Experimental Brain Research (2018) 236:1283–1292
https://doi.org/10.1007/s00221-018-5220-8

RESEARCH ARTICLE

Visual mismatch negativity is unaffected by top-down prediction of the timing of deviant events

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Received: 19 August 2017 / Accepted: 25 February 2018 / Published online: 27 February 2018

Abstract

Visual mismatch negativity (VMMN) is an event-related brain potential component that is automatically elicited by infrequent (deviant) stimuli that are inserted among frequent (standard) stimuli (i.e., an oddball sequence). Although the elicitation of VMMN is basically determined in a stimulus-driven manner, it can be modulated by top-down control. In a previous study using a "patterned" oddball sequence, where deviant (D) stimuli were regularly inserted among standard (S) stimuli (i.e., repetitions of an SSSSD pattern), VMMN was largely reduced when participants noticed the SSSSD pattern and actively predicted both the identity and timing of the deviant stimuli compared to when they did not notice the SSSSD pattern and did not form such active prediction. The present study further investigated whether or not active prediction of only the timing of deviant stimuli is sufficient for the reduction of VMMN. With the patterned oddball sequence with one deviant (here, deviant stimuli were fixed throughout the block), VMMN was reduced when the participants noticed the SSSSD pattern and actively predicted both the identity and timing of deviant stimuli (i.e., replication of the previous finding). In contrast, with the patterned oddball sequence with two deviants (deviant stimuli were randomly varied between two possibilities), VMMN was not significantly reduced when the participants noticed the SSSSD pattern and actively predicted only the timing of deviant stimuli. These results suggest that active prediction of only the timing of deviant stimuli is not sufficient to reduce VMMN.

Keywords Automatic deviance processing · Event-related brain potentials (ERPs) · Top-down prediction · Visual mismatch negativity (VMMN)

Introduction

The processing resources of the human brain are fairly limited. Thus, these resources are preferentially allocated to process sensory events that are related to the ongoing task. However, processing resources can also be allocated to process task-unrelated sensory events when they are of biological significance. For example, event-related brain potential (ERP) studies have provided ample evidence that the brain is well organized to automatically process visual events that deviate from regular aspects of the environment. When a visual event deviates from sequential rules embedded in a stimulus sequence, an ERP component called visual mismatch negativity (VMMN) is elicited (Czigler 2007; Kimura et al. 2011; Kimura 2012; Winkler and Czigler 2012; Stefanics et al. 2014). VMMN is a negative-going ERP component with an occipito-temporal maximum scalp distribution that peaks at around 150–400 ms after event onset, and has typically been observed in response to infrequent (deviant) stimuli that are randomly inserted among frequent (standard) stimuli (i.e., an oddball sequence). VMMN is clearly elicited even when the participant's ongoing task is unrelated to the stimulus sequence and thus much attention is not directed to the stimulus sequence. Furthermore, VMMN is not modulated as a function of task load (Heslenfeld 2003; Pazo-Alvarez et al. 2004; Kimura and Takeda 2013; Kremláček et al. 2013) and is similarly elicited when the participant's attention is directed to the stimulus sequence and when it is not (Winkler et al. 2005; Berti 2011). Therefore, it is widely accepted that VMMN reflects automatic deviance processing.

Although VMMN is automatically elicited by deviant stimuli, the elicitation of VMMN is not necessarily determined in a stimulus-driven manner; rather, it can be

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flexibly controlled in a top-down manner (Kimura et al. 2010; for the original design in the auditory domain, see; Sussman et al. 2002). Kimura et al. (2010) found that VMMN could be largely reduced when participants actively predicted the identity and timing of deviant stimuli. They used a patterned oddball sequence in which standard (S) and deviant (D) stimuli were presented regularly (i.e., repetitions of an SSSSD pattern), and occasionally replaced with a target (T) stimulus: e.g., SSSSDSSSS-DSSSSDSSTSD···. In the first phase of the experiment, participants who did not notice the SSSSD pattern were instructed to press a button when target stimuli appeared (target detection task). In the second phase of the experiment, the same participants who were explicitly informed about the SSSSD pattern were instructed to press a button when the SSSSD pattern was violated by target stimuli (pattern-violation detection task); that is, while the target stimuli in these two tasks were the same, the instructions promoted different ways of detecting them. The results showed that VMMN was elicited by deviant stimuli in the target detection task, whereas it was largely reduced in the pattern-violation detection task. These results mean that VMMN was largely reduced when the participants actively predicted both the identity and timing of deviant stimuli, suggesting that automatic deviance processing can be controlled in a top-down manner.

The purpose of the present study was to further explore the critical factor for the top-down control of automatic deviance processing. In particular, the present study aimed to determine whether or not active prediction of only the timing of deviant stimuli is sufficient for the top-down control of automatic deviance processing. For this purpose, the present study used two types of patterned oddball sequences: a sequence with one deviant and a sequence with two deviants (Fig. 1). In both sequences, standard (S) and deviant (D) stimuli differing in orientation were presented regularly (i.e., repetitions of an SSSSD pattern), and occasionally replaced with a target (T) stimulus: e.g., SSSSDSSSS-DSSSSDSSTSD···. In the sequence with one deviant, the orientation of deviant stimuli was fixed throughout the block. In the sequence with two deviants, the orientation was randomly varied among two possibilities. In the first phase of the experiment, participants who did not notice the SSSSD pattern were instructed to press a button when target stimuli appeared (target detection task). In the second phase of the experiment, the same participants who were explicitly informed about the SSSSD pattern were instructed to press a button when the SSSSD pattern was violated by target stimuli (pattern-violation detection task).

When the sequence with one deviant is used, VMMN should be elicited by deviant stimuli in the target detection task, whereas it should be reduced in the pattern-violation

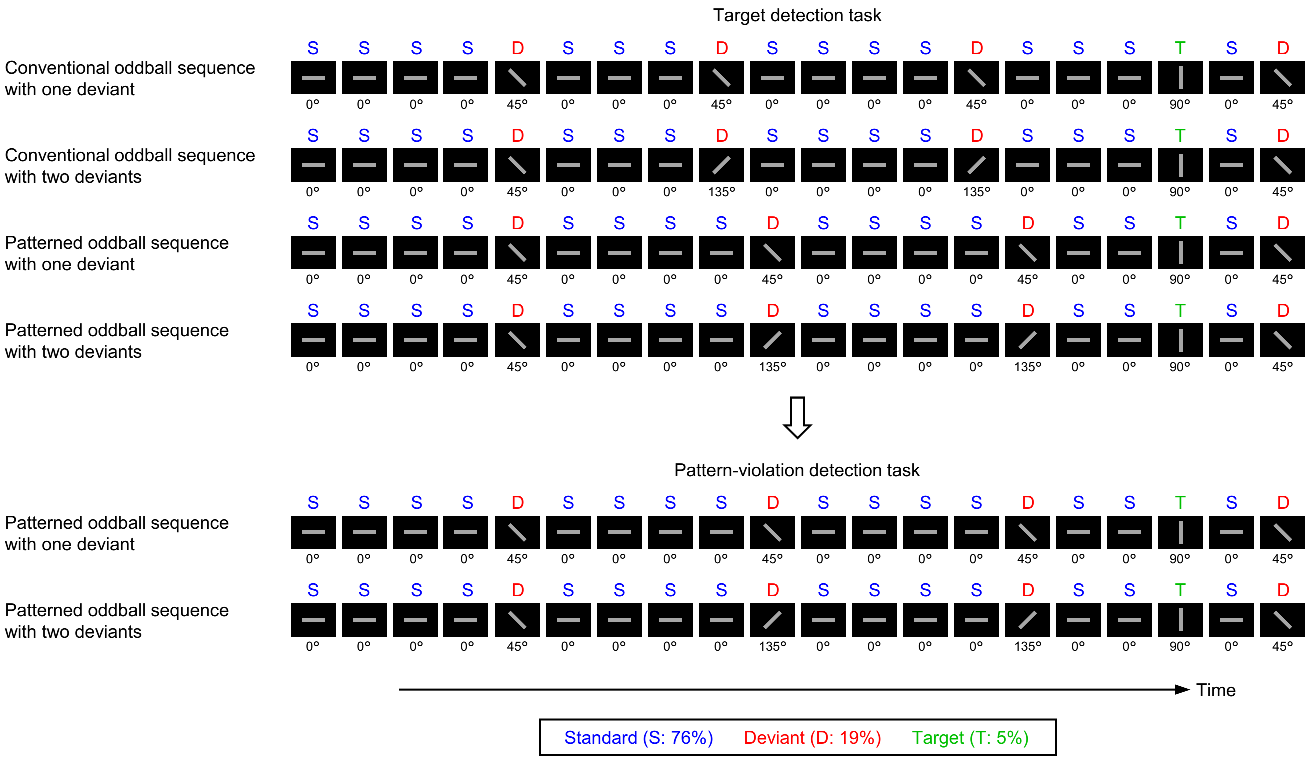

Fig. 1 Schematic illustration of the stimulus sequences

detection task; this would replicate the finding of Kimura et al. (2010). When the sequence with two deviants is used, VMMN should be elicited by deviant stimuli in the target detection task. The critical point for the present purpose was the elicitation pattern of VMMN in the pattern-violation detection task. In this case, only the timing of deviant stimuli could be precisely predicted. Therefore, if active prediction of only the timing of deviant stimuli is sufficient for the top-down control of automatic deviance processing, then VMMN should be reduced in the pattern-violation detection task. In contrast, if it is not sufficient for top-down control of automatic deviance processing, then VMMN comparable to that in the target detection task should be elicited.

Materials and methods

Participants

Eighteen healthy young adults (15 males, 3 females; mean age 23.7 years; age range 19–34 years; 15 right-handed, 3 left-handed) participated in this experiment. All participants had normal or corrected-to-normal vision. Written informed consent was obtained from each participant after the nature of the study had been explained. The experiment was approved by the Safety and Ethics Committee of the National Institute of Advanced Industrial Science and Technology (AIST).

The data from 4 of the 18 participants were omitted from the data analyses, since these participants incidentally noticed the existence of the SSSSD pattern in the target detection task (i.e., in the first phase of the experiment). Thus, the data from the remaining 14 participants (11 males, 3 females; mean age 23.6 years; age range 19–34 years; 11 right-handed, 3 left-handed) will be reported here.

Stimuli and procedure

The experiment was controlled by MATLAB (Mathworks) on Mac OSX with the Psychophysics Toolbox (Brainard 1997; Pelli 1997). Four gray bars on a black background with different orientations (0°, 45°, 90°, and 135° from horizontal to clockwise; luminance of 15.8 cd/m^2; width of 0.9° × height of 5.7°) were used as stimuli. All stimuli were presented on a 17-inch cathode ray tube display (Sony, Trinitron Multiscan G220) at a viewing distance of about 57 cm.

Figure 1 shows the four types of stimulus sequences used in the present study: two patterned oddball sequences (i.e., a sequence with one deviant and a sequence with two deviants) as well as the two corresponding conventional oddball sequences (i.e., a sequence with one deviant and a sequence with two deviants). The conventional oddball sequence was included to ensure that the patterned oddball sequence (i.e., a relatively atypical stimulus sequence in VMMN studies) was truly valid for obtaining VMMN. These stimulus sequences were presented in separate blocks, each of which consisted of the presentation of 180 stimuli: 136 standard, 34 deviant, and 10 target stimuli (about 76, 19, and 5%, respectively). The duration of the stimulus was 250 ms and the stimulus onset asynchrony was 600 ms.

In the conventional oddball sequence, standard, deviant, and target stimuli were ordered so that a deviant stimulus and the next deviant stimulus were separated by three, four, or five standard stimuli, and the standard and deviant stimuli were occasionally replaced with target stimuli: e.g., SSSSDSSSDSSSSDSSSTSD···. In the patterned oddball sequence, the stimuli were ordered so that a deviant stimulus and the next deviant stimulus were separated by four standard stimuli, and the standard and deviant stimuli were occasionally replaced with target stimuli: e.g., SSSSDSSSSDSSSSDSSTSD···. In the sequence with one deviant, the orientation of the standard, deviant, and target stimuli was fixed throughout the block. In the sequence with two deviants, the orientation of the standard and target stimuli was fixed throughout the block, while the orientation of deviant stimuli was randomly chosen from among two possibilities with equal probabilities (i.e., in each block, 17 deviant stimuli each: 9.5% each).

The first phase of the experiment consisted of 32 blocks, in which four types of stimulus sequences (i.e., the conventional oddball sequence with one deviant, the conventional oddball sequence with two deviants, the patterned oddball sequence with one deviant, and the patterned oddball sequence with two deviants) were presented in eight blocks each. The order of these blocks was randomized across participants. In these 32 blocks, the participants performed the target detection task; hereafter, the four conditions defined by stimulus sequence and task will be denoted as the (1) conventional/target condition with one deviant, (2) conventional/target condition with two deviants, (3) patterned/target condition with one deviant, and (4) patterned/target condition with two deviants. The total number of standard, deviant, and target stimuli in each of these conditions was 1088, 272, and 80, respectively.

The second phase of the experiment consisted of 16 blocks, in which two types of stimulus sequences (i.e., the patterned oddball sequence with one deviant and the patterned oddball sequence with two deviants) were presented in eight blocks each. The order of the 16 blocks was randomized across participants. In these 16 blocks, the participants performed the pattern-violation detection task; hereafter, the two conditions defined by stimulus sequence and task will be denoted as the (1) patterned/pattern-violation condition with one deviant and (2) patterned/pattern-violation condition with two deviants. The total number of standard, deviant, and target stimuli in each of these conditions was 1088, 272, and 80, respectively.

In the eight blocks for each of the three conditions with one deviant, the following eight combinations of orientation were assigned for standard, deviant, and target stimuli in one block each: (1) 0°, 45°, and 90°, (2) 0°, 135°, and 90°, (3) 45°, 0°, and 135°, (4) 45°, 90°, and 135°, (5) 90°, 45°, and 0°, (6) 90°, 135°, and 0°, (7) 135°, 0°, and 45°, and (8) 135°, 90°, and 45°. In the eight blocks for each of the three conditions with two deviants, the following four combinations of orientation were assigned for standard, deviant, and target stimuli in two blocks each: (1) 0°, 45°/135°, and 90°, (2) 45°, 0°/90°, and 135°, (3) 90°, 45°/135°, and 0°, and (4) 135°, 0°/90°, and 45°. In all conditions, the orientation of the target stimulus was always orthogonal to that of a standard stimulus. As a result of these assignments, the physical properties of standard, deviant, and target stimuli were on average the same in all conditions.

The participants performed the tasks while seated in a chair in a sound-attenuated, dimly lit room. The participants were instructed to keep their eyes on the center of the display and to minimize blinks and eye movements during the tasks. Before the start of the first phase of the experiment, they were instructed to press a button with the right forefinger as quickly as possible when the target stimulus (i.e., a stimulus oriented orthogonal to the standard stimulus) appeared (target detection task). Before the start of each block, the participants were informed about the orientation of standard, deviant, and target stimuli in the upcoming block.

Immediately after the first phase finished, the participants were asked whether or not they had noticed the existence of the SSSSD pattern. Specifically, they were asked, “Do you think there was any regular pattern in the order of stimulus presentation?” and “If so, what was the regular pattern?” Four of the 18 participants have noticed the SSSSD pattern, and their data were omitted from data analyses. Before the start of the second phase of the experiment, the participants were informed that standard and deviant stimuli would be presented in a regular manner (i.e., as repetitions of an SSSSD pattern) and the target stimulus (i.e., the stimulus oriented orthogonal to the standard stimulus) will sometimes violate the SSSSD pattern. They were then instructed to press a button with the right forefinger as quickly as possible when the target stimulus violated the SSSSD pattern (pattern-violation detection task). Before the start of each block, the participants were informed about the orientation of standard, deviant, and target stimuli in the upcoming block.

Recordings

The electroencephalogram (EEG) was recorded with a digital amplifier (Nihon-Kohden, Neurofax EEG1200) and Ag/AgCl electrodes placed at 27 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FCz, T7, C3, Cz, C4, T8, CPz, P7, P3, Pz, P4, P8, PO7, PO3, POz, PO4, PO8, O1, Oz, and O2 according to the extended International 10–20 System). All electrodes were referenced to the nose tip. To monitor blinks and eye movements, vertical and horizontal electrooculograms (EOGs) were also recorded with two electrodes above and below the right eye and two electrodes at the right and left outer canthi of the eyes, respectively. The impedance of all electrodes was kept below 10 kΩ. The EEG and EOG signals were digitized at a sampling rate of 1000 Hz and bandpass-filtered offline at 1–30 Hz with a finite impulse response filter (7246-point Kaiser-windowed filter) implemented in EEGLAB (Delorme and Makeig 2004). A high-pass cutoff frequency of 1 Hz was chosen to attenuate the possible superposition of P3 which can distort the waveform of VMMN (cf. Rinne et al. 2001; Kimura and Takeda 2014).

Data analysis

Behavioral performance

For each participant, performance in each condition was measured in terms of (1) the percentage of button presses in response to target stimuli (i.e., hit rate; button presses were scored as a hit if the button was pressed within 200–1200 ms after target onset), (2) the mean hit reaction time in response to target stimuli, and (3) the number of button presses in response to non-target stimuli (i.e., the number of false alarms per block). Separately for conditions with one deviant and two deviants, the measured values were subjected to repeated-measures ANOVAs with one factor: three Conditions (conventional/target, patterned/target, vs. patterned/pattern-violation). The Greenhouse–Geisser ε correction for the violation of sphericity was applied.

ERPs

For each participant, the EEG and EOG signals time-locked to the onset of stimulus presentation were extracted. The extracted epochs were 700 ms, including a 100-ms baseline period. Artifacts derived from blinks and eye movements were removed using an independent component analysis (Delorme and Makeig 2004). The epochs were averaged for standard and deviant stimuli in each condition. In the averaging procedure, (1) the first ten epochs in each block, (2) two epochs that were preceded by epochs in which the deviant stimulus was presented, (3) five epochs that were preceded by epochs in which the target stimulus was presented, (4) epochs during which the participants made a button press and the two subsequent epochs, and (5) epochs during which signal changes exceeded ± 80 μV on any of the electrodes, were excluded from averaging. As a result, the number of averaged epochs for standard and deviant stimuli was, on average, 406 ($SE = 9$) and 202 (5) in the conventional/target condition with one deviant, 412 (10) and 204 (4) in the patterned/target condition with one deviant, 408 (11) and 202 (5) in the patterned/pattern-violation condition with one deviant, 412 (8) and 203 (5) in the conventional/target condition with two deviants, 414 (9) and 203 (5) in the patterned/target condition with two deviants, and 412 (9) and 203 (5) in the patterned/pattern-violation condition with two deviants, respectively.

For each participant, to extract VMMN, ERPs elicited by standard stimuli were subtracted from those elicited by deviant stimuli for each condition. In the grand-average deviant-minus-standard difference waves, a posterior negative deflection was observed at around 150–300 ms after the stimulus onset. It is, however, important to note that a negative deflection itself does not necessarily exclusively represent VMMN. It is well known that, due to the large difference in the presentation probability of standard and deviant stimuli in the oddball sequence, visual N1 in response to deviant stimuli can be greater than that in response to standard stimuli (i.e., the refractoriness effect; Alho et al. 1992; Kenemans et al. 2003; Kimura et al. 2009). Thus, not only VMMN but also the N1 effect can be included in the negative deflection. In the present study, based on a consideration of these two ERP effects, the mean amplitudes of difference waves were calculated within two windows: (1) 150–200 ms at the PO8 and PO7 electrode sites and (2) 200–250 ms at the P8 and P7 electrode sites. These windows were determined based on previous studies which demonstrated that the posterior negative deflection obtained with orientation deviants similar to the present study could be decomposed into (1) the N1 effect that peaks at around 150–200 ms with an occipito-temporal (PO8 and PO7) maximum scalp distribution and (2) VMMN that peaks at around 200–250 ms with a more lateralized occipito-temporal (P8 and P7) maximum scalp distribution (Kimura et al. 2009; Kimura and Takeda 2014). Based on this finding, the effects of active prediction on VMMN should be more prominently observed within 200–250 ms (i.e., VMMN-dominant window) than within 150–200 ms (i.e., N1-dominant window).

To test the significance of the posterior negative deflection in each condition, the mean amplitudes of difference waves were compared to zero with one-tailed *t*-tests. Next, to compare the negative deflection among conditions, separately for conditions with one deviant and two deviants, the mean amplitudes of difference waves were subjected to repeated-measures ANOVAs with two factors: three Conditions (conventional/target, patterned/target, vs. patterned/pattern-violation) and two Electrodes (left vs. right). The Greenhouse–Geisser ε correction for the violation of sphericity was applied.

Results

Behavioral performance

One deviant

Table 1 shows the behavioral performance in three conditions with one deviant. For the hit rate, one-way ANOVAs (three Conditions) revealed no significant effect ($p = .94$). For the hit reaction time, one-way ANOVAs (three Conditions) revealed a main effect of Condition [$F(2,26) = 6.94$, $p < .05$, $\varepsilon = 0.65$, partial $\eta^2 = 0.35$]. Multiple comparisons (two-tailed *t*-tests with the Bonferroni correction) revealed that the reaction time was longer in the patterned/pattern-violation condition than in the patterned/target condition ($p < .05$). There was no significant difference between the conventional/target and patterned/target conditions ($p = .88$) or between the conventional/target and patterned/pattern-violation conditions ($p = .12$). For the number of false alarms per block, one-way ANOVAs (three Conditions) revealed no significant effect ($p = .54$).

Table 1 Behavioral performance (*SE*s in parentheses)

	Conventional/target	Patterned/target	Patterned/pattern-violation
One deviant			
Hit rate (%)	97.2 (1.3)	97.1 (1.3)	97.6 (0.7)
Reaction time (ms)	467 (13)	462 (14)	489 (17)
False alarm (times/block)	0.2 (0.1)	0.3 (0.2)	0.2 (0.1)
Two deviants			
Hit rate (%)	97.8 (1.2)	96.7 (1.5)	97.7 (0.6)
Reaction time (ms)	472 (13)	471 (12)	494 (18)
False alarm (times/block)	0.2 (0.1)	0.2 (0.1)	0.3 (0.1)

Two deviants

Table 1 also shows the behavioral performance in three conditions with two deviants. For the hit rate, one-way ANOVAs (three Conditions) revealed no significant effect ($p = .52$). For the hit reaction time, one-way ANOVAs (three Conditions) revealed a main effect of Condition [$F(2,26) = 5.53$, $p < .05$, $\varepsilon = 0.55$, partial $\eta^2 = 0.30$]. Multiple comparisons (two-tailed t-tests with the Bonferroni correction), however, revealed no significant difference between the patterned/pattern-violation and patterned/target conditions ($p = .08$), between the conventional/target and patterned/target conditions ($p = .99$), or between the conventional/target and patterned/pattern-violation conditions ($p = .11$). For the number of false alarms per block, one-way ANOVAs (three Conditions) revealed no significant effect ($p = .23$).

ERPs

One deviant

Figure 2A, B show standard and deviant ERPs and deviant-minus-standard difference waves in three conditions with one deviant. In the difference wave, a posterior negative

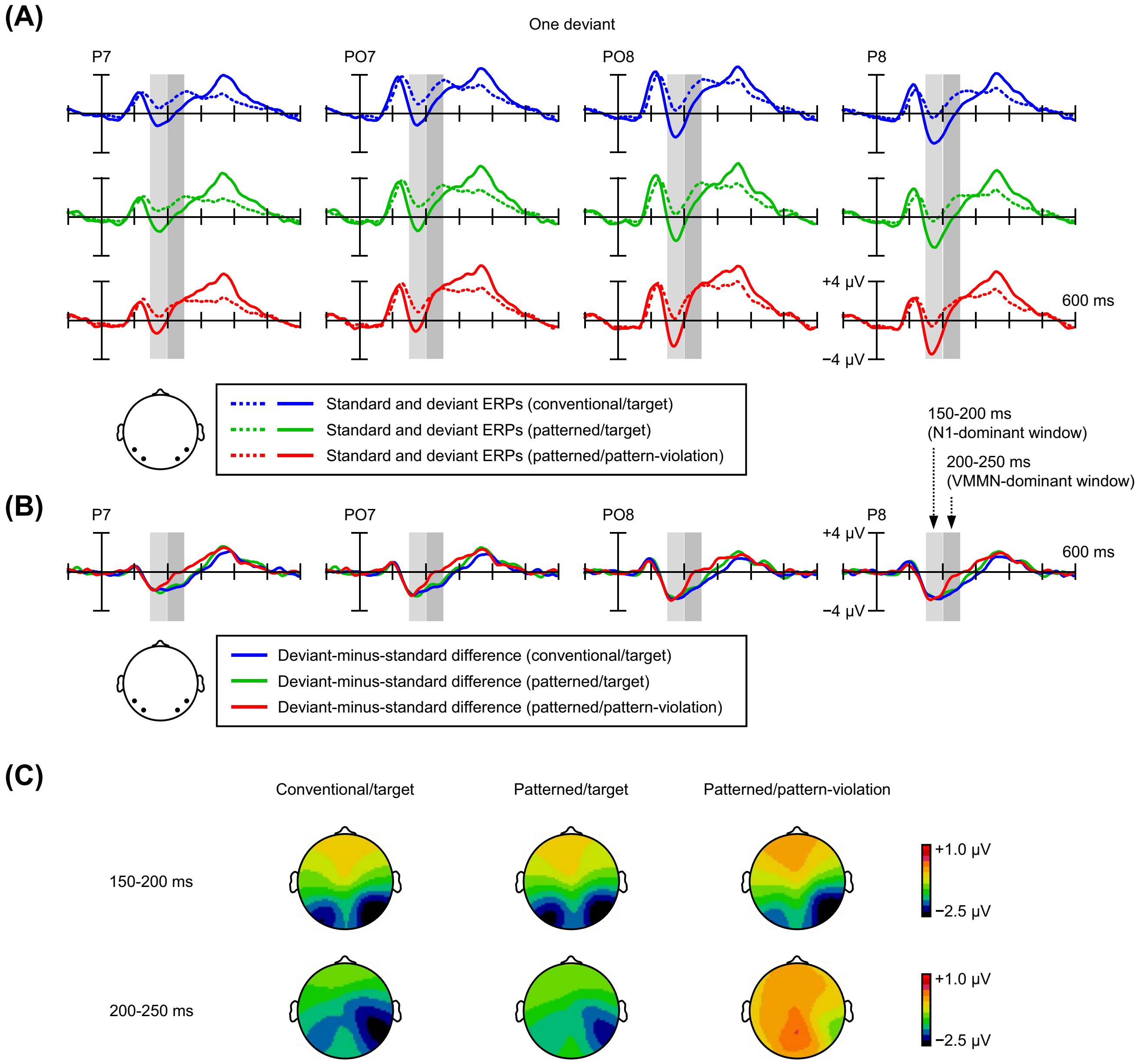

Fig. 2 **A** Grand-average ERPs in response to standard and deviant stimuli in three conditions with one deviant. **B** Grand-average deviant-minus-standard difference waves. **C** Topographical maps of the difference waves

deflection at around 150–300 ms was observed. Figure 2C shows topographical maps of difference waves. Within 150–200 ms, the negative deflection had an occipito-temporal (PO8 and PO7) maximum scalp distribution. Within 200–250 ms, the negative deflection had a more lateralized occipito-temporal (P8 and P7) maximum scalp distribution.

Table 2 shows the mean amplitudes of difference waves. For 150–200 ms, one-tailed *t*-tests revealed significant negative deflection in the conventional/target condition at PO8 [$t(13)=5.89$, $p<.01$, $d=1.58$] and PO7 [$t(13)=5.23$, $p<.01$, $d=1.40$], in the patterned/target condition at PO8 [$t(13)=7.11$, $p<.01$, $d=1.90$] and PO7 [$t(13)=6.18$, $p<.01$, $d=1.65$], and in the patterned/pattern-violation condition at PO8 [$t(13)=5.63$, $p<.01$, $d=1.51$] and PO7 [$t(13)=4.55$, $p<.01$, $d=1.22$]. Two-way ANOVAs (three Conditions × two Electrodes) revealed a main effect of Electrode [$F(1,13)=5.76$, $p<.05$, partial $\eta^2=0.31$], reflecting that the negative deflection was greater at PO8 compared to PO7. Neither a main effect of Condition ($p=.81$) nor the interaction of Condition × Electrode ($p=.22$) was significant.

For 200–250 ms, one-tailed *t*-tests revealed significant negative deflection in the conventional/target condition at P8 [$t(13)=4.03$, $p<.01$, $d=1.08$] and P7 [$t(13)=2.97$, $p<.01$, $d=0.79$], in the patterned/target condition at P8 [$t(13)=3.87$, $p<.01$, $d=1.04$] and P7 [$t(13)=3.03$, $p<.01$, $d=0.81$], and in the patterned/pattern-violation condition at P8 [$t(13)=2.33$, $p<.05$, $d=0.62$] but not at P7 ($p=.23$). Two-way ANOVAs (three Conditions × two Electrodes) revealed a main effect of Electrode [$F(1,13)=8.59$, $p<.05$, partial $\eta^2=0.40$], reflecting that the negative deflection was greater at P8 compared to P7. Two-way ANOVAs also revealed a main effect of Condition [$F(2,26)=7.49$, $p<.01$, partial $\eta^2=0.37$]. Multiple comparisons (two-tailed *t*-tests with the Bonferroni correction) revealed that the negative deflection was smaller in the patterned/pattern-violation condition than in the conventional/target condition ($p<.05$) and the patterned/target condition ($p<.05$). The interaction of Condition × Electrode was not significant ($p=.91$).

Table 2 Mean amplitudes of deviant-minus-standard difference waves (*SE*s in parentheses)

	Conventional/target	Patterned/target	Patterned/pattern-violation
One deviant (150–200 ms)			
PO8	− 2.7 (0.5)**	− 2.6 (0.4)**	− 2.6 (0.5)**
PO7	− 2.2 (0.4)**	− 2.3 (0.4)**	− 2.0 (0.4)**
One deviant (200–250 ms)			
P8	− 2.2 (0.6)**	− 2.0 (0.5)**	− 0.9 (0.4)*
P7	− 1.7 (0.6)**	− 1.5 (0.5)**	− 0.3 (0.4)
Two deviants (150–200 ms)			
PO8	− 2.7 (0.3)**	− 2.8 (0.4)**	− 3.4 (0.5)**
PO7	− 2.3 (0.4)**	− 2.5 (0.4)**	− 2.8 (0.4)**
Two deviants (200–250 ms)			
P8	− 2.3 (0.5)**	− 2.6 (0.6)**	− 2.0 (0.6)**
P7	− 1.5 (0.5)**	− 1.8 (0.5)**	− 1.3 (0.5)*

**$p<.01$, *$p<.05$ by one-tailed *t*-test

Two deviants

Figure 3A, B show standard and deviant ERPs and deviant-minus-standard difference waves in three conditions with two deviants. Figure 3C shows topographical maps of difference waves. In general, the posterior negative deflection was similar to that observed under conditions with one deviant.

Table 2 shows the mean amplitudes of difference waves. For 150–200 ms, one-tailed *t*-tests revealed significant negative deflection in the conventional/target condition at PO8 [$t(13)=8.16$, $p<.01$, $d=2.18$] and PO7 [$t(13)=6.54$, $p<.01$, $d=1.75$], in the patterned/target condition at PO8 [$t(13)=7.36$, $p<.01$, $d=1.97$] and PO7 [$t(13)=6.85$, $p<.01$, $d=1.83$], and in the patterned/pattern-violation condition at PO8 [$t(13)=6.33$, $p<.01$, $d=1.69$] and PO7 [$t(13)=7.08$, $p<.01$, $d=1.89$]. Two-way ANOVAs (three Conditions × two Electrodes) revealed a main effect of Electrode [$F(1,13)=5.44$, $p<.05$, partial $\eta^2=0.30$], reflecting that the negative deflection was greater at PO8 compared to PO7. Neither a main effect of Condition ($p=.11$) nor the interaction of Condition × Electrode ($p=.30$) was significant.

For 200–250 ms, one-tailed *t*-tests revealed significant negative deflection in the conventional/target condition at P8 [$t(13)=4.77$, $p<.01$, $d=1.27$] and P7 [$t(13)=2.78$, $p<.01$, $d=0.74$], in the patterned/target condition at P8 [$t(13)=4.45$, $p<.01$, $d=1.19$] and P7 [$t(13)=3.37$, $p<.01$, $d=0.90$], and in the patterned/pattern-violation condition at P8 [$t(13)=3.45$, $p<.01$, $d=0.92$] and P7 [$t(13)=2.43$, $p<.05$, $d=0.65$]. Two-way ANOVAs (three Conditions × two Electrodes) revealed a main effect of Electrode [$F(1,13)=11.80$, $p<.01$, partial $\eta^2=0.48$], reflecting that the negative deflection was greater at P8 compared to P7. Neither a main effect of Condition ($p=.24$) nor the interaction of Condition × Electrode ($p=.66$) was significant.

Discussion

In the conventional/target and patterned/target conditions with one deviant, posterior negative deflection was observed within 150–250 ms. The negative deflections in these two conditions were comparable, which ensures that the patterned oddball sequence was valid for obtaining VMMN. In addition, these negative deflections consistently showed a clear right lateralization, one of the properties of VMMN

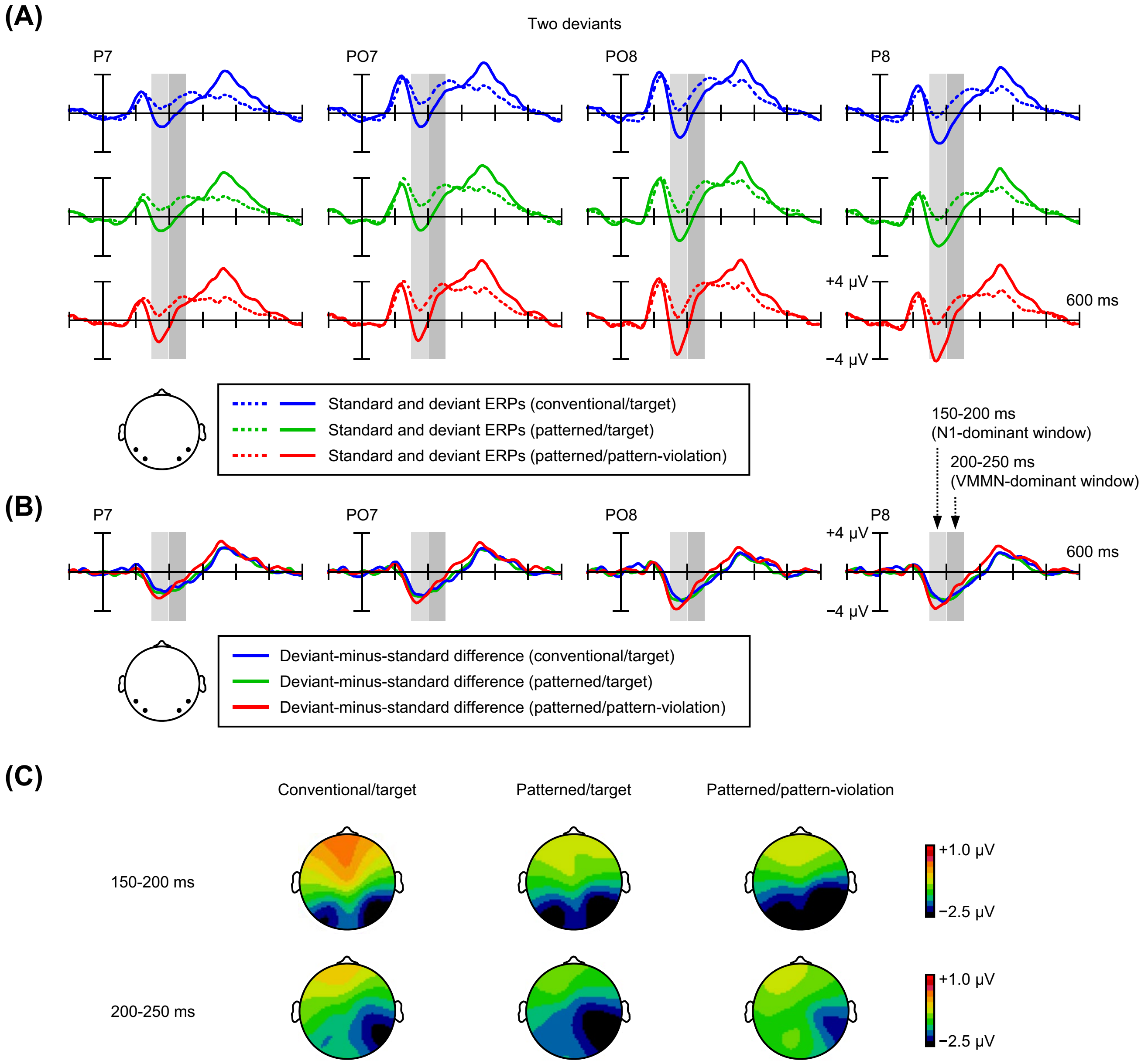

Fig. 3 **A** Grand-average ERPs in response to standard and deviant stimuli in three conditions with two deviants. **B** Grand-average deviant-minus-standard difference waves. **C** Topographical maps of the difference waves

(Czigler et al. 2002; Grimm et al. 2009; Kimura et al. 2009), which ensures that these deflections truly included VMMN.

In the patterned/pattern-violation condition with one deviant, the posterior negative deflection was observed within 150–250 ms. Within 150–200 ms, the negative deflection was comparable to those in the patterned/target and conventional/target conditions. In contrast, within 200–250 ms, it was reduced compared to those in the patterned/target and conventional/target conditions. Previous studies with orientation deviants similar to the present study have shown that the posterior negative deflection is comprised of (1) the N1 effect that peaks at around 150–200 ms and (2) VMMN that peaks at around 200–250 ms (Kimura et al. 2009; Kimura and Takeda 2014). Thus, the present results with one deviant suggest that VMMN was reduced when both the identity and timing of deviant stimuli were actively predicted (i.e., replication of the previous finding by Kimura et al. 2010), whereas the N1 effect (i.e., the refractoriness effect) was intact irrespective of the participant's active prediction.

It can be argued that the reduction of VMMN in the patterned/pattern-violation condition may reflect the variation of task load, since the hit reaction time was longer in this condition. However, this is very unlikely, since it has been consistently shown that VMMN is stable against the manipulation of task load (Heslenfeld 2003; Pazo-Alvarez et al. 2004; Kimura and Takeda 2013; Kremláček et al. 2013). It can also be argued that the reduction of VMMN in the patterned/pattern-violation condition may reflect the influence of task order, since the pattern-violation detection task was always performed after the target detection task. If this account is correct, VMMN should have also been reduced in the patterned/pattern-violation condition with two deviants; however, this was not the case (see next section).

In the conventional/target and patterned/target conditions with two deviants, posterior negative deflection was observed within 150–250 ms. Like the conditions with one deviant, these negative deflections were comparable, and consistently showed a clear right lateralization. In the patterned/pattern-violation condition with two deviants, posterior negative deflection was observed within 150–250 ms. Unlike the conditions with one deviant, the negative deflection in the patterned/pattern-violation condition did not significantly differ from those in the patterned/target and conventional/target conditions. These results suggest that VMMN was not reduced when only the timing of deviant stimuli was actively predicted.

While this observation was not statistically significant, VMMN was somewhat smaller in the patterned/pattern-violation condition with two deviants than in the conventional/target and patterned/target conditions with two deviants. This may imply that active prediction of only the timing of deviant stimuli could affect VMMN to a very small extent. Another possibility is that the participants actively predicted the identity of deviant stimuli even in the patterned/pattern-violation condition (i.e., either of two possible orientations in each trial), and this identity prediction matched the actual deviant stimuli by chance in some portion of trials. Although the present results would be enough to suggest that predicting only the timing of deviant stimuli has no major impact on VMMN, stronger evidence could be provided by future studies that use multiple (i.e., more than two) deviant stimuli.

Given the latency and scalp distribution of the present negative deflection, it may be argued that the deflection that was considered to be VMMN actually represented a selective attention effect such as selection negativity (SN; Harter and Previc 1978; Anllo-Vento and Hillyard 1996). However, it is difficult to explain the present negative deflection in terms of SN. SN is an ERP effect that is observed in response to stimuli with a target feature value compared to stimuli without the target feature value. Importantly, SN does not reflect the selection process itself but rather a cognitive process initiated after selection is finished (Smid et al. 1999). In the present study, the orientations of both deviant and standard stimuli were prominently different from the orientation of the target stimuli, and thus it is very unlikely for SN to be elicited in response to deviant and standard stimuli.

Taken together, the present results suggest that active prediction of only the timing of deviant events is not sufficient for the top-down control of automatic deviance processing; active prediction of both the identity and timing of deviant events is required for such top-down control. Many previous VMMN studies have shown that deviant events can be automatically processed even when they are unrelated to the ongoing task. Given the limited processing resources of the human brain, this appears to be highly advantageous, since it implies that the processing resources can be automatically allocated to selectively process deviant events that can carry novel information. However, when deviant events carry no novel information, such as when the identity and timing of deviant events can be precisely predicted, the allocation of processing resources would be unnecessary (or may be even disadvantageous). The top-down control of automatic deviance processing may be implemented to avoid such unnecessary resource allocation (for a similar argument, see Kimura and Takeda 2014). From this perspective, it seems reasonable that processing resources are still automatically allocated to process deviant events when only the timing can be precisely predicted, since deviant events can still carry novel information.

According to recent theories of VMMN, the elicitation of VMMN is the outcome of automatic predictive processes in the brain (Kimura et al. 2011; Kimura 2012): (1) sequential rules embedded in a stimulus sequence are extracted, (2) an internal model encoding the extracted rules is established, (3) predictions about the forthcoming sensory event are formed based on the model, and (4) representations of the current and predicted sensory events are compared. When incongruence between them is detected, VMMN is elicited; in the case of the oddball sequence, the automatic predictive processes are thought to predict a standard stimulus, and therefore, deviant stimuli elicit VMMN. VMMN is thought to represent prediction-error signals that are projected from lower sensory brain areas to higher brain areas and used to adjust the internal model to minimize future prediction errors (Kimura 2012; Winkler and Czigler 2012; Stefanics et al. 2014). Given these theoretical proposals, the present results are considered to imply that (1) a sensory event predicted by the automatic predictive processes underlying VMMN can be modulated by active prediction of both the identity and timing of deviant events (i.e., what was predicted was changed from a standard stimulus to a deviant stimulus), so that prediction-error signals are not generated, while (2) the predicted sensory event is not significantly modulated by active prediction of only the timing of deviant events (i.e., what was predicted was still a standard stimulus), so that prediction-error signals are generated to adjust the internal model.

Conclusion

Active prediction of only the timing of deviant events is not sufficient for the top-down control of automatic deviance processing. Active prediction of both the identity and timing of deviant events is required for the top-down control of automatic deviance processing.

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