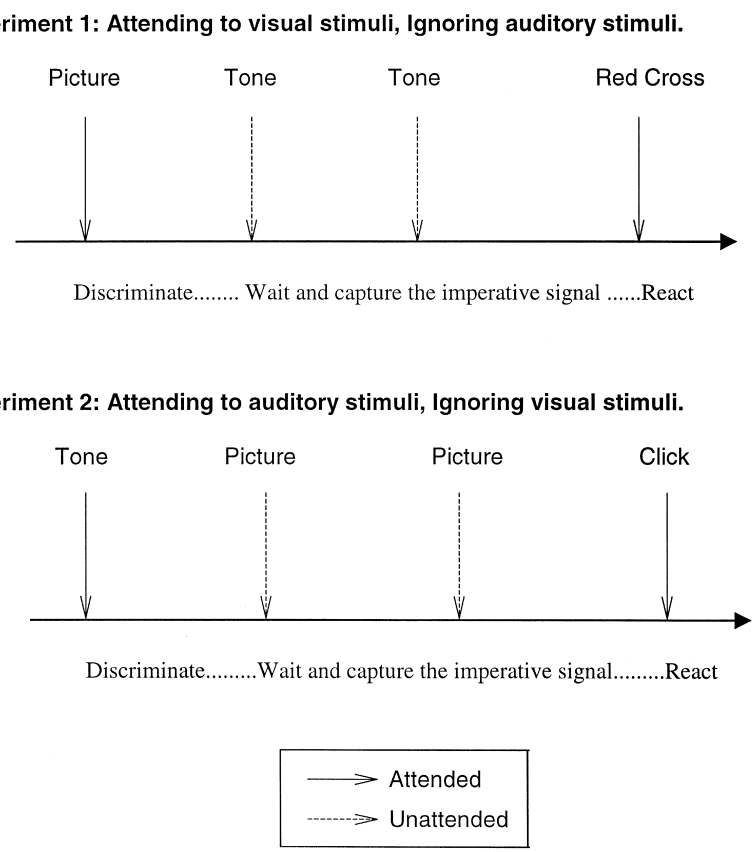

Fig. 1. The paradigm. Shows one trial. The whole sequence consists of 433 trials. The pictures and tones were either standard or deviant stimuli.

were asked to be prepared to press the button with one thumb when the standard picture appeared and with the other thumb when the deviant picture appeared. When the response imperative signal (red cross) appeared, they had to press the button corresponding to the category (standards/deviant) of the stimulus in the attend modality as soon as possible.

2.3.2. Experiment 2, attend auditory modality

The subjects were instructed to fixate on the central point of the screen but to attend to tones rather than to the pictures. They were asked to be prepared to press the button with one thumb when the standard tone appeared and with the other thumb when the deviant tone appeared (see the bottom of Fig. 1). When the response imperative signal (click) appeared, they had to press the button corresponding to the category (standards/deviant) of the stimulus in the attend modality as soon as possible.

Central fixation was confirmed by recording the subject's electrooculargram (EOG). Several practice trials were run until the subjects' performance was correct and skilled.

2.4. EEG Recording

The electroencephalogram (EEG) was recorded using an electrode cap (Electrode-cap International, Eaton, OH, USA) from 16 scalp electrodes placed at Fz, F3, F4, F7, F8, Cz, C3, C4, T3, T4, Pz, T5, T6, Oz, O1, and O2, with the reference on the left and right mastoids (see Fig. 2). The vertical EOGs were recorded with electrodes placed above and below the right eye. The horizontal EOGs were recorded with electrodes placed near the external canthus of each eye. The electrode impedance was maintained below 5 k · The EEG and EOG were amplified with filter 0.1–40 Hz and continuously sampled (250 Hz/channel) for off-line analysis.

2.5. Data analysis and statistics

2.5.1. Average

The averaged epoch was 652 ms including a 52 ms prestimulus baseline. Since more standard stimuli were presented than deviants (306 vs. 65), 65 trials standard trials were selected for averaging to equalize the signal-to-noise ratios for the two trial types. In addition, the ISI of the 241 trial standards which were not averaged were shorter than the epoch (652 ms), hence only the ISI of the averaged 65 trials standards were equated or more than 652 ms, so that the experimental time was saved and the subjects' tiredness was decreased. EOG artifact was automatically corrected by Neuro Scan software [27]. Trials with contamination from amplifier clipping, bursts of EMG activity, or peak-to-peak deflection exceeding 100 μv were

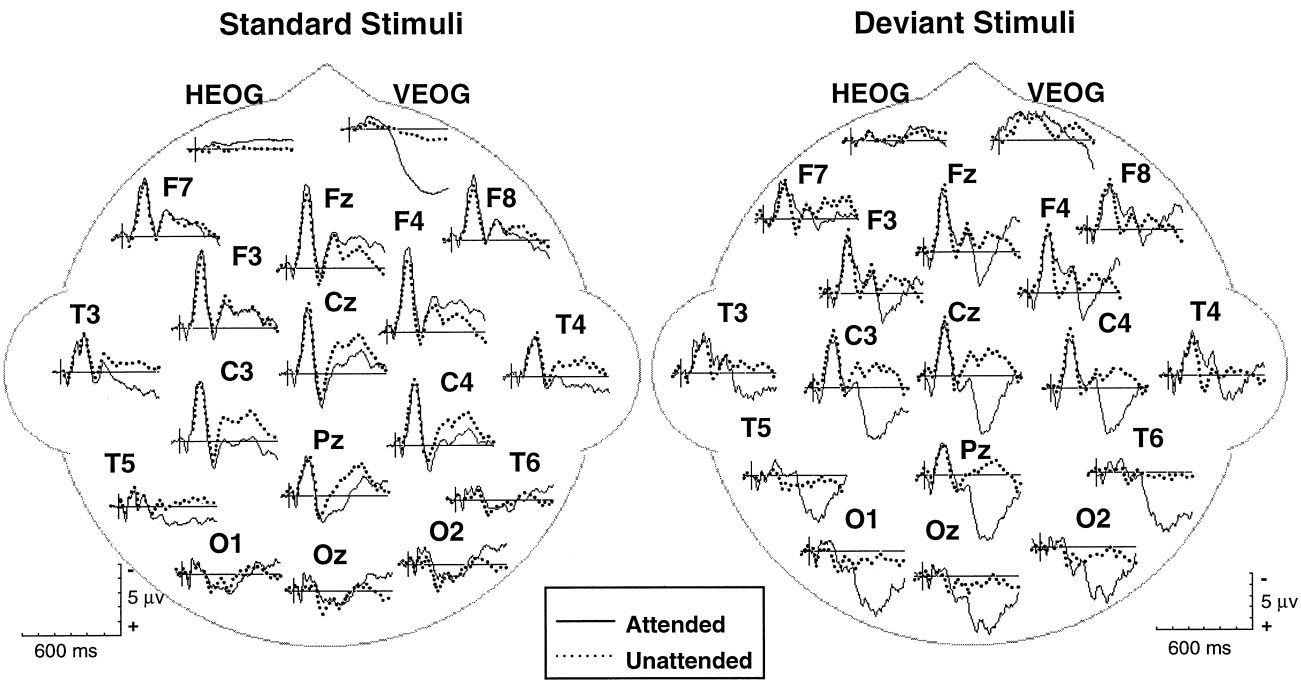

Fig. 2. Grand-average ERPs to auditory standard stimuli (left) and auditory deviant stimuli (right) in attended (solid line) and unattended (dashed line) conditions.

excluded from averaging. The EEG evoked by standard/deviant stimuli, in the auditory/visual modalities under attention and inattention were averaged separately, and eight ERP waveforms were obtained. The actual number of individual trials per waveform ranged from 53 to 65 (mean 58).

2.5.2. Subtraction

The difference waves were obtained by subtracting ERPs in the unattended condition from those in the attended condition. In the present report, we focus on the exogenous N1 and the endogenous early negative difference (Nd1) ERP components.

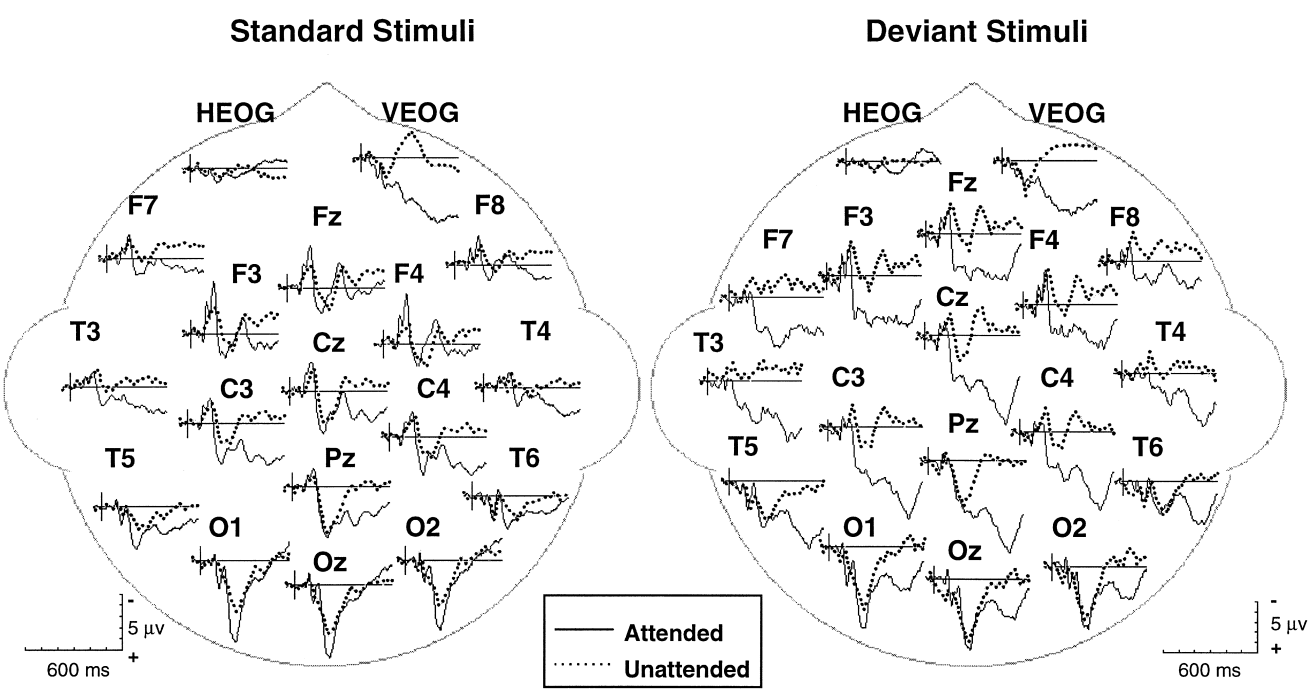

Fig. 3. Grand-average ERPs to visual standard stimuli (left) and deviant stimuli (right) in attended (solid line) unattended (dashed line) conditions.

2.5.3. Measurement

The measurement range of the peaks of ERP components were identified with the methods used in previous reports [2,20]. In the auditory modality, the mean amplitudes of N1 and Nd1, relative to the prestimulus baseline, were measured over consecutive 20 ms time windows from 60 to 180 ms poststimulus. The onset latency was measured at the point of intersection of N1/Nd1 and the baseline. Results were expressed as mean ± standard deviations (SD).

2.5.4. Statistics

For the latencies and amplitudes of ERP components, three-way or four-way analyses of variance (ANOVAs) with repeated measurements were conducted. The factors were attention (two levels: attend and unattended), stimulus (two levels: standard and deviant stimulus), modality (2 levels: auditory and visual modality), components (three levels: attend N1, unattended N1 and Nd1) and electrodes site (16 sites). The *P*-values were corrected by the Greehouse–Geisser method. In comparing the scalp distributions of different components, the data were first normalized to control for distribution · electrode interactions resulting simply from differences in component amplitude [19].

3. Results

3.1. Behavioral data

In the attended condition, reaction times (RTs) to auditory standard and deviant stimuli were 398.9 · 69.7 ms and 386.8 · 68.2 ms, respectively, and the corresponding accuracy (percentage of correct responses) were 92.8 · 7.1% and 86.2 · 11.2%, respectively. RTs to visual standard and deviant stimuli were 418.1 · 50.1 ms and 402.8 · 49.7 ms, respectively, and the corresponding accuracy were 90.6 · 4.9% and 86.4 · 16.4%, respectively. Two-way ANOVA (modality · · stimulus) of RT did not yield any significant difference between the auditory and visual modalities ($F_{1,11} = 3.34,\ P < 0.095$) or between standard and deviant stimuli ($F_{1,11} = 4.13,\ P < 0.067$). Two-way ANOVA (modality · · stimulus) of accuracy also did not show a significant difference between the auditory and visual modalities ($F_{1,11} = 1.66,\ P < 0.225$) or between standard and deviant stimuli ($F_{1,11} = 2.96,\ P < 0.113$). Interactions were non-significant for each performance measure. These results indicate that task difficulty was similar for auditory and visual stimuli and for standard and deviant stimuli.

Table 1
Mean amplitudes (μv) of attended N1, unattended N1 and early negative difference (Nd1) at largest amplitude sites to standard and deviant stimuli in visual and auditory modalities
Amp = Amplitude; Devi = Deviant Stimuli; Mod = Modal; Stan = Standard Stimuli; Stim = Stimuli.

Mod	Stim	Time (ms)	Attended N1		Unattended N1		Nd1	
			Site	Mean Amp.	Site	Mean Amp.	Site	Mean amp.
Visual	Stan	60	Pz	−0.04 (0.86)	T3	−0.42 (0.68)	T4	−0.08 (0.82)
		80	Oz	−0.87 (2.34)	T3	−0.50 (0.39)	Oz	1.13 (2.20)
		100	F4	−2.07 (2.37)	F3	−1.33 (1.01)	Fz	−1.19 (2.80)
		120	F3	−3.04 (2.84)	F3	−2.04 (1.49)	Pz	−1.17 (2.75)
		140	F3	−3.99 (3.01)	F3	2.08 (2.07)	Oz	−2.90 (4.40)
		160	T4	−1.19 (2.09)	F3	−1.44 (2.73)	T6	−0.93 (0.96)
	Devi	60	T4	−0.07 (1.11)	Fz	−0.35 (1.84)	Oz	−0.97 (1.15)
		80	Oz	−1.00 (2.34)	F7	−0.44 (1.31)	Oz	−0.48 (1.75)
		100	Fz	−1.72 (2.67)	F4	−1.19 (2.46)	Cz	−1.07 (2.95)
		120	Fz	−2.47 (2.63)	F3	−1.63 (2.89)	Oz	−2.75 (5.00)
		140	F4	−3.39 (4.05)	Fz	−2.90 (3.29)	F4	−1.99 (2.55)
		160	T4	−0.33 (2.55)	Fz	−2.59 (4.10)	Oz	−1.14 (2.99)
Auditory	Stan	60	O2	−1.09 (0.84)	Pz	−1.01 (1.18)	O2	−0.45 (1.28)
		80	C3	−2.11 (1.50)	C3	−1.82 (1.85)	F4	−0.75 (1.31)
		100	Fz	−5.03 (2.27)	Fz	−4.21 (1.89)	F4	−1.05 (1.74)
		120	F4	−5.72 (1.36)	F4	−4.88 (1.66)	F4	−0.83 (1.09)
		140	F4	−4.25 (1.77)	F3	−3.54 (1.40)	F4	−1.13 (1.45)
		160	F8	−2.39 (1.37)	F8	−1.62 (0.95)	F4	1.01 (1.52)
	Devi	60	O2	−1.30 (1.58)	Pz	−1.05 (1.36)	F7	−0.47 (1.35)
		80	T3	−2.38 (2.10)	C3	−1.97 (1.05)	T5	−1.14 (2.13)
		100	Fz	−4.54 (2.49)	Fz	−5.01 (1.72)	T5	−0.73 (2.08)
		120	F4	−5.13 (2.02)	F4	−5.95 (2.60)	T5	−0.70 (1.80)
		140	F4	−4.38 (2.38)	Fz	−3.73 (1.93)	F4	−0.92 (2.47)
		160	F8	−2.66 (2.07)	F8	−2.48 (1.79)	T6	−1.40 (1.63)

3.2. N1 Component

The grand-average ERPs elicited by standard and deviant auditory stimuli for the attended (solid line) and unattended (dashed line) conditions are shown in Fig. 2. Those elicited by visual stimuli are shown in Fig. 3.

The typical P3 components were only found under for attended deviant stimuli in both the auditory and visual modalities. The N1, P2 and N2 components were elicited under all conditions in both modalities. The largest N1 peak in the auditory modality occurred 120–140 ms after stimulus onset and distributed at the right frontal (F4) site for both standard and deviant stimuli in both attended and unattended conditions. The biggest N1 peak in the visual modality occurred 140–160 ms after stimulus onset and was located over the left frontal scalp (F3) for both standard and deviant stimuli in both attended and unattended conditions (see Figs. 2 and 3, and Table 1).

Four-way ANOVA with repeated measurements were carried out for the mean amplitude during 120–140 ms and 140–160 ms. During 120–140 ms, the mean amplitudes in the auditory modality (mean -2.85 μv) were higher ($F_{1,11} = 32.291$, $P < 0.0001$) than that in the visual modality (-0.46 μv). The main effect of electrode site was significant ($F_{15,165} = 55.242$, $P < 0.0001$). The interaction (Attention × stimulus × site), $F_{15,165} = 4.279$ ($P < 0.0136$) that showed the difference between attended and unattended stimuli for the deviant or standard stimulus varied across sites. During 140–160 ms, a significant difference was also found between the auditory (-2.02 μv) and visual (-0.70 μv) modality ($F_{1,11} = 6.958$, $P < 0.0231$), and among sites ($F_{15,165} = 35.154$, $P < 0.0001$). Furthermore, the mean amplitude under the attended condition (-1.66 μv) tended to be larger ($F_{1,11} = 3.694$, $P < 0.0809$) compared to the unattended condition. The interaction also occurred among attention, stimulus and site, $F_{15,165} = 5.070$, $P < 0.0044$.

3.3. Early negative difference (Nd1)

Fig. 4 presents the difference components obtained by subtracting ERPs elicited by unattended stimuli from those elicited by attended stimuli. Table 1 also shows the site of the largest peak and their values of mean amplitudes. The largest Nd1 peak elicited by standard stimuli in the auditory modality was -1.30 μv at F4 during the time window 140–160 ms poststimulus. The Nd1 elicited by deviant stimuli occurred earlier (160–180 ms) with the largest peak mean amplitude of -1.40 μv at T6. In the visual modality, the largest Nd1 evoked by standard stimuli was -2.90 μv at Oz during 140–160 ms and -1.19 μv at Fz during 100–120 ms. The largest Nd1 evoked by visual deviant stimuli was -2.75 μv at Oz during 120 -140 ms. The Three-way (modality × stimulus × sites) ANOVA with repeated measurements were conducted during 120–140 ms and 160–180 ms. Only an interaction between modality and sites was significant during 140–160 ms ($F_{15,165} = 4.203$, $P < 0.0158$) and 160–180 ms ($F_{15,165} = 5.569$, $P < 0.0017$). At occipital and lateral temporal sites,

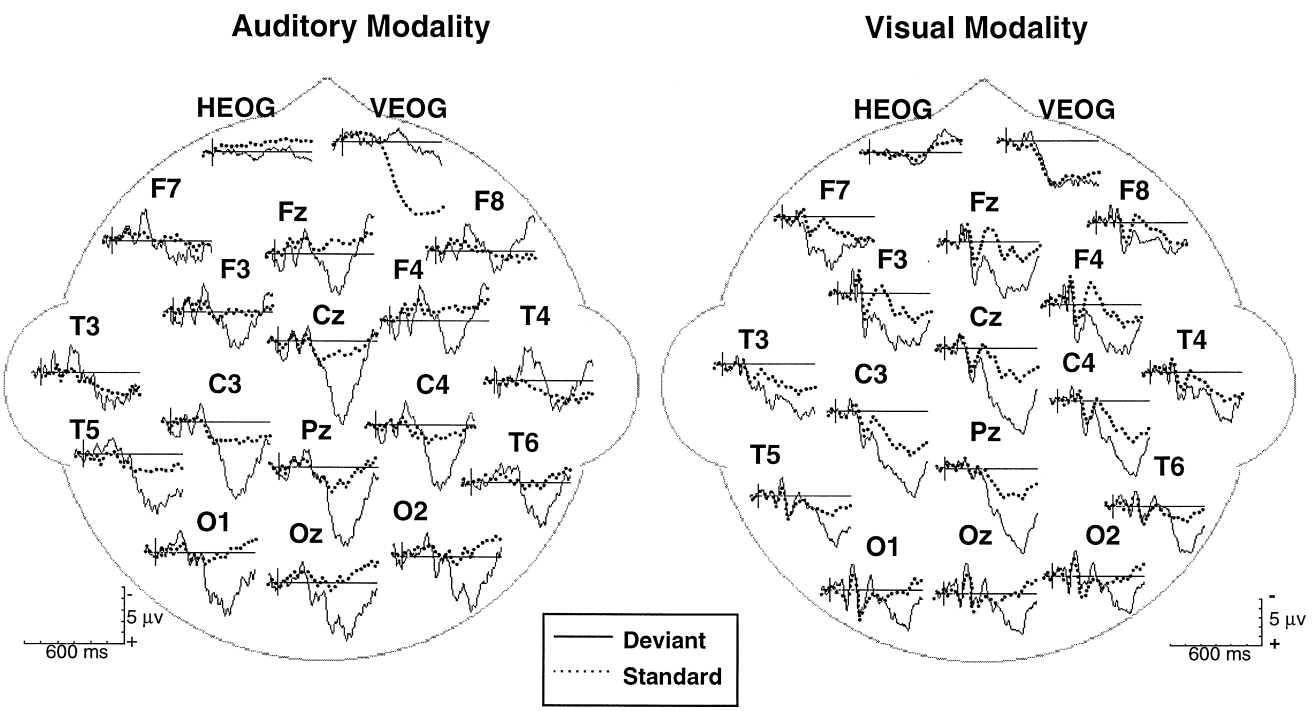

Fig. 4. Grand-average of the difference waves obtained by subtracting the attended ERPs from the unattended ERPs for the standard (dashed line) and deviant (solid line) stimuli in auditory (left) and visual (right) modalities.

(Oz, O1 O2, T5 and T6), the negativity elicited by the deviant stimuli was enhanced more than that by the standard stimuli. But at frontal, central and parietal scalp sites, the mean voltage indicated positivity or larger positivity (as shown as Fig. 4).

3.4. Comparing onsets of N1 and Nd1

Four-way repeated ANOVA (modality × component × stimulus × sites) showed that modality ($F_{1,11} = 18.86$, $P < 0.001$), ERP components ($F_{2,22} = 16.27$, $P < 0.0001$), and stimuli ($F_{1,11} = 5.19$, $P < 0.044$) had significant main effects. These showed that onset time in the auditory (mean 63.2 ms) was earlier than that in the visual modality (73.6 ms), the onset of unattended N1 (58.7 ms) was earlier than attend N1 (74.7 ms) and Nd1 (71.8 ms). Moreover, there was a significant interaction between ERP components and stimulus types ($F_{2,22} = 65.51$, $P < 0.0001$). For the attended N1, the onset elicited by deviant stimuli (57.2 ms) was much earlier than that by standard stimuli (92.2 ms). But for the Nd1, the onset time by deviant stimuli (81.1 ms) was later than that by standard stimuli (62.5 ms). For the unattended N1, the onset time was similar (deviant: 57.6 ms; standard: 59.8 ms).

Fig. 5 illustrates the distribution of the N1 under attended and unattended conditions and the Nd1 in the auditory and visual modalities. The topography of the mean amplitude in a latency segment (8 ms) is displayed below each picture. The topography during 72–80 and 84–92 ms (the second and third column) showed that the onset time of the attended N1 occurred as same as Nd1 but earlier than that of unattended N1 regardless of auditory and visual modality, or standard and deviant stimuli. In addition, the distributions of the attended N1 and the Nd1

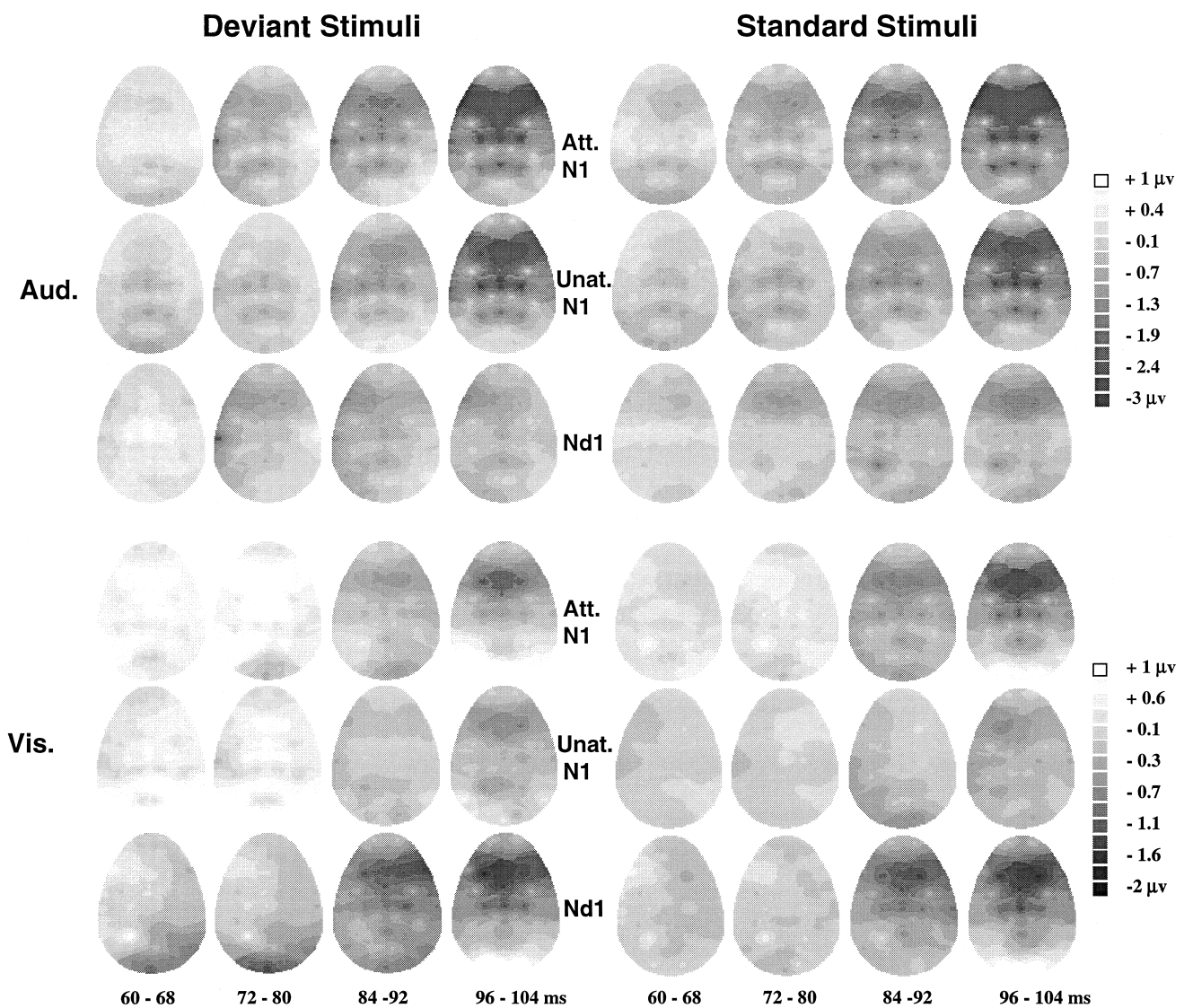

Fig. 5. The scalp topography of the attended N1, unattended N1 and Nd1 (time window 60–104 ms with interval 8 ms). Note: Att. = Attended, Aud. = Auditory, Nd1 = early Negative difference, Vis. = Visual, Unat. = Unattended

were basically identical but both they were different with that of the unattended N1 during this period. Both the attended N1 and the Nd1 elicited by auditory deviant stimuli were located at the left temporal site, those by visual deviants at occipital area, and those by auditory and visual standard stimuli over frontal scalp. However, the unattended N1 almost distributed at frontal area regardless of auditory and visual modality, or standard and deviant stimuli.

4. Discussion

There is a long-lasting controversy regarding the temporal locus and cortical origin of selective attention effects on ERP components of the human brain. The issue is whether the early Nd associated with selective attention is caused by a genuine enhancement of the exogenous N1 component [13], or by an endogenous PN component [21,22] overlapping with the exogenous N1, which is unaffected by attention [1]. A major problem with previous studies is that they have either used a short ISIs in which case exogenous and endogenous components cannot be differentiated, or a long ISI under conditions where attention to irrelevant stimuli cannot be prevented.

In the present study, we employed a newly developed cross-modal, delayed-response paradigm to overcome these difficulties and address this issue directly. The paradigm uses a long ISI and a response imperative signal, thereby allowing a separate examination of the exogenous N1 and the endogenous PN, as well as a reliable manipulation of the subject's allocation of attention to relevant and irrelevant stimuli. The task components in this paradigm consist of selective attention, discrimination, preparedness, and response. Stimuli in the unattended modality were presented during the interval in which subjects focused their attention on searching for imperative signals for pressing the button as soon as possible. In other words, subjects' tasks had not yet been completed when stimuli were presented in the unattended modality, so that it would be unlikely for them to transfer their attention to the irrelevant stimuli. Reliable and pure inattention to the irrelevant stimuli was therefore ensured in this situation.

Teder et al. [28] reported that when the ISIs were shorter, the differences between the attended N1 and the unattended N1 were larger, and the early Nd peak latencies were earlier. But they did not statistically compare the difference between attended and unattended N1. The results from the present study showed that the attention for the standard stimuli in auditory and visual modality and for the deviant stimuli in visual modality elicited the enhancement of N1. These results indicate that the ''N1 enhancement effect'' under the condition of longer ISI and higher unattended purity really took place in cortically specific areas. Researchers from the other laboratories using the cross-modal paradigm also found that the N1 in the attention condition was larger than that in the unattended condition over temporal–occipital scalp [3,10,31]. There are two different interpretations of the result. Hackley et al. [10] considered that this N1 enhancement was exogenous, but Näätänen [20] argued that it is hard to conclude that the enlarged N1 at temporal–occipital sites was the exogenous enhancement.

We can understand that the N1 to unattended stimuli is an exogenous component and the Nd1 obtained by subtracting unattended ERPs from attended ERPs is an endogenous component. On this premise, we can further analyze the following results from our present study. First, the results showed that the onset time and scalp distribution of both attentive N1 and Nd1 were similar regardless of standard or deviant stimuli in the auditory and visual modality. Second, the onset time of Nd1 elicited by auditory and visual deviant stimuli was earlier than that of the unattended N1, and their scalp distributions were different. Third, the scalp distribution of the unattended N1 and Nd1 elicited by auditory and visual standard stimuli was over frontal scalp sites, which suggests the same origins of these signals. However, the Nd1 onset was earlier than the unattended N1 and thus did not confirm that the exogenous N1 was related to the Nd1. In total, these results suggest that the N1 enhancement in attention is mainly caused by an endogenous component rather than a genuine exogenous component.

In addition, as foregoing, the onset time of the Nd1 was identical with the attended N1 but earlier when comparing with the unattended N1. These data suggest that attention effects occurred before did the exogenous component under unattended condition, and meant the stimulus input under attention condition preferentially enters the attentive channel and yield early attention effects but the stimulus input in the unattended channel is delayed to a certain extent. With regards to the basic problem of early and late selective attention theory, the present experiment results provide strong evidence supporting the early selective attention theory.

Another purpose of the present study was to observe the scalp distribution of ERPs. There was a contrary proposition regarding modality specificity supported by behavior experiment [4,9] or supramodal mechanism supported by electrophysiological results [8,10,14,31,32]. As shown in the Figs. 4 and 5, during the onset latency period, the Nd1 peak elicited by auditory deviant stimuli was located at the left temporal scalp and that the Nd1 peak elicited by visual deviant stimuli was distributed at the occipital scalp. However, the largest Nd1 evoked by standard stimuli was only distributed at the frontal scalp regardless of which modality. The results support the view that the cross-modal attention to deviant stimuli modulates modality-specific processing in the brain, whereas attention to standard stimuli affects modality-nonspecific or supramodal brain systems.

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