Is there a mismatch negativity during change blindness?

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The mismatch negativity is an event-related potential that represents a preattentive change detection process. The aim of this study was to determine whether the mismatch negativity was present during 'change blindness', a striking phenomenon in which surprisingly large changes in a complex scene are not seen when they occur during a blink or an eye movement. In this study, large orientation changes elicited a candidate mismatch negativity between 180 and 320 ms that appeared to be independent of participants' performance (uncued 76% correct, miscued 59% correct with chance performance at 50%). This negativity, however, disappeared in the miscued 'change blind' condition. In conclusion, the mismatch negativity does not appear to be present during change blindness suggesting that in complex scenes even large changes may not trigger preattentive change detection processes. *NeuroReport* 17:1011–1015 © 2006 Lippincott Williams & Wilkins.

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Introduction

The mismatch negativity (MMN) is a scalp-recorded event-related potential (ERP) that is evoked when an infrequent change occurs in a sequence of auditory signals [1]. The MMN has been shown to be preattentive as it can be elicited when the participant attends to another task while ignoring the auditory input. The mechanism underlying the MMN is thought to be memory related as it occurs even when a stimulus is omitted from a sequence of rapidly presented tones [2]. At present, evidence exists for an MMN in the visual modality (for a review see Pazo-Alvarez *et al.* [3]). Early negativities over posterior cortex have been found when participants ignore infrequent stimuli while performing an unrelated task [4–7]. These results are very interesting in the context of a phenomenon known as 'change blindness'. This surprising inability to see large changes in a complex scene occurs when the change coincides with a blink or an eye movement [8–10]. Grimes [8] describes how observers often failed to detect striking changes such as the heads of two cowboys being swapped in a computer image. Cueing the participant to the location of change greatly increases the likelihood that the change will be seen [11].

As an explanation for change blindness, Mitroff *et al.* [12] have proposed that change detection may occur only if there is an explicit comparison process between the prechange and postchange scene. Although there is evidence that some cortical activation does occur during change blindness [13–15], it appears to be very limited compared with conscious change detection [15]. An alternative point of view is, however, that changes can be detected preattentively by a process (as indexed by the MMN) that can direct attention to consciously detect change. As the MMN represents an independent-of-cue process, if the participant misses the change owing to an incorrect spatial cue to the location of change, the MMN measured should be present and, crucially, an identical strength during change blindness and conscious change detection.

Previous electrophysiological studies have failed to show this MMN marker of preattentive change detection [14,16–18] but infrequent stimuli, which increase the MMN amplitude, were not presented. The aim of this study was to determine whether the MMN would be present to infrequent changes in a change blindness paradigm.

Methods

Twelve paid participants (university staff and students, aged 18–36 years, mean age 24.5 years, five men) took part in this study. Each participant gave informed consent before participating in the experiments and the study was approved by the departmental ethics committee. Prescreening was conducted to exclude poor visual acuity. The participants sat 1.42 m from the monitor (gamma corrected Phillips model 109E, FIMI, Saronno, Italy, 640 × 480 resolution, 67 Hz) and fixated a small rectangle at the center. Participants used their right hand and keys 0 and 1 on the computer keypad to record 'same' and 'different', respectively. These responses were stored and analysed as behavioural data. The patterns were presented for 100 ms and there was a 900 ms interstimulus interval. To discourage a conservative response bias, participants were given written instructions on the nature of the task, designed to ensure they understood that some of the changes would be miscued. As shown in Fig. 1, each element of the pattern was a 'grating patch' (a D6 pattern [11,19] with a six cycles per degree dominant spatial frequency). These stimuli were chosen as simplified patterns, eliciting smaller visual-evoked potentials, thus improving the identification of the MMN. Six of these elements were presented on an equiluminant grey background at an eccentricity of 2.9°. To provide a control for stimulus-related potentials, two patterns were alternated every 300 trials. The orientations in base pattern 1 were 22, 65, 145, 100, 39 and 119° (to the vertical). The orientations in base pattern 2 were orthogonal to these.

Change blindness was maximized by miscuing participants from the spatial location of the change using a cue at the centre of the screen (see Fig. 1). There were three conditions: correctly cued, uncued and miscued. Before the onset of the first pattern of the pair presented, the correctly cued trials had a cue pointing to the patch in which a change might occur. The uncued trials were preceded by a cross at fixation that did not give any cue to which patch might change. The miscued trials always had a cue that pointed to a patch that did not change. To ensure that the participants paid attention to the cue, there was a difficult to detect change of just 12° that occurred on 50% of cued trials. During pilot studies, a 90° change in orientation in one element of a six-element pattern was found to be rarely seen (56%) when participants were miscued, but was more easily seen when the patterns were correctly cued (92%) or uncued (80%). As the auditory MMN tends to increase in size with larger changes (for a review see Näätänen [1]), the miscued and uncued trials had changes of 90° (and again these changes occurred on 50% of trials). To ensure that the 90° change occurred infrequently, correct cueing occurred on 60% of change trials, the remaining trials being an equal proportion of miscued and uncued trials. Therefore, the 90° change only occurred on 20% of all the trials during the experiment.

ERPs were recorded using InstEP version 4.2 recording software (InstEP Systems, Ottawa, Canada). Electroencephalogram was recorded from 20 scalp electrodes (Iz, Oz, POz, Pz, Cz, Fz, O1, O2, P9, P10, P7, P8, PO7, PO8, P3, P4, C3, C4, F3, F4) and referenced to an electrode on the right mastoid. Ground was at AFz. Analogue filters were high pass 0.08 Hz and low pass 100 Hz. Impedances were reduced to below 10 kΩ. Horizontal and vertical electrooculograms were recorded and any trial with voltage above 100 μV was removed, so that trials with blinks and large eye movements would be removed from the final average. Each participant had 1800 trials recorded in total and this allowed, after artifact rejection, a mean of 125 trials per average.

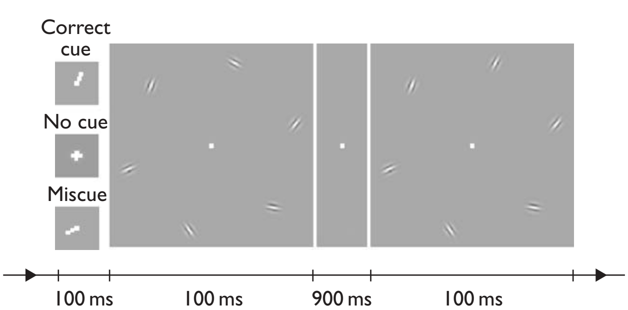

Fig. 1 Stimulus presentation paradigm. The time-line indicates the order and duration of the stimuli; at 4000–4100 ms after the start of the last stimulus pair, cues were presented in the centre of the display and pointed to the patch that may change (correctly cued) or to a patch that would remain unchanged (miscued). On uncued trials, the cross appeared instead of the spatial cue. Changes of 90° occurred infrequently: on 20% of trials. In this figure, the top-most element had a 90° change in orientation.

All statistical tests were calculated using SPSS for Macintosh Version 9 (SPSS Inc., Woking, UK). For repeated-measures analysis of variance, corrections to the degrees of freedom were made using the Geisser–Greenhouse F-test [20].

To assess the difference between 'no-change' and 'change' trials, the ERPs to the second pattern of the pair were analysed. This was performed irrespective of whether the participants' responses were correct or not. The measures taken were mean amplitudes in the selected time windows. The early negativity was measured at all electrodes between 180 and 320 ms and the later positivity was measured between 350 and 600 ms. Inspection of the subtracted grand average waveforms (Fig. 2) reveals that the early negativity may be slightly later in the miscued trials. Latency was not measurable owing to poorly defined early negativity at some electrodes sites. Hence, the broader time windows were selected to accommodate possible differences in latencies.

Results

Behavioural data

The cued (12°) performance was $74.2 \pm 1.9\%$ (standard error across participants). The uncued (90°) performance was $75.9 \pm 2.1\%$ correct, whereas miscued performance for the same 90°change, was poorer at $59.5 \pm 1.9\%$.

Event-related potential data

Uncued trials

Figure 2 shows the second-half of the trial pair for 'change' minus 'no-change' trials. Inspection of Fig. 2 indicates two candidate components representing change detection. An early negativity exists over the posterior electrode sites with a polarity reversal at anterior sites [comparison over the interval of 180–320 ms gives $F(3.3,35.8)=8.01$, $P<0.0001$]. A positive component also exists across the scalp, the P3 [comparison over the interval of 350–600 ms gives $F(1,11)=7.7$, $P<0.02$].

Miscued trials

As in the uncued case, to detect specific markers of change, the 'no-change' trials were subtracted from the 'change' trials. Again, there was an early negativity to change over the posterior electrode sites with a polarity reversal at anterior sites [$F(2.8,31.5)=4.0$, $P<0.025$]. From the grand averages however, there was no significant P3 in the time interval 350–600 ms [$F(1,11)=1.3$, $P=0.27$].

Cued trials

From Fig. 2 it appears that the early negativity to change is slightly larger in the cued condition. The negativity,

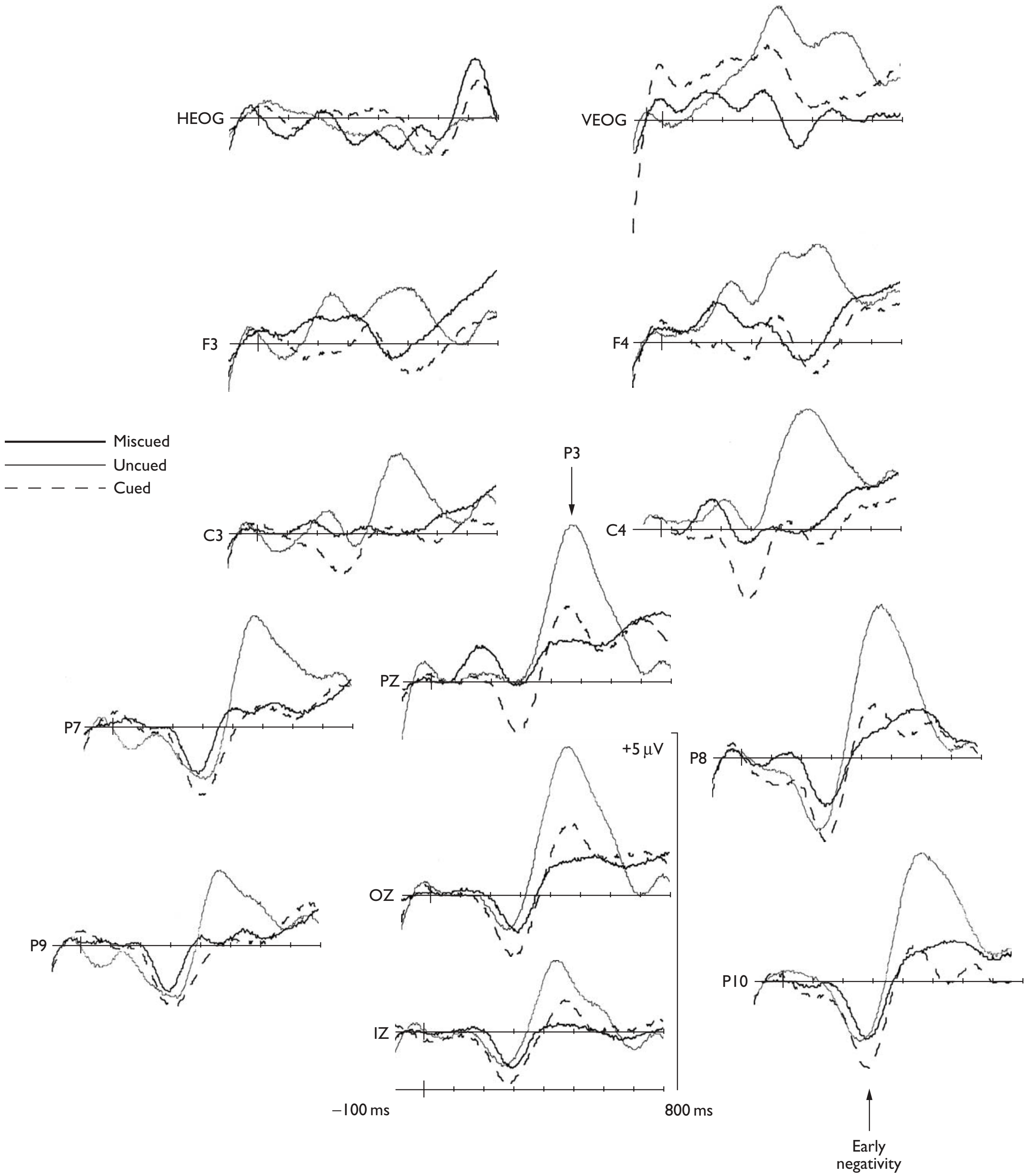

Fig. 2 Grand average (n=12) of cued, uncued and miscued difference waveforms (change−no change). A statistically significant early negativity exists in the miscued and uncued conditions. The P3 is statistically significant in the uncued and cued conditions.

however, was not statistically significant owing to increased variability of data, although there was significance before the Geisser–Greenhouse corrections. A small P3 was seen on the grand average at midline sites and this component was significant [F(3.9, 43.3)=3.03, $P<0.03$].

Comparison of the early negativity across all conditions
No significant difference exists between the early negativity elicited in the uncued, miscued and cued conditions (F(1.96,22.16)=1.735 $P=0.200$). In addition there was no significant difference between conditions in the

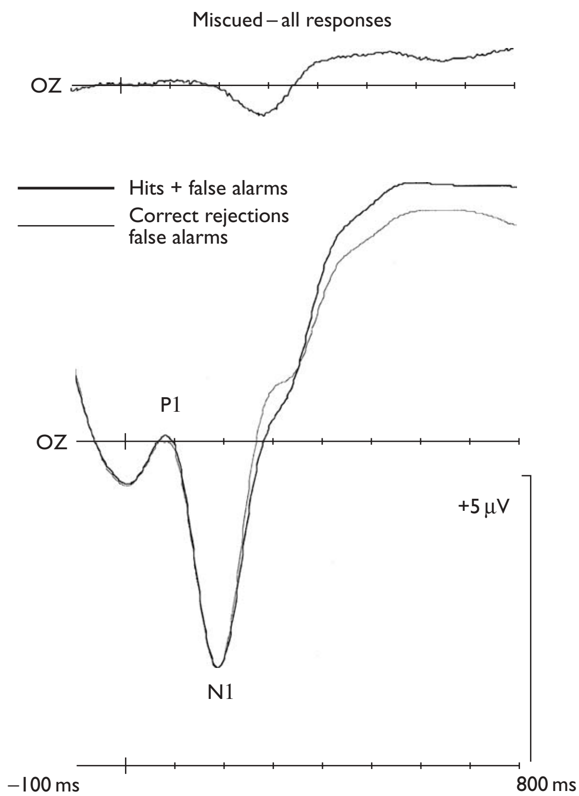

Fig. 3 Is there a mismatch negativity (MMN) for undetected change trials in the miscued condition? The lower waveforms are unsubtracted grand averages. The top traces are subtracted waveforms. In the low-performance, miscued condition, the sensory P1 and N1 are unaffected by change but there is a later, change dependent, early negativity. It was not, however, present for 'misses' leaving no evidence for an MMN during change blindness.

distribution of the early negativity across the scalp (F(4.464, 49.1)=0.359).

Comparison of the late positivity across all conditions

A trend towards significance for differences between the positivities elicited in the uncued, miscued and cued conditions in the 'P3 interval' [(F(1.71,19.48)=3.029 $P=0.077$)] exists. No significant difference, however, exists between conditions in the distribution of this positivity across the scalp [F(6.043, 66.468)=0.359].

Miscued misses

Figure 3 shows that the P1 and N1 peaks are identical regardless of whether the participants detect the change or not. The left side shows waveforms in which all responses are averaged together, whereas the right-hand side looks at 'misses' in isolation. As noted above, there is a clear early difference after N1 as shown on the traces on the lower left side. The difference on the upper left shows that there is a clear early negativity. This miscued data suggest that this negativity is a marker for change detection, independent of participant responses. This interpretation, however, did not survive further analysis. When 'misses only' were analysed in this condition, there is no discernable early negativity between 180 and 320 ms [F(2.991,32.9) = 1.016, $P=0.398$] as shown in the top right traces.

Discussion

The aim of this study was to determine whether an MMN could be elicited under conditions of 'change blindness'. The working hypothesis was that the MMN, if present, would be similar in size during change blindness compared with change detection. To support this, an early negativity was found even when participants' performance dropped to 59% in the miscued condition. Moreover, a later positive peak (P3) was large when the participant was detecting the stimulus at 76% correct but was much smaller when performance declined to 59%. A critical finding in studies attempting to show that MMN is preattentive is that the P3, indicating attentive processing, is minimal. The dissociation of the early negativity and the P3 when miscued might lead to assumptions that this peak was an MMN. In the uncued condition it is tempting to posit a mechanism, represented by the MMN, responsible for calling attention to the location of change. When miscued it would be expected that the MMN would still operate, but owing to focused attention a shift in attention may not occur, leading to a decrease in performance. This is indeed what was concluded initially because the early negativity appeared to be similar in the miscued and uncued conditions. Further analysis, however, demonstrated that this conclusion was premature: the early negativity disappeared when the misses were isolated from the hits. This does not appear to be due to confounds such as eye movements or loss of vigilance as the P1 and N1 are identical regardless of whether the participant missed the change. Of course, one could argue that the lack of an MMN in the misses is the cause of the participant missing the change. The major determinant in the participants' performance in this study, however, is the validity of the cue. As the MMN is conceived as preattentive, it cannot by definition be influenced by cueing. Furthermore, the

MMN might be expected to be influenced by the size of the change and little difference was seen between the response to the 12 and 90° change. Therefore, it is concluded that the early negativity seen in this study is not an MMN.

What then, might this early negativity represent? As participants detection performance is above chance in the miscued condition, it is likely to be an N2pb, a peak that represents target detection and is sensitive to probability [21]. This N2pb has been described in visual search experiments and was shown to have the predominantly posterior distribution found in this study.

Given that there is a similar N2pb in both conditions, why is the P3 present in the uncued, but much reduced in the miscued condition? Previous work has shown that the size of the P3 is related to the degree of confidence of detection [22]. For instance, it was demonstrated that there was P3 to highly confident false alarms and to hits that were similar in size. Therefore, the large P3 in the uncued condition indicates that participants are confident of detection of change. In the miscued condition, the participants are least confident (as reflected by their poor performance) and therefore have a negligible P3.

Conclusion

Why was there a failure to observe an MMN? This experiment was motivated by the possibility that the large changes not consciously recognized in change blindness might, nevertheless, trigger preattentive processes that would evoke an MMN. Owing to the miscueing design, large changes, over six times the threshold for cued detection, were often missed by participants. It is unlikely that inadequate signal-to-noise ratio is an issue as there was a significant ERP response (the N2pb) to the change despite the participants' performance being close to chance levels. A more plausible explanation is that the MMN process is unable to operate even for changes that would be detectable by an attending observer and that much larger changes are required to activate the MMN process. Future studies investigating the type of changes required to trigger preattentive visual processing in complex scenes would be of interest.

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