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Attention switching function of memory-comparison-based change detection system in the visual modality

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Abstract

To elucidate the attention switching function of a memory-comparison-based change detection system in the visual modality, the effects of task-irrelevant infrequent stimulus-size decrements that engaged memory-comparison-based change detection as well as stimulus-size increments that engaged memory-comparison-based change detection and refractoriness-based rareness detection on behavioral and event-related brain potential (ERP) measures were assessed using the distraction paradigm. Both size increments and size decrements caused distraction in forced-choice task performance, which was mirrored by a posterior negativity (peaking at around 240-260 ms, posterior N2) and a broad positivity (420-460 ms, P3a) that reflected attentional capture. Preceding these effects, size increments elicited a posterior negativity (120-140 ms, change-related negativity), while size decrements elicited a posterior positivity (140-160 ms, change-related positivity) and an anterior positivity (160-180 ms, frontal positivity). Taken together, these results indicate an attention switching function of a memory-comparison-based change detection system in the visual modality, which is most probably indexed by change-related positivity.

Key words: Visual distraction; Visual change detection; Event-related brain potentials (ERPs)

Attention switching function of memory-comparison-based change detection system in the visual modality

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1. Introduction

The detection of task-irrelevant stimulus changes is an important sensory function for adaptive behavior (e.g., Näätänen, 1990, 1992). Also, the change detection system is assumed to play an important role in attention switching for subsequent attentional capture, which enables us to evaluate stimulus changes (e.g., Schröger, 1997). Recently, strong evidence of such an attention switching function of the change detection system in the auditory modality has been obtained using the “distraction” paradigm (for reviews, see Alho et al., 2003; Escera et al., 2000).

1. 1. Distraction paradigm

To elucidate the attention switching function of the change detection system, several auditory studies have used the distraction paradigm, in which the effects of task-irrelevant infrequent stimulus changes on behavioral and event-related brain potential (ERP) measures were investigated (e.g., Alho et al., 1997; Berti et al., 2004; Berti and Schröger, 2001; Escera et al., 1998, 2001, 2002; Jääskeläinen et al., 1996; Rinne et al., 2006; Schröger, 1996; Schröger et al.,

2000; Schröger and Wolff, 1998; Yago et al., 2001, 2003). In a typical auditory distraction paradigm, participants were required to discriminate between two equiprobable stimuli that differed in duration as quickly and accurately as possible, while task-irrelevant pitch changes were presented infrequently (e.g., Berti et al., 2004; Berti and Schröger, 2001; Schröger et al., 2000; Schröger and Wolff, 1998). At the behavioral level, these pitch changes distracted behavioral performance regarding duration discrimination (e.g., prolonged reaction times, decreased hit rates, or increased error rates). At the ERP level, the pitch changes that caused behavioral distraction were mirrored by a negativity at around 100-200 ms after stimulus onset with a frontal scalp-distribution (mismatch negativity, MMN; Näätänen et al., 1978) and a positivity at around 250-350 ms after stimulus onset with a wide scalp-distribution over the parietal to frontal areas (P3a; Courchesne et al., 1975; Squires et al., 1975). MMN is thought to reflect memory-comparison-based change detection in the auditory modality, which detects stimulus changes by comparing the current stimulus input and a memory trace of the preceding stimulus (e.g., Näätänen et al., 2005), while P3a is thought to reflect attentional capture (e.g., Escera et al., 1998; Schröger and Wolff, 1998). Thus, these results strongly support the notion that a memory-comparison-based change detection system is involved in attention switching for subsequent attentional capture.

1. 2. Visual distraction

It has been unclear whether a similar involuntary processing of stimulus changes occurs in other

modalities. Berti and Schröger (2001, 2004, 2006) recently investigated the effects of task-irrelevant infrequent visual stimulus changes on behavioral and ERP measures. In these studies, participants were required to discriminate between two equiprobable stimuli that differed in duration, while location changes occurred infrequently. At the behavioral level, the location changes distracted behavioral performance regarding the discrimination of duration. At the ERP level, the location changes that caused behavioral distraction were mirrored by a negativity at around 100-300 ms after stimulus onset with a posterior scalp-distribution and a positivity at around 400-450 ms after stimulus onset with a wide scalp-distribution over the parietal to frontal areas. The authors interpreted the positivity as P3a, which is thought to reflect attentional capture. However, it is more difficult to interpret the posterior negativity. Although Berti and Schröger (2001, 2004) interpreted the negativity in terms of memory-comparison-based change detection (e.g., Czigler et al., 2002, 2006; Winkler et al., 2005) as auditory MMN (Näätänen et al., 1978), they later (Berti and Schröger, 2006) interpreted the negativity in terms of lower adaptation levels of afferent neurons that specifically responded to infrequent stimuli (i.e., refractoriness-based rareness detection, e.g., Alho et al., 1992; Kenemans et al., 2003; Kimura et al., 2006c; Mazza et al., 2005) as an auditory N1 component (Näätänen and Picton, 1987). Refractoriness-based rareness detection may also be related to memory, since afferent neurons indirectly contain information about previous stimulation. However, in contrast to memory-comparison-based change detection, no specific memory representations are necessarily involved in refractoriness-based rareness detection, which may therefore be considered to be less memory-related (see Schröger and Wolff, 1998).

1. 3. Present study

Previous visual distraction studies have found that task-irrelevant infrequent changes in location caused attentional capture and behavioral distraction (Berti and Schröger, 2001, 2004, 2006). However, considering the retinotopic organization of the visual cortex, infrequent changes in location theoretically engage not only memory-comparison-based change detection but also refractoriness-based rareness detection. Thus, it remains unclear whether a genuine memory-comparison-based visual change detection system is involved in attention switching for subsequent attentional capture.

To answer this question, the present study extended previous visual distraction studies in two regards. First, the present study examined the effects of infrequent energy decrements (i.e., stimulus-size decrements) as well as infrequent energy increments (stimulus-size increments) on behavioral and ERP measures (e.g., Escera et al., 2002; Rinne et al., 2006). Infrequent energy increments are assumed to engage both memory-comparison-based change detection and refractoriness-based rareness detection, whereas infrequent energy decrements are assumed to engage memory-comparison-based change detection but to not strongly engage refractoriness-based rareness detection (for the associated logic, see e.g., Kaukoranta et al., 1989; Näätänen et al., 1989; Woldorff et al., 1991). Therefore, we can hypothesize that if a memory-comparison-based change detection system is involved in attention switching for subsequent attentional capture, then not only size increments but also size decrements should be

accompanied by the elicitation of P3a and behavioral distraction.

Second, to enable the reliable assessment of behavioral distraction by size increments and decrements, these stimulus changes were presented within a wide range of time-intervals compared to the onset of task-relevant stimuli. This approach is based on the results of a previous visual distraction study (Berti, 2006). In that study, participants were required to discriminate between two equiprobable stimuli that differed in shape, while changes in location and color infrequently occurred in separate blocks. Location changes distracted behavioral performance in shape discrimination (e.g., Berti and Schröger, 2001, 2004, 2006), while color changes did not. This result seems to indicate that color changes did not distract behavioral performance. However, it is still possible that the appropriate timing for distracting behavioral performance differs according to the type of stimulus change.

The present study was also intended to shed light on an ERP correlate of memory-comparison-based visual change detection. The earliest change-related effect observed in response to both size increments and decrements should be regarded as an ERP correlate of memory-comparison-based change detection. In contrast, the earliest change-related effect observed in response to size increments but not size decrements should be regarded as an ERP correlate of refractoriness-based rareness detection. A likely candidate for memory-comparison-based change detection is change-related negativity or change-related positivity (see Kimura et al., 2006c). Change-related negativity is usually observed at around 100-200 ms after stimulus onset with a posterior scalp-distribution (e.g., Alho et al., 1992; Czigler et al., 2002, 2004, 2006; Heslenfeld, 2003; Kenemans et al., 2003; Kimura et al., 2006c; Mazza et

al., 2005; Winkler et al., 2005, for a review, see Pazo-Alvarez et al., 2003). As seen in the interpretation by Berti and Schröger (2001, 2004, 2006), this component might reflect memory-comparison-based change detection (e.g., Czigler et al., 2002, 2006; Winkler et al., 2005) or refractoriness-based rareness detection (e.g., Alho et al., 1992; Kenemans et al., 2003; Kimura et al., 2006c; Mazza et al., 2005). Also, change-related positivity is usually observed at around 100-200 ms after stimulus onset with a posterior scalp-distribution (e.g., Fonteneau and Davidoff, 2007; Fu et al., 2003; Kimura et al. 2005a, 2005b, 2006a, 2006b, 2006c; Wang et al., 2003). Recently, Kimura et al. (2005a, 2005b, 2006a, 2006b, 2006c) and Fonteneau and Davidoff (2007) proposed that this component reflects memory-comparison-based change detection.

2. Methods

2. 1. Participants

Twelve students (7 women, 5 men; age range = 21-33 years, $M = 24.5$ years) participated in this experiment. All participants were right-handed and had normal or corrected-to-normal vision. Written informed consent was obtained from each participant after the nature of the study had been explained.

2. 2. Stimuli and Procedure

Two task-relevant stimuli that differed in shape (white square and triangle, luminance of 95 cd/m², visual angle of 2.0° × 2.0° from a viewing distance of 100 cm) were presented in random order with equal probability at a central location, while three types of task-irrelevant stimuli, which consisted of eight gray circles (luminance of 42 cd/m²) at eight peripheral locations (4.0° upper, lower, left, and right, and 5.7° upper-left, upper-right, lower-left, and lower-right) that differed in size (Standard, Large, and Small stimuli, visual angles of 1.7° × 1.7°, 3.4° × 3.4°, and 0.8° × 0.8°, respectively), were randomly presented in nine types of experimental blocks defined by the combination of time-interval condition (three types) and probability condition (three types). The durations of the central and peripheral stimuli were 200 ms, and the inter-trial intervals (onset-to-onset) were 1600 ms in all experimental blocks (see Fig. 1).

For the time-interval conditions, the peripheral stimuli were presented with three types of time-intervals relative to the central stimuli in separate blocks (Same, Pre200, and Pre400 conditions). The peripheral stimuli preceded the central stimuli by 0 ms in the Same condition, by 200 ms in the Pre200 condition, and by 400 ms in the Pre400 condition (see Fig. 1). Further, for each time-interval condition, three types of peripheral stimuli were presented with three probabilities in separate blocks (Distraction, Large control, and Small control conditions). In the Distraction conditions, Large (i.e., *Large deviant stimuli*) and Small stimuli (*Small deviant stimuli*) were infrequently presented (8% each) within a repetitive Standard stimulus sequence (*Standard stimuli*). In the Large control conditions, the peripheral stimuli were always Large stimuli (*Large control stimuli*). In the Small control conditions, the peripheral stimuli were always Small stimuli (*Small control stimuli*) (see Fig. 1).

This experiment consisted of 15 blocks (5 blocks for each time-interval condition, which consisted of 3 Distraction conditions, 1 Large control condition, and 1 Small control condition), each of which consisted of 250 trials. The order of these blocks was randomized across participants. In all blocks, the participant was seated in a reclining chair in a sound- and electro-shielded room and instructed to press a button with the right (left) thumb when the central stimulus was a square and with the left (right) thumb when the central stimulus was a triangle as quickly and accurately as possible. The stimulus-response hand configuration was counterbalanced across participants. The participants were also asked to focus on the center of the display, and to minimize any eye movement during each experimental block.

Insert Fig. 1 around here.

2. 3. Recordings

The electroencephalogram (EEG) was recorded from 25 silver-silver chloride cup electrodes attached to an electrocap (Quik-Cap), with electrodes placed at Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, 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. Blinks and eye movements were monitored with electrodes above and below the right eye (vertical

electrooculogram, V-EOG) and at the right and left outer canthi of the eyes (horizontal electrooculogram, H-EOG). The impedance of the electrodes was kept below 5 k Ω . EEG and EOG signals were amplified with a bandpass of 0.03-30 Hz, and digitized at a sampling rate of 250 Hz. Averaging epochs were 1000 ms (100 ms before to 900 ms after the onset of the peripheral stimulus). In the averaging procedure, the first three epochs in each experimental block and epochs in which the EEG or EOG exceeded $\pm 100 \mu\text{V}$ on any of the electrodes were omitted. Epochs with erroneous responses were also excluded from averaging.

2. 4. Data Analysis

Behavioral performance was measured in terms of reaction time, hit rate, and error rate. Responses were scored as hits if the correct button was pressed within 100-800 ms after the onset of the central stimuli. Incorrect responses during this period were classified as errors. To estimate the distraction effects of Large and Small deviant stimuli, the behavioral performance in the Standard trials was subtracted from those in the Large and Small deviant trials (i.e., Deviant-versus-standard comparisons). Also, to estimate the genuine distraction effects of Large and Small deviant stimuli that were not contaminated by the physical difference between the standard and deviant stimuli, the behavioral performances in the Large and Small control trials were subtracted from those in the Large and Small deviant trials, respectively (Deviant-versus-control comparisons). To test the significance of distraction effects, these measures were subjected to one-tailed paired *t*-tests. In addition, to compare the distraction

effects of the Large and Small deviant stimuli, these measures were subjected to repeated-measures ANOVAs with three factors: 2 Deviant types (Large deviant, Small deviant) \times 3 Time intervals (Same, Pre200, Pre400) \times 2 Comparison types (Deviant-versus-standard, Deviant-versus-control). The Greenhouse-Geisser ϵ correction was used to reduce the positive bias of the *F*-test due to possible violations of the assumption of sphericity.

ERPs in response to peripheral stimuli were averaged according to 15 categories defined by 5 types of stimuli (Standard, Large deviant, Small deviant, Large control, and Small control stimuli) and 3 types of time-intervals (Same, Pre200, and Pre400 conditions). To estimate the genuine effects of the Large and Small deviant stimuli, ERPs in response to Large and Small control stimuli were subtracted from those in response to Large and Small deviant stimuli, respectively (e.g., Legrain et al., 2005; Nager et al., 2001; Rinne et al., 2006). Since the effects of stimulus changes on ERPs were not affected by the time-interval conditions (e.g., Escera et al., 2001; Schröger, 1996), to improve the signal-to-noise ratio, difference waves were pooled over the time-interval conditions.¹

In difference waves, Large deviant stimuli were accompanied by five ERP effects: a positivity that peaked at around 100-120 ms after the onset of the peripheral stimulus with a parietal (Pz) maximum scalp-distribution (change-related positivity), a negativity at around 120-140 ms with an occipital (Oz) scalp-distribution (change-related negativity), a positivity at around 160-180 ms with a frontal (Fz) scalp-distribution (frontal positivity), a negativity at around 240-260 ms with an occipito-temporal (PO7 and PO8) scalp-distribution (posterior N2), and a positivity at around 420-440 ms with a wide scalp-distribution over the parietal to frontal (Fz, Cz, and Pz) areas (P3a).

In contrast, Small deviant stimuli were accompanied by four ERP effects: a positivity at around 140-160 ms with a parietal (Pz) scalp-distribution (change-related positivity), a positivity at around 160-180 ms with a frontal (Fz) scalp-distribution (frontal positivity), a negativity at around 240-260 ms with an occipito-temporal (PO7 and PO8) scalp-distribution, and a positivity at around 440-460 ms with a wide scalp-distribution over the parietal to frontal (Fz, Cz, and Pz) areas (P3a). To test the significance of the elicitation of these ERP components, one-tailed paired *t*-tests were applied to the mean amplitudes of the difference waves within the time-windows at the electrodes described above. In addition, to compare the effects common to both Large and Small deviant stimuli, the corresponding mean amplitudes were subjected to repeated-measures ANOVAs with two factors: 2 Deviant types (Large deviant, Small deviant) × Electrodes. The Greenhouse-Geisser ϵ correction was used to reduce the positive bias of the *F*-test due to possible violations of the assumption of sphericity.

3. Results

3. 1. Behavioral Performance

Table 1 shows the behavioral performance in response to the central stimuli (i.e., reaction times, hit rates, and error rates) and Table 2 shows the distraction effects (prolongation of the reaction time, decrease in the hit rate, and increase in the error rate). For the reaction times, Deviant-versus-standard comparisons revealed that Large deviant stimuli prolonged the reaction

times in the Same ($t(11) = 2.51, p < .05$), Pre200 ($t(11) = 5.06, p < .01$), and Pre400 conditions ($t(11) = 2.93, p < .01$), while Small deviant stimuli prolonged the reaction times in the Pre200 ($t(11) = 5.40, p < .01$) and Pre400 conditions ($t(11) = 4.08, p < .01$). Further Deviant-versus-control comparisons revealed that Large deviant stimuli prolonged the reaction times in the Same ($t(11) = 1.88, p < .05$) and Pre200 conditions ($t(11) = 2.08, p < .05$), while Small deviant stimuli prolonged the reaction times in the Pre200 ($t(11) = 4.09, p < .01$) and Pre400 conditions ($t(11) = 3.03, p < .01$). However, no significant effects were revealed in three-way ANOVAs (2 Deviant types \times 3 Time intervals \times 2 Comparison types). With regard to hit rates, Deviant-versus-standard comparisons revealed that Large and Small deviant stimuli each decreased the hit rates in the Pre200 condition ($t(11) = -2.49, p < .05$ and $t(11) = -3.04, p < .01$, respectively). Further Deviant-versus-control comparisons revealed that Small deviant stimuli only decreased the hit rates in the Pre200 condition ($t(11) = -3.65, p < .01$). However, no significant effects were revealed in three-way ANOVAs. With regard to error rates, Deviant-versus-standard comparisons revealed that Large deviant stimuli increased the error rates in the Same ($t(11) = 1.86, p < .05$) and Pre200 conditions ($t(11) = 1.94, p < .05$), while Small deviants increased the error rates in the Pre200 ($t(11) = 2.87, p < .01$) and Pre400 conditions ($t(11) = 1.89, p < .05$). Further Deviant-versus-control comparisons revealed that Small deviant stimuli only increased the error rates in the Pre200 condition ($t(11) = 3.50, p < .01$). However, no significant effects were revealed in three-way ANOVAs.

Insert Tables 1 and 2 around here.

3. 2. *Event-related brain potentials*

Fig. 2 shows the grand averaged ERPs (electrodes: Fz, Cz, Pz, POz, and Oz) in response to Large deviant and control stimuli (Fig. 2A) and Small deviant and control stimuli (Fig. 2B) in three time-interval conditions. In these ERP waveforms, a large positivity that peaked at around 400-450 ms after the onset of the central stimuli with a parietal scalp-distribution was observed (labeled P3b). Furthermore, the ERP waveforms were different for the deviant and control stimuli.

Fig. 3 shows deviant-minus-control difference waves (Fig. 3A) and topographical maps (Fig. 3B) in which the time-interval conditions were collapsed. Large and Small deviant stimuli elicited a negativity that peaked at around 240-260 ms after the onset of the peripheral stimuli with a bilateral occipito-temporal scalp-distribution (labeled posterior N2). After the posterior N2, Large deviant stimuli elicited a positivity at around 420-440 ms with a wide scalp-distribution over the parietal to frontal areas (P3a). Small deviant stimuli also elicited a similar positivity, but it peaked at around 440-460 ms with a slightly more parietal scalp-distribution than the positivity in response to Large deviant stimuli (P3a).

Fig. 4 shows an enlargement of the same difference waves as in Fig. 3A (Fig. 4A) and topographical maps (Fig. 4B). Before the posterior N2 and P3a, Large deviant stimuli elicited a

positivity at around 100-120 ms with a parietal scalp-distribution (change-related positivity), a negativity at around 120-140 ms with an occipital scalp-distribution (change-related negativity), and a positivity at around 160-180 ms with a frontal scalp-distribution (frontal positivity). In contrast, Small deviant stimuli elicited a positivity at around 140-160 ms with a parietal scalp-distribution (change-related positivity) and a positivity at around 160-180 ms with a frontal scalp-distribution (frontal positivity).

Insert Figs. 2-4 around here.

The elicitation of these components was tested by one-tailed paired *t*-tests. For Large deviant stimuli, these tests revealed the elicitation of change-related negativity ($t(11) = -3.16, p < .01$ at Oz within 120-140 ms), posterior N2 ($ts(11) = -4.34$ and $-4.95, ps < .01$ at PO7 and PO8 within 240-260 ms), and P3a ($ts(11) = 2.78, 2.55,$ and $2.28, ps < .01, .05,$ and $.05$ at Fz, Cz, and Pz within 420-440 ms). The elicitation of change-related positivity and frontal positivity was not significant. In contrast, for Small deviant stimuli, these tests revealed the elicitation of change-related positivity ($t(11) = 1.97, p < .05$ at Pz within 140-160 ms), frontal positivity ($t(11) = 1.98, p < .05$ at Fz within 160-180 ms), posterior N2 ($ts(11) = -4.66$ and $-5.69, ps < .01$ at PO7 and PO8 within 240-260 ms), and P3a ($ts(11) = 1.41, 1.68,$ and $2.00, ps < .10, .10,$ and $.05$ at Fz, Cz, and Pz within 440-460 ms).

To compare posterior N2 observed in response to Large and Small deviant stimuli, the mean amplitudes of the difference waves at PO7 and PO8 within the 240-260 ms time-window were subjected to two-way ANOVAs (2 Deviant types x 2 Electrodes). This analysis revealed the main effect of Deviant type ($F(1,11)= 7.90, p < .05$), which was derived from a larger posterior N2 for Large deviant stimuli. To compare P3a, the mean amplitudes of the difference waves at Fz, Cz, and Pz within the 420-440 ms (for Large deviant stimuli) and 440-460 ms time-windows (for Small deviant stimuli) were subjected to two-way ANOVAs (2 Deviant types x 3 Electrodes). This analysis revealed no significant differences for the two deviant types.

4. Discussion

Previous visual distraction studies found that task-irrelevant infrequent changes in location caused attentional capture and behavioral distraction (Berti and Schröger, 2001, 2004, 2006). However, such infrequent changes in location theoretically engage both memory-comparison-based change detection and refractoriness-based rareness detection, and it is unclear whether a genuine memory-comparison-based change detection system is involved in attention switching for subsequent attentional capture. To answer this question, we investigated whether not only infrequent size increments (i.e., Large deviant stimuli) that engaged memory-comparison-based change detection and refractoriness-based rareness detection but also infrequent size decrements (Small deviant stimuli) that engaged memory-comparison-based change detection could cause attentional capture and behavioral distraction. The present study was also intended to

shed light on an ERP correlate of memory-comparison-based change detection in the visual modality.

4. 1. Behavioral distraction and attentional capture by visual stimulus changes

Size increments and decrements both caused significant behavioral distraction. With regard to reaction times, Deviant-versus-standard and Deviant-versus-control comparisons revealed that size increments and decrements prolonged reaction times. With regard to hit rates, Deviant-versus-standard comparison revealed that size increments and decrements decreased hit rates, while Deviant-versus-control comparison revealed that size decrements only decreased hit rates. With regard to error rates, Deviant-versus-standard comparison revealed that size increments and decrements both increased error rates, while Deviant-versus-control comparison revealed that only size decrements increased error rates.

Although a systematic assessment of behavioral distraction is readily available, the present finding that only size decrements caused distraction effects on hit and error rates in Deviant-versus-control comparisons seems interesting. Since size decrements are assumed to only engage memory-comparison-based change detection, they are likely to cause weaker behavioral distraction than size increments. Although further investigations on behavioral distraction are necessary, the present result might be in line with previous findings that behavioral distraction was qualitatively different according to the involvement of memory-comparison-based change detection and refractoriness-based rareness detection (e.g., Alho et al., 1997; Escera et al.

1998, 2000, 2001; Jääskeläinen et al., 1996; Rinne et al., 2006; Yago et al., 2003).

Within the late phase of ERPs (200 ms-), size increments and decrements both elicited a negativity that peaked at around 240-260 ms with an occipito-temporal scalp-distribution, which was larger for size increments than decrements. Berti and Schröger (2006) reported that infrequent location changes at peripheral locations could elicit a negativity that peaked at around 200-300 ms with a posterior scalp-distribution (posterior N2). Although the functional significance of posterior N2 is still unclear, it seems possible that posterior N2 is similar to N2pc (Luck and Hillyard, 1994a), which has been considered to be an ERP correlate of attentional capture (e.g., Eimer, 1996; but see also Luck and Hillyard, 1994b). Further investigations on the nature of posterior N2 are necessary (e.g., contralateralization).

Following posterior N2, size increments and decrements both elicited a positivity that peaked at around 420-460 ms with a wide scalp-distribution over the parietal to frontal areas. The peak latency and scalp-distribution of this positivity are consistent with P3a observed in previous visual distraction studies (e.g., Berti and Schröger, 2001), which has been considered to be an ERP correlate of attentional capture. Although the P3a in response to size decrements has a slightly later peak latency and a slightly more parietal scalp-distribution than that in response to size increments, the differences in the P3a amplitudes were not statistically significant, which indicates that both size increments and decrements elicited similar P3a. ² One might argue that since task-irrelevant stimulus changes occurred at peripheral locations in the present study, it is possible that not only attentional capture but also the cost of spatial filtering could cause behavioral distraction (e.g., Folk and Remington, 1998). However, the elicitation of posterior N2 and P3a,

which have been observed even in response to changes in a task-irrelevant aspect of target stimuli (Berti and Schröger, 2001, 2006), can rule out such an alternative interpretation (for the associated logic, see e.g., Turatto and Galfano, 2001).

In previous visual distraction studies, infrequent changes in location that engaged both memory-comparison-based change detection and refractoriness-based rareness detection caused attentional capture and behavioral distraction (Berti and Schröger, 2001, 2004, 2006). The present finding that size increments and decrements both caused attentional capture and behavioral distraction further indicates that not only stimulus changes that engage both memory-comparison-based change detection and refractoriness-based rareness detection but also stimulus changes that engage memory-comparison-based change detection can cause attentional capture and behavioral distraction (for an alternative account, see below).

Taken together, the present results support the notion that a memory-comparison-based visual change detection system is involved in attention switching for subsequent attentional capture. At present, however, this notion should be treated with caution. To our knowledge, size-specific neuronal organization has not been found in early visual areas. Thus, refractoriness-based rareness detection is assumed to make very little contribution to size decrements. However, one might argue that deviant and standard stimuli differed not only in size but also in some stimulus features such as luminance, spatial frequency, or local contrast, some of which are known to be encoded by feature-specific neural organizations, which would lead to some contribution by refractoriness-based rareness detection to size decrements. In future studies, a direct investigation with a more strict control condition such as that used by Schröger and Wolff (1998)

would be necessary to demonstrate the attention switching function of a memory-comparison-based change detection system.

4. 2. An ERP correlate of memory-comparison-based change detection

The present study may shed light on an ERP correlate of memory-comparison-based visual change detection. Within the early phase of ERPs (100-200 ms), size increments elicited a negativity that peaked at around 120-140 ms with an occipital scalp-distribution, while size decrements did not elicit such occipital negativity. The peak latency and scalp-distribution of the negativity are consistent with those of change-related negativity observed in previous studies (e.g., Alho et al., 1992; Czigler et al. 2002, 2004, 2006; Heslenfeld, 2003; Kenemans et al., 2003; Kimura et al., 2006c; Mazza et al., 2005; Winkler et al., 2005). In previous visual distraction studies, change-related negativity was elicited by infrequent changes in location that engaged both memory-comparison-based change detection and refractoriness-based rareness detection (Berti and Schröger, 2001, 2004, 2006). The present finding that change-related negativity was elicited by size increments but not by size decrements further suggests that change-related negativity could be elicited only when the stimulus changes engaged refractoriness-based rareness detection. In previous studies, several studies have suggested that change-related negativity reflects refractoriness-based rareness detection (e.g., Alho et al., 1992; Kenemans et al., 2003; Kimura et al., 2006c; Mazza et al., 2005). For example, Kenemans et al. (2003) found that change-related negativity could be observed in response to infrequent stimuli even when frequent

standard stimuli were omitted, which supports the notion that change-related negativity reflects refractoriness-based rareness detection (for the associated logic, see e.g., Korzyukov et al., 1999; Näätänen et al., 1989; Sallinen et al., 1994). The present results also support the latter notion that change-related negativity reflects refractoriness-based rareness detection.

In addition, size decrements elicited a positivity that peaked at around 146-160 ms with a parietal scalp-distribution. The peak latency and scalp-distribution of the positivity are consistent with change-related positivity observed in previous studies (e.g., Fonteneau and Davidoff, 2007; Fu et al., 2003; Kimura et al., 2005a, 2005b, 2006a, 2006b, 2006c; Wang et al., 2003). The present finding that change-related positivity was elicited by size decrements suggests that such change-related positivity could be elicited when stimulus changes engage memory-comparison-based change detection but do not strongly engage refractoriness-based rareness detection. However, since size increments also engage memory-comparison-based change detection, change-related positivity should also be elicited in response to size increments. One possible interpretation of the absence of change-related positivity in response to size increments is the overlapping of change-related negativity, which had a similar latency and a posterior scalp-distribution (see Kimura et al., 2006c). In previous studies on the functional significance of change-related positivity, it has been suggested that change-related positivity reflects memory-comparison-based change detection (Fonteneau and Davidoff, 2007; Kimura et al., 2005a, 2005b, 2006a, 2006b, 2006c). For example, Kimura et al. (2006c) found that change-related positivity was observed in response to stimulus changes even when the stimulus changes were not infrequent events, and the amplitude was determined by the mismatch between

the current stimulus and the immediately preceding stimulus regardless of the probability of eliciting stimuli. Since the refractoriness-based rareness detection hypothesis predicts that the amplitude of a change-related component is modulated as a function of the probability of eliciting stimuli, the probability-independent elicitation of change-related positivity cannot be explained by the refractoriness-based rareness detection hypothesis. Thus, this result supports the notion that change-related positivity reflects memory-comparison-based change detection (for the associated logic, see e.g., Giese-Davis et al., 1993; Jankowiak and Berti, 2007; Sams et al., 1984; Sato et al., 2000). In addition, Fonteneau and Davidoff (2007) found that the peak latency of change-related positivity was modulated as a function of the magnitude of stimulus deviance. This result supports the notion that change-related positivity is an endogenous component, as expected by the memory-comparison-based change detection hypothesis, rather than an exogenous component, as expected by the refractoriness-based rareness detection, since the refractoriness-based rareness detection hypothesis predicts amplitude variations rather than latency variations of a change-related effect as a function of the magnitude of stimulus deviance (for similar arguments, see e.g., Näätänen et al., 1989; Tiitinen et al., 1994). The present results partly support the notion that change-related positivity reflects memory-comparison-based change detection.

Following change-related positivity, size decrements elicited a positivity that peaked at around 160-180 ms with a frontal scalp-distribution. Although a similar positivity that peaked at around 160-180 ms with a frontal scalp-distribution was observed in response to size increments (see Fig. 4B), the elicitation was not significant. In a previous study on visual change detection, Heslenfeld (2003) reported that task-irrelevant stimulus changes at peripheral locations could elicit a positivity

that peaked at around 100-200 ms with a frontal scalp-distribution (frontal positivity). Although the functional significance of frontal positivity is still unclear, the author hypothesized that this frontal positivity might be functionally similar to the frontal subcomponent of MMN (Giard et al., 1990), which has been considered to be an ERP correlate of attention switching (e.g., Alho et al., 1994; Näätänen and Michie, 1979) or a contrast-enhancement process (e.g., Doeller et al., 2003; Opitz et al., 2002; Restuccia et al., 2005). The frontal subcomponent of MMN has slightly later latencies than the temporal subcomponent of MMN which reflects memory-comparison-based change detection (Rinne et al., 2000, but see also Yago et al., 2001, for an opposite finding), which is similar to the temporal relationship of change-related positivity and frontal positivity in the present study. Furthermore, the frontal subcomponent of MMN in response to small stimulus changes has greater amplitudes than that in response to large stimulus changes (e.g., Doeller et al., 2003; Opitz et al., 2002), which is similar to the present result that size decrements clearly elicited frontal positivity. Although further investigations on the nature of frontal positivity are necessary, according to the previous interpretation by Heslenfeld (2003), frontal positivity might reflect such an attention switching or contrast-enhancement process in the visual modality.

Taken together, the present results partly support the notion that change-related positivity is an ERP correlate of memory-comparison-based change detection. As mentioned above, stimulus changes in other stimulus features such as luminance, spatial frequency, or local contrast, some of which are known to be encoded by feature-specific neural organizations, should be expected to affect change-related ERPs. However, such effects are assumed to overlap change-related effects in response to both size increments and decrements, and thus different early change-related

effects in response to size increments and decrements should be attributed to energetic increments and decrements. It might also be argued that change-related effects reflect selective-attention-related components, such as P1 enhancement (e.g., Hillyard et al., 1995; Mangun and Hillyard, 1995) and PD130 (e.g., Anllo-Vento et al., 1998; Martínez et al., 2001). However, since both deviant and control stimuli at peripheral locations were task-irrelevant non-target stimuli, it is unlikely that only deviant stimuli elicited selective-attention-related effects. Therefore, the present suggestion that change-related positivity reflects memory-comparison-based change detection would still be valid.

4. 3. Future research

Finally, we point out some important issues that should be addressed in future studies. First, although the present results support the notion that change-related negativity reflects refractoriness-based rareness detection (e.g., Alho et al., 1992; Kenemans et al., 2003; Kimura et al., 2006c; Mazza et al., 2005), change-related negativity has also been thought to reflect memory-comparison-based change detection (e.g., Czigler et al., 2002, 2006; Winkler et al., 2005). For example, Czigler et al. (2006) found that change-related negativity was observed in response to sudden stimulus omission, which supports the notion that change-related negativity reflects memory-comparison-based change detection (for similar arguments, see e.g., Nordby et al., 1994; Tervaniemi et al., 1994; Yabe et al., 1998). Although this discrepant interpretation is difficult to explain, the present results might provide some guidance. In the present study, Large deviant

stimuli elicited two successive negativities (change-related negativity at around 100-200 ms and posterior N2 at around 200-300 ms) (see also Berti and Schröger, 2006). In some previous studies which have suggested that change-related negativity reflects memory-based change detection, a negativity at around 200-300 ms was analyzed as change-related negativity (e.g., Czigler, Weisz, and Winkler, 2006). This negativity seems to be more similar to posterior N2 or N2b than to change-related negativity, and the confounding of change-related negativity and other deviant-related negativities might underlie the discrepant interpretation of change-related negativity. A more detailed definition of these negativities might help to resolve this discrepancy.

Second, although the present results support the notion that change-related positivity reflects memory-comparison-based change detection (e.g., Fonteneau and Davidoff, 2007; Kimura et al., 2005a, 2005b, 2006a, 2006b, 2006c), except for S1-S2 matching studies (Fu et al., 2003; Kimura et al., 2005a, 2005b, 2006a, 2006b, 2006c; Wang et al., 2003) and some oddball studies (Fonteneau and Davidoff, 2007; Kimura et al., 2006c), most oddball studies have not reported change-related positivity. This appears to be inconsistent with the notion that this component reflects memory-comparison-based change detection. However, in some cases, despite the elicitation of posterior positivity at around 100-200 ms, this positivity was not analyzed or fully interpreted. Furthermore, since change-related positivity and change-related negativity have similar latencies and scalp-distributions, the extent of the overlap of these components may influence the appearance of change-related effects (Kimura et al., 2006c). Since there have been few studies that focused on change-related positivity, the further investigation of change-related positivity might contribute to an understanding of change-detection mechanisms in the visual

modality.

Finally, the present study found three early change-related effects (change-related negativity, change-related positivity, and frontal positivity). At present, the precise relationship between attentional capture and these early change-related effects is still unclear. To clarify the mechanisms of involuntary attention in the visual modality, it should be important to determine how these change-related activities are associated with each other and how they contribute to attentional capture.

5. Conclusion

Both infrequent size increments that engage memory-comparison-based change detection and refractoriness-based rareness detection and infrequent size decrements that engage memory-comparison-based change detection caused behavioral distraction. Such behavioral distraction was mirrored by the elicitation of posterior N2 and P3a, which have been thought to reflect attentional capture. Preceding these effects, size increments elicited change-related negativity, while size decrements elicited change-related positivity and frontal positivity. Taken together, these results indicate that memory-comparison-based visual change detection, which is most probably indexed by change-related positivity, is involved in attention switching for subsequent attentional capture.

Footnotes

¹ Previous auditory distraction studies have shown that the effects of task-irrelevant stimulus changes on ERPs were constant regardless of the time-interval between the stimulus changes and task-relevant target stimuli (e.g., Escera et al., 2001; Schröger, 1996). In fact, when the mean amplitudes of the deviant-minus-control difference waves within the corresponding time-intervals were compared by three-way ANOVAs (2 Deviant types (Large deviant, Small deviant) × 3 Time-intervals (Same, Pre200, Pre400) × 7 Electrodes (Fz, Cz, Pz, PO7, POz, PO8, Oz)), no significant effects related to the Time-interval factor were observed. The ERP results also confirmed the involuntary nature of the distraction effects. In previous distraction studies, when target stimuli were preceded by task-irrelevant stimuli, the task-irrelevant stimuli may have been used as warning cues for the following target stimuli (e.g., Alho et al., 1997; Escera et al., 1998). This is the case for the Pre200 and Pre400 conditions in the present study, and the reaction times in response to frequent standard stimuli were actually shorter in the Pre200 and Pre400 conditions than in the Same condition (see Table 1). However, the ERP results confirmed that stimulus changes per se, which were completely task-irrelevant and unpredictable, were processed similarly in the three time-interval conditions.

² The slight differences in the peak latency and scalp-distribution of P3a in response to size increments and decrements might be in line with the classical notion that less-salient stimulus changes elicited P300 with a later peak latency and a more parietal scalp-distribution (e.g., Courchesne et al., 1975; Squires et al., 1975). However, such effects were not robust enough to

tolerate a statistical analysis, which indicates that both luminance increments and decrements elicited similar P3a.

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Figure Captions

Fig. 1. Schematic illustrations of the stimuli, three time-interval conditions, and three probability conditions in the present study.

Fig. 2. A: Grand averaged ERPs in response to Large deviant and control stimuli in the three time-interval conditions. **B:** Grand averaged ERPs in response to Small deviant and control stimuli in the three time-interval conditions. Filled squares in the time scales indicate the presentation of central target stimuli.

Fig. 3. A: Difference waves obtained by subtracting ERPs in response to Large and Small control stimuli from those in response to Large and Small deviant stimuli (the three time-interval conditions were pooled). **B:** Topographical maps of the difference waves within the 240-260 ms, 420-440 ms, and 440-460 ms time-windows (for posterior N2 and P3a).

Fig. 4. A: Difference waves obtained by subtracting ERPs in response to Large and Small control stimuli from those in response to Large and Small deviant stimuli (the three time-interval conditions were pooled). **B:** Topographical maps of the difference waves within the 100-120 ms, 120-140 ms, 140-160 ms, 160-180 ms, and 180-200 ms time-windows (for change-related negativity, CRN, change-related positivity, CRP, and frontal positivity, FP).

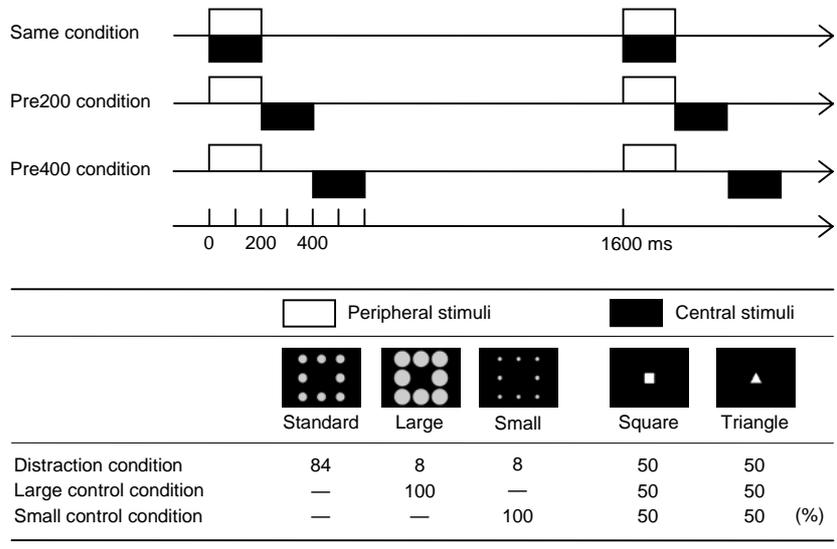
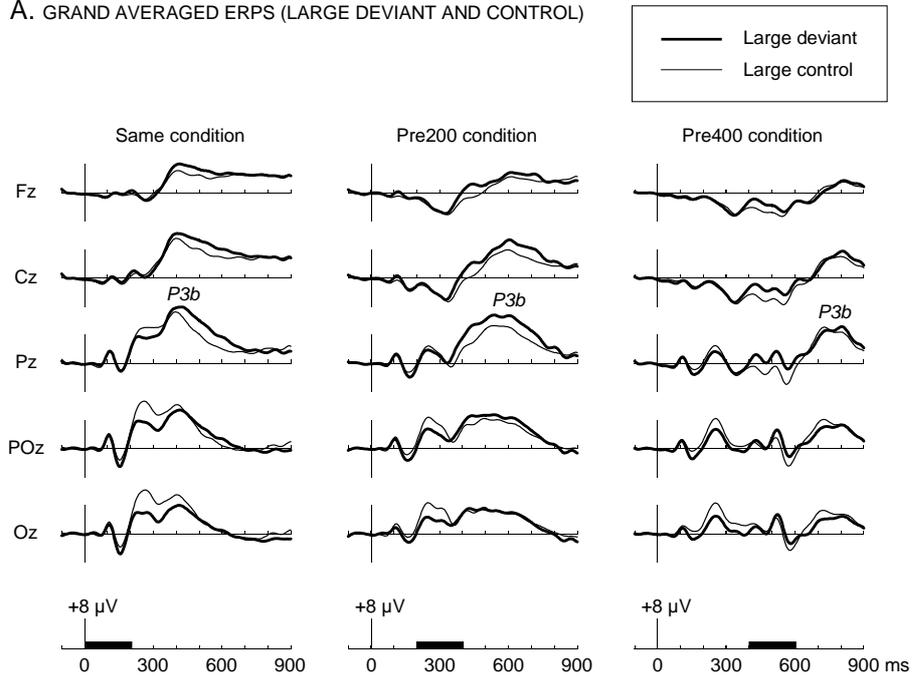


Fig. 1

A. GRAND AVERAGED ERPS (LARGE DEVIANT AND CONTROL)



B. GRAND AVERAGED ERPS (SMALL DEVIANT AND CONTROL)

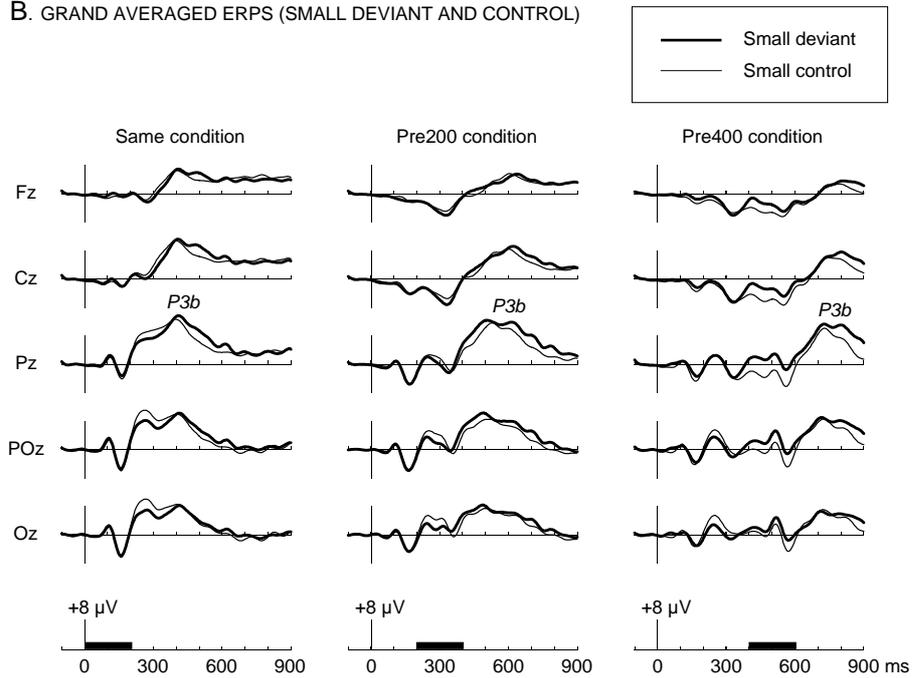
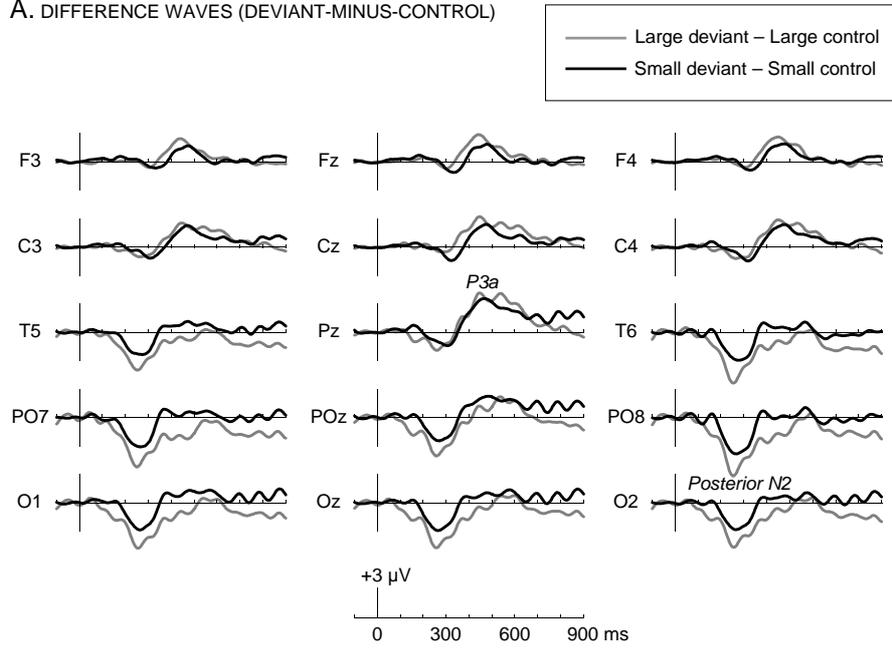


Fig. 2

A. DIFFERENCE WAVES (DEVIANT-MINUS-CONTROL)



B. TOPOGRAPHICAL MAPS OF DIFFERENCE WAVES (DEVIANT-MINUS-CONTROL)

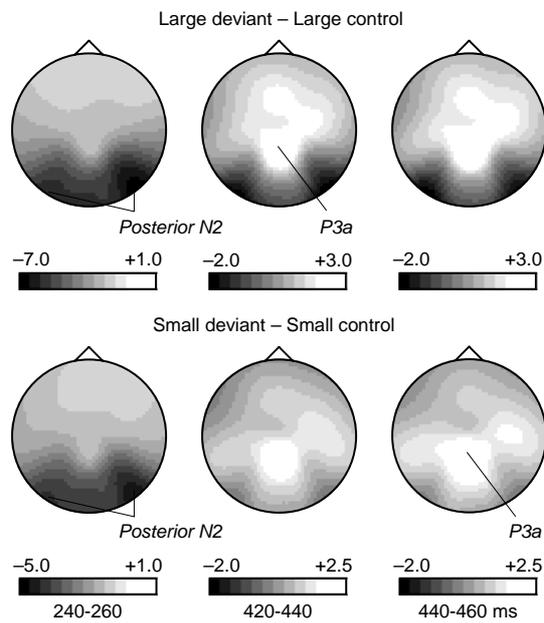
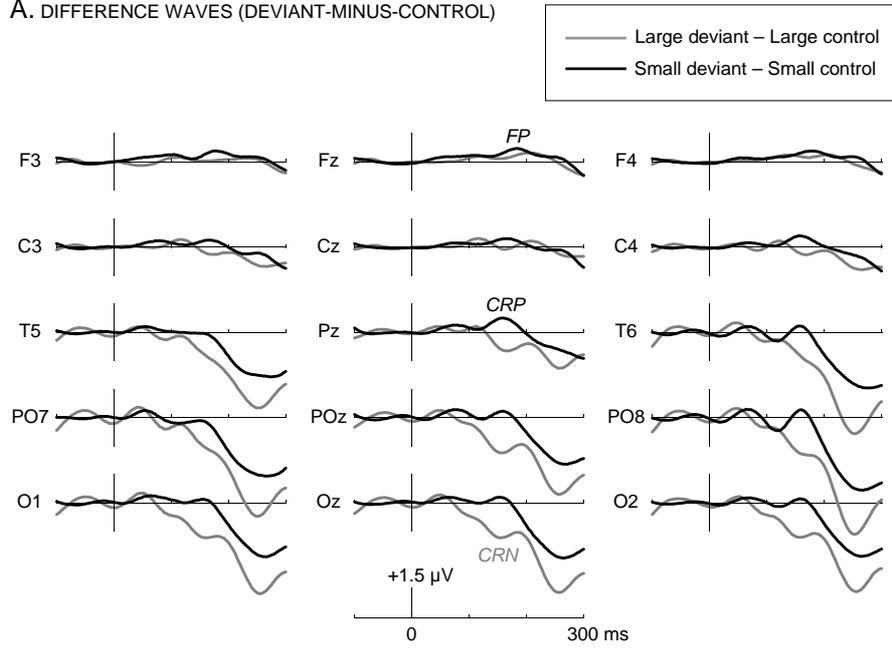


Fig. 3

A. DIFFERENCE WAVES (DEVIANT-MINUS-CONTROL)



B. TOPOGRAPHICAL MAPS OF DIFFERENCE WAVES (DEVIANT-MINUS-CONTROL)

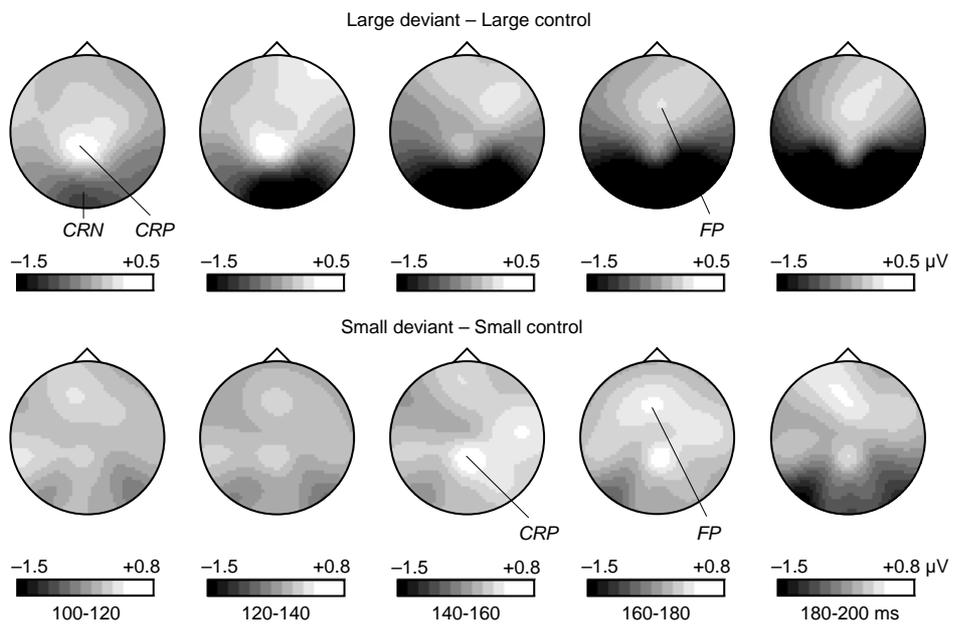


Fig. 4