Event-related potentials during preattentional processing of color stimuli

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To investigate whether visual mismatch negativity (VMMN) could be evoked in the preattentional condition, we designed an oddball task with different red color stimuli in visual modality. Electroencephalograms were recorded and VMMN and N2–P3 complex waveforms were analyzed. The results indicated that VMMN generated at occipital region with 110–180 ms peak latency, and N2b and P3a were just following VMMN with 170–300 and 400–450 ms latencies, respectively. VMMN, N2b, and P3a components were all affected by the amount of deviations between the standard stimuli and deviant stimuli. This study further proved that VMMN existed under hard detection condition in color-related visual modality, and this design distinguished early sensory processing and late sensory processing successfully as well. *NeuroReport* 19:1221–1225
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Introduction

Mismatch negativity (MMN) is an important component of event-related potentials (ERPs), and it is computed by subtracting the neural responses to standard stimuli from the responses to deviant stimuli [1]. In the early studies of MMN, it was thought to be specific to the auditory modality [1], but later researches suggested that auditory MMN-like components could also be investigated in the visual modality, that is, visual MMN (VMMN) [2,3]. VMMN has been explored in several ways: color, shape, motion direction, and so on (see review paper, [3]). Earlier results of VMMN studies have some differences with the findings of auditory MMN (AMMN) studies: first, it is widely regarded that VMMN exhibits a more occipital scalp distribution [4] whereas AMMN has a more fronto-central distribution and mainly in the auditory cortex [1]. Second, VMMN might need larger deviant condition to be elicited than AMMN [3].

It is known that color stimuli are processed automatically, even without conscious awareness. Researchers have been trying to study brain's automatic processing of color changes recognition [4–8]. Czigler *et al.* [4] used colored grating patterns in a passive oddball condition and a multicolor condition to explore VMMN in the color domain, and they reported that deviant stimuli induced similar negativity over posterior areas in both conditions. Some other studies also used easily detected color stimuli (red and green) to study characteristics of VMMN [6,8]. Czigler *et al.* [6] used repeated color visual stimuli (some of the stimuli sequences were regular repetitions, and some were irregular), and they recorded two negativity latencies (100–140 and 220–260 ms). The first latency was related to neural sensitivity to stimulus repetition and the second latency to sequential regularity.

MMN represents the preattentively neural processing, and the following N2–P3 complex waveform always relates to attentive neural processing [9,10]. It is known that MMN is a component of N2 family, and it is often mixed with N2b in latency. The two ERP components could be distinguished by different neural generations, and MMN could be evoked even without conscious awareness and N2b was always induced in attentional condition (with conscious awareness).

In this study, we used hardly detected color stimuli as standard and deviant stimuli to induce VMMN and we wanted to prove that VMMN is also more evidently evoked in larger deviant condition than that in smaller deviant condition like AMMN [1]. Meanwhile, earlier studies have proved that MMN and N2b could be elicited under the same experimental condition in auditory modality [10], and the second aim of this study was to explore whether MMN and N2b would be induced in the same visual condition and further distinguished these two negative components by this designed experimental condition.

Materials and methods

Participants

Fifteen healthy students of the Graduate School of Chinese Academy of Sciences (10 men and five women, age range 23–31, mean 25.1 years, all right-handed) were paid to participate in this study, after providing informed consent. All the participants reported normal or corrected-to-normal visual acuity. Color blindness checkbook was used, and all the participants had normal color vision. None of them had a history of neurological or psychiatric problems.

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Stimuli and procedure

Four kinds of stimuli were observed: standard stimulus [red picture with red, blue, and green (RGB)RGB=200, 0, 0], two kinds of deviant stimuli (red pictures with different RGB values; small deviation stimulus RGB=225, 0, 0; large deviation stimulus RGB=255, 0, 0) and target stimuli (color pictures of flowers). Three kinds of red colors were presented in the center of the monitor with light gray background. All the stimuli were square shape with $3.7^\circ \times 3.7^\circ$ visual angle, and they were presented in the center of computer monitor. The brightness of all the stimuli was adjusted to the same parameter (luminance=24 cd/m^2) to each participant. Participants sat at a viewing distance of 70 cm form a 17-in computer monitor (DELL LATITUDE D610 laptop computer, Pentium-M Dothan-53 processor, 512 MB RAM, 1024×768 pixel resolution, the time which the screen needed to have the picture presented in full was 75 Hz).

Four blocks of 1000 standard and deviant stimuli were presented to every participant, and there were 8, 9, 6, 11 target stimuli in each block, respectively. The sequences of four blocks were balanced in participants. The standard stimulus was presented at a probability of 0.8, whereas the two deviant stimuli occurred at a probability of 0.1 each. Both the standard and deviant stimuli lasted 100 ms, and the flower task stimuli lasted 300 ms with all the blocks using 900 ms interstimulus interval. The stimulus sequences were in a pseudorandom order. Each deviant stimulus was preceded by at least two standard stimuli, and at least four standard stimuli were presented at the beginning of each stimulus block.

During the electrophysiologic acquisition period, participants sat comfortably in a reclining chair within an electrically shielded, sound-attenuated booth and counted the number of flower pictures. All participants were instructed to silently count the number of flower pictures and to ignore other stimuli. The stimuli were presented by the E-Prime system (Psychology Software Tools, Inc.). None of the patients experienced difficulty complying with the instructions. The time duration of the recording session was approximately 25 min.

Event-related potential recording and data analysis

Nose-referenced electroencephalograms (Neuroscan Inc., amplified by SynAmps 2 online bandpass filtering: 0.05–100 Hz, sampling rate 1000 Hz) was recorded with Ag–AgCl electrodes attached to the scalp sites F3, Fz, F4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, P3, Pz, P4, O1, Oz, and O2 according to the International 10–20 system [11]. Vertical and horizontal eye movements were monitored with electrodes attached upper and below and outer canthi of both eyes. Electroencephalograms epochs of 700 ms, including 100 ms of prestimulus baseline time, were offline averaged separately for each stimulus class. ERPs were zero phase shift digitally filtered (bandwidth: 0.05–30 Hz, slope: 24 dB/octave). Epochs with artifacts exceeding 100 μV at any electrode as well as the first three epochs of each block were omitted from further analysis.

According to earlier studies and the characteristics of present ERP waveforms, VMMN latency was chosen 110–180 ms window for peak detection, and 170–300 ms time window for N2b and 400–450 ms time window for detecting P3a peak. Differences in the amplitudes, latencies, and electrode sites of the ERP components were analyzed with 3-way analysis of variance: deviation differences (large deviation difference vs. small deviation difference) × anterior–posterior electrode sites (anterior, posterior) × laterality (left, central, right). The Greenhouse–Geisser correction was used to compensate for sphericity violations.

Results

Participants reported the number of flower pictures after they finished each experimental block, and all the participants counted the right numbers in each block of the whole experiment.

Event-related potential results

Table 1 showed the peak latencies and peak amplitudes of VMMN, N2b, and P3a in both large and small deviation conditions. ERPs elicited by the standard stimuli and deviant stimuli with both large and small deviation differences are presented in Fig. 1. As it is shown in Fig. 2, VMMN peaked significantly faster in large deviation condition than that in small deviation condition [main effect of deviation differences $F(1,14)=28.93$, $P=0.033<0.05$]. Posterior electrode sites induced larger VMMN amplitudes than anterior electrode sites did [main effect of anterior–posterior electrode sites effect $F(1,14)=207.69$, $P=0.005<0.05$]. Significant interactions between deviation differences and anterior–posterior electrode sites effect [$F(1,14)=39$, $P=0.025<0.05$] for VMMN amplitude were observed: anterior–posterior electrode sites effect was smaller in large deviation condition than that in small deviation condition.

Large deviation difference condition had significantly longer N2b peak latencies than the small deviation difference condition did [main effect of deviation differences $F(1,14)=50.66$, $P<0.001$]. Small deviation difference condition induced much smaller N2b amplitudes than the large deviation difference condition did [main effect of deviation differences $F(1,14)=45.12$, $P<0.001$]. Right hemisphere had significantly the shortest N2b latencies than other two parts of laterality [main effect of laterality $F(2,14)=6.85$, $P=0.022<0.05$].

Large deviation difference condition showed significantly longer P3a peak latencies than the small deviation difference condition did [main effect of deviation differences

Table 1 Peak latency and amplitude of VMMN, N2b, and P3a in both large and small deviation conditions

	VMMN		N2b		P3a	
Conditions	Latency (ms)	Amplitude (μV)	Latency (ms)	Amplitude (μV)	Latency (ms)	Amplitude (μV)
Small deviation condition	178.83 (23.7)	−0.59 (0.3)	263.22 (72.02)	−0.76 (0.22)	411.22 (7.2)	0.58 (0.14)
Large deviation condition	144.39 (27.07)	−0.56 (0.22)	301.83 (28.76)	−1.53 (0.25)	442.61 (6.25)	0.85 (0.42)

VMMN, visual mismatch negativity.

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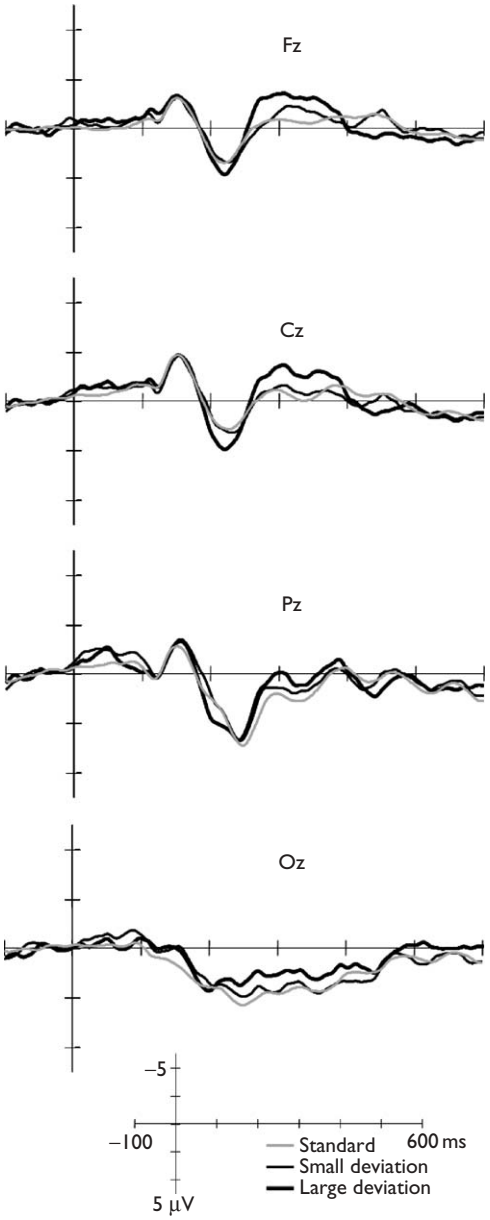

Fig. 1 The event-related potentials elicited by the standard stimuli and deviant stimuli with both large and small deviation.

$F(1,14)=4181.44$, $P<0.001$], and large deviation difference induced much larger P3a amplitudes than the small deviation difference did [main effect of deviation differences $F(1,14)=45.19$, $P=0.021<0.05$]. Posterior electrode sites had longer P3a peak latency than the anterior electrode sites [main effect of anterior–posterior electrode sites $F(1,14)=5.89$, $P=0.046<0.05$], and posterior electrode sites had smaller P3a amplitude than the anterior electrode sites [main effect of anterior–posterior electrode sites $F(1,14)=19.47$, $P=0.048<0.05$]. For P3a latency, there were significant interactions between deviation differences and laterality effect [$F(2,14)=21.61$, $P=0.044<0.05$]: Laterality effect was larger in large deviation condition than that in small deviation condition. Significant interactions between deviation differences and anterior–posterior electrode sites effect [$F(1,14)=167.29$, $P=0.006<0.05$] for P3a latency were also observed: anterior–posterior electrode sites effect was larger in small deviation condition than that in large deviation condition. For P3a amplitude, there were significant interactions between deviation differences and anterior–posterior electrode sites effect [$F(1,14)=49.73$, $P=0.02<0.05$]: anterior–posterior electrode sites effect was larger in large deviation condition than that in small deviation condition.

Discussion

From this study, it was found that VMMN could be induced in both the designed large and small deviant conditions with clear generation in posterior areas, and the N2–P3 complex was also significantly affected by the different levels of deviations of deviant stimuli from standard stimuli. In this study, deviant stimuli elicited a prominent negativity starting at posterior regions and then spreading to central regions, and the present neural characteristic of VMMN was consistent with that of earlier studies [4,6,12,13]. These findings also indicated that VMMN peaked earlier than N2b and it could be separated from N2b not only from their different latencies but also their different generations. These findings indicated that N2b had frontal and right hemisphere dominances and this result was consistent with that of Restuccia, Marca, Marra, Rubino, and Valeriani [14]. P3a had shorter peak latency in anterior regions than that in posterior regions, and P3a had larger peak amplitude in anterior electrode sites than that in posterior electrode sites. So this study further proved that N2–P3 complex reflected the frontal function.

In this study, we revised the classical oddball paradigm to induce automatic brain processings in the color deviation condition, and the whole procedure represented the automatic visual change detection [5]. As compared with earlier studies on color-related VMMN, the present VMMN was elicited in the relatively hard detection condition, and it had some similar characteristics with earlier findings, such as peak latency [4–6,8] and generation [4–8]. So we might deduce that color-related MMN existed steadily under hard detection conditions in human visual modality. Some other earlier studies, which did not use color-related stimuli (for example, shape, size, and location) got longer VMMN latencies over posterior areas (see, review paper: [3]), and we might deduce that color change detection processing was much closer to automatic processing than other stimulus change detection processings. So it is further proved that color-related preattentional processing was more suited for MMN studies in visual modality.

In this study, we also wanted to explore whether this color-related VMMN was affected by different degrees of deviations between deviant stimuli and standard stimuli. These findings showed that VMMN amplitudes were not altered by the degrees of deviation and they were consistent with Näätänen's findings on AMMN [15]. These VMMN latencies varied with different degrees of deviations, which were consistent with Czigler and Csibra's findings [16]. Czigler and Csibra [16] used a counting task and a reaction time task to study neural characteristics of deviant stimuli. Their ERP results demonstrated that simple deviant stimuli (large deviation condition) induced a 140–180 ms posterior distributed negativity, whereas complex deviant features (small deviation condition) elicited another negative wave in 180–260 ms time window. Some parts of these findings were different from an earlier study [7]. Horimoto and his

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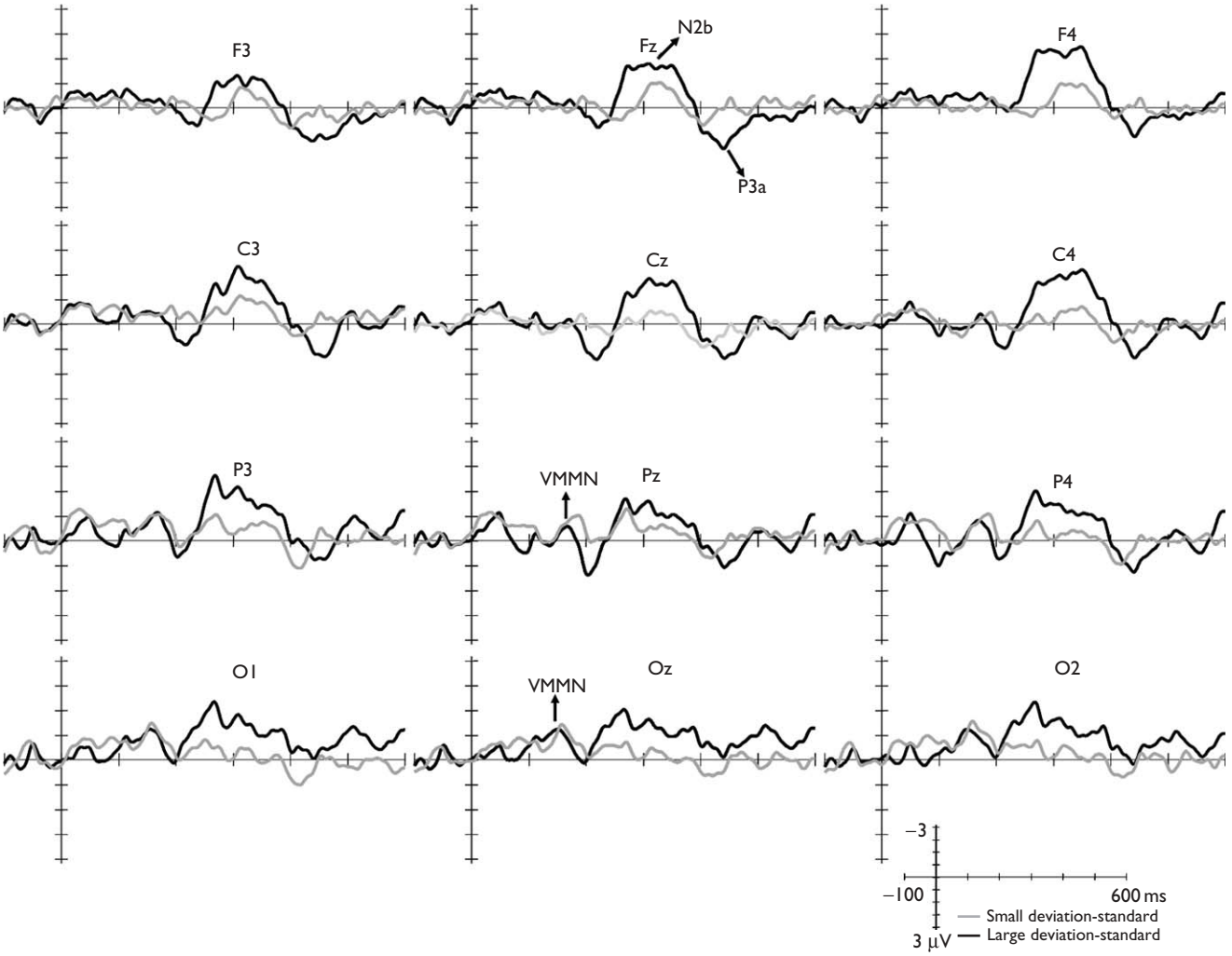

Fig. 2 The nose-referenced deviant-minus-standard differences of the large and small deviation conditions. VMMN, visual mismatch negativity.

colleagues [7] also recorded VMMN in visual color modality under auditory selective attention condition. They used blue color screen as standard stimuli, and red, or greenish blue color screen (GB) as deviant stimuli. They found that VMMN had a latency of 250–280 ms in normal children, and the negativity was over posterior areas in GB color screen deviant condition whereas in red color screen deviant condition the negativity was over frontal areas. They reported that VMMN was more clearly elicited in GB color screen deviant condition than that in red color screen deviant condition. From their findings, it may be a little difficult to argue the red color screen deviant condition induced a real ''VMMN'', and most of the recorded VMMN was generated posteriorly [3]. In Horimoto *et al.* [7] study, red color screen deviant condition was more like novel stimuli, which might induce involuntary attention with frontal functional processing. This study further revealed that VMMN could be regarded as an early sensory neural response which was substantially unaffected by attention [3], and N2–P3 complex waveform reflected that attention effects seemed to be in the later neural processing [17]. In this design, we could distinguish these early sensory processing (preattentional processing) and late sensory processing (involuntary attentional processing).

Conclusion

These findings supported that human brain could detect visual color changes of deviant stimuli embedded in the standard stimuli sequences, which revealed the neural mechanism of the occipital negativity. All the VMMN, N2b, and P3a components were affected by the amount of deviations between standard stimuli and deviant stimuli.

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