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Brief article

Looking without seeing the background change: electrophysiological correlates of change detection versus change blindness

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Abstract

We examined electrophysiological correlates of conscious change detection versus change blindness for equivalent displays. Observers had to detect any changes, across a visual interruption, between a pair of successive displays. Each display comprised grey circles on a background of alternate black and white stripes. Foreground changes arose when light-grey circles turned dark-grey and vice-versa. Physically stronger background changes arose when all black stripes turned white and vice-versa. Despite their physical strength, background changes were undetected unless attention was directed to them, whereas foreground changes were invariably seen. Event-related potentials revealed that the P300 component was suppressed for unseen background changes, as compared with the same changes when seen. This effect arose first over frontal sites, and then spread to parietal sites. These results extend recent fMRI findings that fronto-parietal activation is associated with conscious visual change detection, to reveal the timing of these neural correlates. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

One of the most impressive demonstrations of the role of attention in conscious vision is provided by the 'Change Blindness' phenomenon (O'Regan, Rensink, & Clark, 1999; Rensink, O'Regan, & Clark, 1997). This is the inability of observers to consciously see substantial changes in a scene in the presence of some other visual interruption such as

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flicker, ‘mudsplashes’ elsewhere, eye movements or blinks (Simons & Levin, 1997; Levin & Simons, 1997; McConkie & Currie, 1996; O’Regan, Deubel, Clark & Rensink, 2000). Attentional rather than sensory limits are a key factor. Changes are often missed in less attended regions (Rensink et al., 1997), while items that attract attention due to salient visual features (Turatto & Galfano, 2001) undergo less change blindness (Scholl, 2000).

However, saliency for attention is not determined solely by simple physical features, but also by Gestalt organization. Perceptual units resulting from image segmentation are organized into figures versus ground (Wertheimer, 1923), with the former more salient regardless of their physical properties (Rubin, 1921). One prediction tested in the present study was that change blindness should be more pronounced for grounds than for figures, even when the ground undergoes physically stronger changes.

A second issue addressed was the neural correlates (and level of information processing) for distinguishing change detection versus change blindness, for the same physical stimulus. An event-related potential (ERP) method (e.g. Luck, Woodman, & Vogel, 2000) is well suited for addressing this. Recognizing a scene modification across an interruption (here a blank) implies a comparison between the present visual representation and that of the previous scene from before the blank (Rensink et al., 1997). We may therefore expect that change detection will involve post-sensory mechanisms, like updating of working memory, whose electrophysiological correlates typically start 200–300 ms after stimulus onset, as for the P300 (Donchin & Coles, 1998; Luck et al., 2000; Vogel, Luck, & Shapiro, 1998).

Identification of any ERP components evoked by change detection versus blindness, together with their distributions over the scalp, might provide insight into the temporal aspects of neural activity associated with conscious change detection (see also Fernandez-Duque, Grossi, Thornton, & Neville, 2000; Niedeggen, Wichmann, & Stoerig, 2001). A recent fMRI study (Beck, Rees, Frith, & Lavie, 2001) indicated that conscious detection of change (compared with the same stimulus changes when missed) activated areas of parietal and frontal cortex. It was suggested that interplay between frontal-parietal circuits involved in attention and posterior visual areas involved in extracting particular visual properties may play a crucial role in visual awareness. Because of the relatively poor temporal resolution of fMRI, the role of different components in the activated network, at different points in time, could not be addressed. While ERPs have poorer spatial resolution than fMRI, they can provide better temporal resolution. They could address whether cortical activity associated with conscious change detection follows a posterior-to-anterior sequence (Driver, 1995), or vice-versa.

We used a one-shot technique (Phillips, 1974), in which just two displays (S1 and S2) of simplified stimuli were separated by an intervening blank. Each display comprised six disks (light or dark grey) on a background of alternating black and white vertical stripes (Fig. 1). Subjects had to report whether *anything* changed between S1 and S2. Changes in luminance could apply either to the figural dots (each changing from light to dark grey, or vice-versa), or to all the background stripes (a stronger physical change, with each black stripe becoming white and vice-versa). Even though the strong background changes arose in the same domain (luminance) as any foreground changes, we anticipated that background changes might often be missed. If this is due to a tendency to attend figural items, then background changes should become more detectable when attention is directed to them. In the first

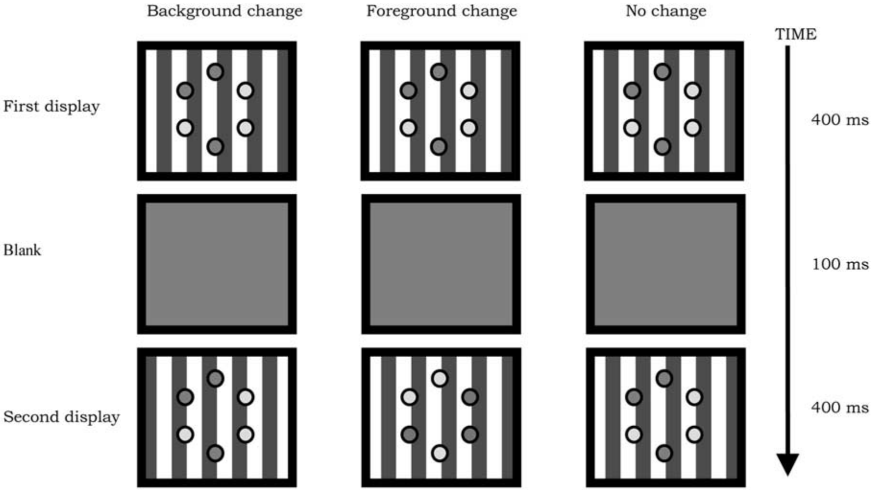

Fig. 1. Examples of displays and events used with time running downwards for each column. The left column depicts background change: all black stripes turn white and vice-versa. The middle column depicts foreground change: all dark-grey disks become light-grey and vice-versa. The right column depicts the no change condition.

block, no information was provided about the location of the possible change. Before the second block, possible background changes were mentioned, and then on each trial a cue indicated where any change could occur (foreground versus background).

2. Method

2.1. Participants

Participants were 11 right-handed, paid volunteers (six males, five females, 22–28 years). All had normal or corrected vision.

2.2. Apparatus and materials

The display (Fig. 1) comprised six grey disks (three light-grey and three dark-grey, each 1° diameter), equally spaced around an imaginary central circle covering 4.7°. The disks appeared on a background of 20 vertical stripes, alternating black and white, with each stripe covering 1°. Each disk was centred on the edge between two stripes. Light-grey disks had a luminance of 43 cd/m^2, dark-grey disks 10 cd/m^2, white stripes 56 cd/m^2, black stripes 6.5 cd/m^2, and blank screen luminance was 0.10 cd/m^2. Displays appeared on a Sony 19 inch monitor (640×480, 75 Hz) at a 1 m viewing distance.

2.3. Design and procedure

There were two blocks of 120 trials: 40 no change trials, 40 background change trials, and 40 foreground change trials, all intermingled. Twelve practice trials preceded each block.

On each trial, an original (S1) and then a potentially modified version (S2) of the same display were each presented for 400 ms, separated by an intervening ‘flicker’ (blank screen) of 100 ms. Background changes consisted of all stripes changing polarity (black to white and vice-versa), and foreground changes were analogous (all light-grey disks became dark-grey, and vice-versa). Background changes were physically stronger, both in terms of the area affected, and local luminance change (49.5 cd/m^2 for stripes, 33 cd/m^2 for disks).

Initial instructions were equaled for emphasis with respect to figure and background: ‘On each trial two consecutive images will appear on the screen for 400 ms. The images will be separated by a blank, which lasts for 100 ms. Each image consists of six circles which stand on 20 black-and-white vertical stripes. Your task is to detect, if present, any change in the second image’. In the first block (uncued), each trial began with the word ‘Attention’ for 500 ms, with the screen then becoming blank for 1 s. The two successive displays were then presented, separated by the brief blank. Before the second block began, subjects were asked if they had noticed background changes to the stripes in previous trials (none had done so). In the second block (cued) the word ‘Attention’ was replaced either by the word ‘Background’ or ‘Circles’, now indicating where a change, if any, would arise. The no change trials presented the word ‘Background’ or ‘Circle’ equiprobably. One second after the offset of S2, the question ‘Did you see any change?’ appeared. Participants indicated change or no change with unspeeded key-presses.

EEG was recorded by a Neuroscan system with two Synamp amplifiers and Neurosoft software. An elastic cap (Electrocap) had 19 tin-electrodes at standard positions (10–20 System; Jasper, 1958), referred to linked mastoids. Two additional electrodes were placed above and below one eye, with two on the external canthii. Signals were band-pass filtered at 0.01–30 Hz and sampled continuously at 250 Hz. Resolution was 0.08 μV/bin. After acquisition, data were epoched in the interval -700 to $+3000$ ms referred to S2 onset. Analysis included epoch detrend, baseline (-700 to –500 ms) subtraction, eye-blink artefact correction, 10 Hz low-pass filtering, epoch cutting (new interval: -700 to $\pm$ 1000 ms), discarding of trials affected by detectable artefacts, and finally averaging of all accepted trials within each condition. Planned statistics were computed on three groups of electrodes: frontal (F3-F4), parietal (P3-P4), and occipital (O1-O2). Five time windows were chosen a priori. Three served as controls: -200 to -100 ms (i.e. 300–400 ms post-S1), 0–100 ms, and 100–200 ms. Two intervals were of primary interest for the experimental hypotheses: 200–300 ms (which should overlap with any N2 evoked by S2) and 300–400 ms (corresponding to the P300 evoked by S2). Statistical analysis concerned the mean amplitude of potentials measured in each time window. Scalp activity maps were obtained through Spline Interpolation.

3. Results

3.1. Behavioural data

For uncued trials, any background change was typically missed despite its physical strength, with a mean hit-rate of only 10% (not different from the false-positive rate of

13% on no change trials). At the end of the first (uncued) block, subjects were explicitly questioned about background changes. None of them reported having seen any background changes, and all showed surprise. This seems to rule out the possibility that background changes had actually been seen, but were considered irrelevant at the time. In the second block, following the questions about the background and the introduction of trial-by-trial cues, subjects had no problem in detecting the same background changes (88%). When the change was in the foreground, regardless of cueing/instructions, subjects detected it reliably (uncued, 98%; cued, 97%), even though the physical change was much smaller than for background changes. Percentage correct detection was entered into a two-way repeated measures ANOVA, with factors of Cueing (cued versus uncued block) and Change location (background versus foreground). The interaction was significant ($F(1, 10) = 108.21$, $P < 0.0001$). These results show that change blindness is stronger for background than foreground changes (even when the former are physically stronger than the latter), and that this depends on attention, being eliminated when attention is cued to the background.

3.2. ERP data

Since change detection across visual interruptions presumably relies on a post-sensory comparison process (Rensink et al., 1997; Simons & Levin, 1997), we expected change detection versus change blindness to primarily affect post-sensory ERP components, such as the P300 (Donchin & Coles, 1998; Luck et al., 2000; Vogel et al., 1998).

We ran planned comparisons on two separate time windows: 200–300 ms and 300–400 ms from the onset of S2. Measuring earlier ERP components (e.g. P1 and N1) is not straightforward in our paradigm, as sensory ERPs caused by offset of the first stimulus may overlap those evoked by onset of the second.

For both time windows, initial planned analysis focused on mean amplitudes of frontal (F3-F4), parietal (P3-P4), and occipital electrodes (O1-O2), collapsed over left and right hemispheres. Data were entered into a three-way repeated measures ANOVA, with factors of Cueing (cued versus uncued blocks), Change location (background versus foreground), and Electrode site (frontal, parietal, or occipital). Note that cued background changes were typically detected, whereas uncued were not. Further comparisons used Newman–Keuls tests.

3.2.1. 200–300 ms time window

Waveforms elicited by background or foreground changes, as a function of instructions, are plotted in Fig. 2 (frontal electrodes at the top, then parietal, with occipital at the bottom). When the background changed, the P300 evoked at frontal sites was present in the cued condition (where background changes were consciously detected) but absent in the uncued condition (where they were not). This is also evident in the scalp activity maps (Fig. 3, compare the 208, 260, and 312 ms maps in the uncued versus cued background conditions, i.e. the lower two rows). By contrast, when the change was in the foreground, the P300 was unaffected by the attentional cueing instructions (Fig. 2, right column), consistent with the behavioural results.

ANOVA showed a main effect of electrode ($F(2, 20) = 14.7$, $P < 0.0002$), with occi-

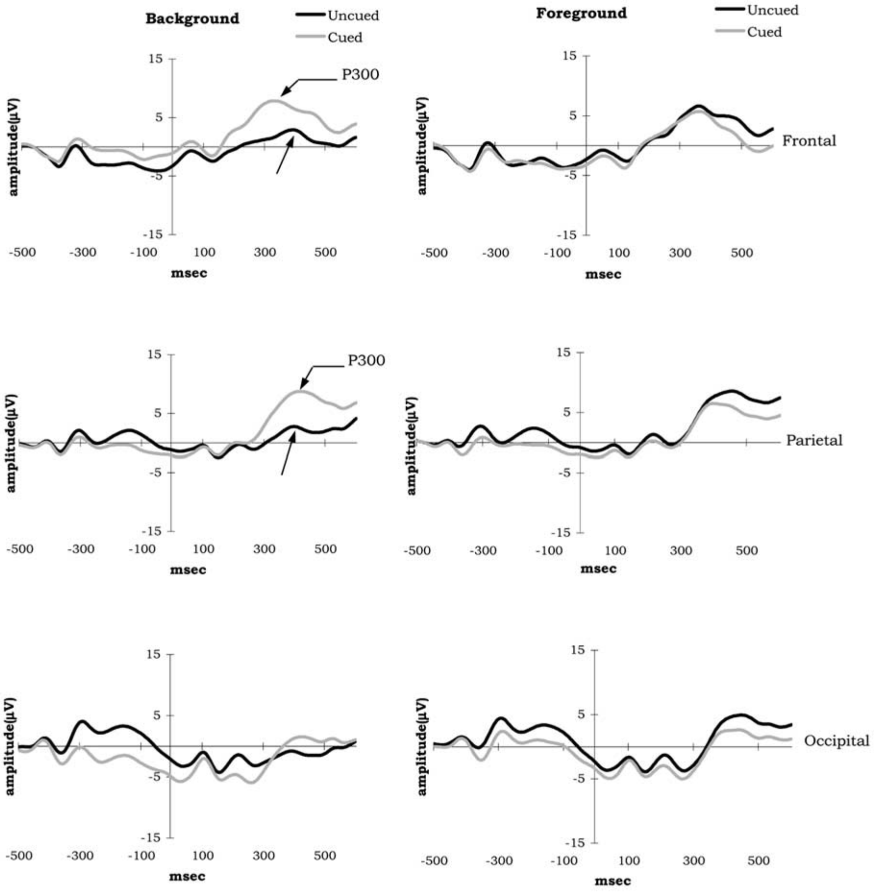

Fig. 2. ERP waveforms at frontal, parietal and occipital electrode sites for background and foreground changes as a function of attentional instructions. At frontal and parietal sites, the amplitude of P300 for background changes depended on whether attention was cued to the background (associated with enhanced P300 amplitude, and also conscious change detection; see behavioural results) or not cued (associated with smaller P300 amplitude and missed changes). This difference emerges earlier at frontal sites. No effect of instructions on the P300 emerged with foreground changes, for which the change was reported correctly regardless of cueing.

pital sites more negative than parietal or frontal (−3.60, 0.02 and 2.50 μV respectively; all $P < 0.004$). This may reflect the involvement of posterior visual areas in response to the visual displays and task. The critical three-way interaction was also significant ($F(2, 20) = 10.4$, $P < 0.0008$). Further analysis confirmed that, at frontal sites, P300 amplitude for background changes was much larger in the cued than uncued condition (4.85 versus 0.58 μV, respectively; $P < 0.01$). No significant differences between cued and uncued conditions were found for the foreground change. In addition, in the uncued condition, a decreased positivity emerged for background versus foreground changes (0.58 versus 2.09 μV, respectively; $P < 0.02$).

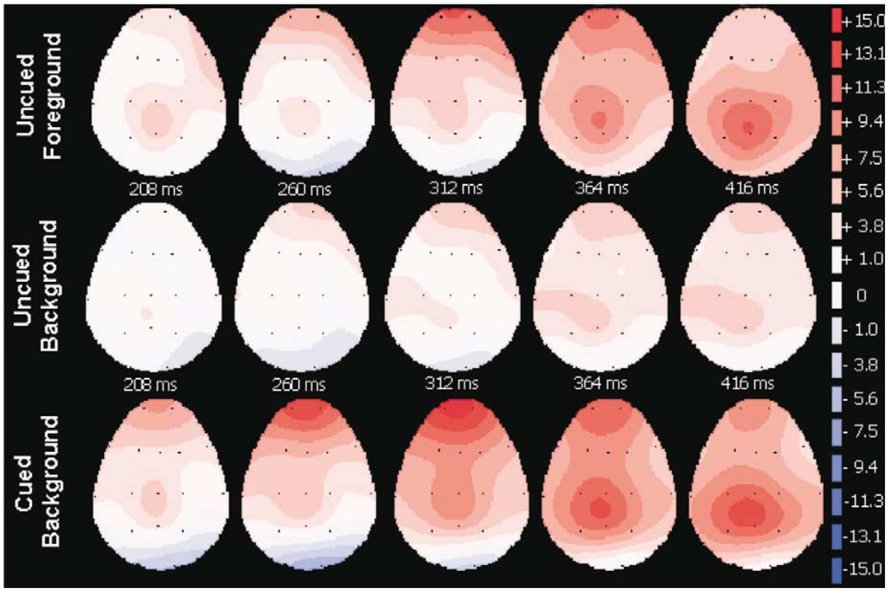

Fig. 3. Scalp activity maps constructed from 19 electrodes. Each map represents a 52 ms interval. The overall time window represented here is 208–416 ms post-S2 onset. The two most important pair-wise comparisons of conditions are both represented: foreground versus background uncued changes, in the top versus middle rows; and uncued versus cued background changes, in the middle versus bottom rows, respectively. See text for further details.

3.2.2. 300–400 ms time window

The effects found earlier (200–300 ms window) at frontal sites now spread toward posterior sites. This is evident in the scalp activity maps of Fig. 3: for conditions associated with conscious change detection (i.e. rows 1 and 3) there was a shift from frontal to parietal sites at later times. The three-way interaction was again significant ($F(2,20) = 6.9$, $P < 0.005$). The difference in P300 amplitude for detected minus undetected background changes was now present at both frontal (2.11 versus 7.44 μV) and parietal (1.47 versus 6.24 μV) sites (both $P < 0.0001$), but not at occipital sites (-1.58 versus -0.99 μV; NS). In the uncued conditions, background changes did not elicit a P300 unlike foreground changes, at all sites (all $P < 0.006$), but with a gradient showing the greatest effect at frontal sites (2.11 versus 5.91 μV, respectively) and the smallest at occipital sites (-1.58 versus 0.81 μV, respectively).

3.3. Control ERP analyses on earlier time windows

As a control, analogous analyses were performed for earlier time windows (-200 to -100 ms) prior to the onset of S2 to address any possible differences in a P300 evoked by S1 only, and also on the 0–100 and 100–200 ms time windows post-S2 to explore any early differential components triggered by S2. The comparisons of background versus foreground (uncued condition) and cued versus uncued (background condition) did not reach significance for any of these time windows (maximum observed difference: 0.50 μV; in the post-hoc analyses all $P > 0.45$). However, instructions about where to expect any change (cued minus uncued conditions) elicited a relatively greater positivity in the background than foreground condition at frontal sites in the time windows of −200 to −100 ms, and also 0–100 ms (−1.13 versus −3.15 μV and 0.20 versus −2.26 μV, respectively; both $P < 0.04$).

Finally, for all time windows analyzed, there was no difference in EOG activity between different experimental conditions (e.g. for the critical cued versus uncued background changes), which indicates that eye movements, if any occurred, cannot account for the critical results.

4. Discussion

The present study combined ERP methods and behavioural reports to investigate electrophysiological correlates of conscious change detection versus change blindness for the very same sequences of two consecutive displays separated by a blank. We also investigated whether change blindness is more pronounced for backgrounds than for figures, and the role of attention in this.

Behavioural data showed that, in the absence of instructions about change location, subjects were often blind to background changes, but accurately reported foreground changes, despite changes in the former being physically much stronger than in the latter. However, when attention was directed to the background, the same changes there now became readily detectable. Thus, attention to the background appears necessary to consciously perceive changes there. If no explicit instructions are provided about attending the background, attention is apparently directed by default (whether this be on a top-down or bottom-up basis) towards foreground items.

Importantly, ERP analysis revealed that the P300 elicited by a seen change was absent when the change was missed (see also Fernandez-Duque et al., 2000; Niedeggen et al., 2001). This ERP component closely accorded with the psychophysical reports, with change blindness being associated with elimination of the P300, an ERP wave thought to reflect updating of working memory (Donchin & Coles, 1998), and conscious target identification processes (Vogel et al., 1998). Further comparisons of ERPs for no change trials versus missed background change trials might in principle reveal any implicit processing of change. In the present study no significant effects were found for this (see also Niedeggen et al., 2001, who used cyclical displays rather than a single-shot presentation). However, any such implicit effects might involve early sensory components, for which we had little power here given the temporal proximity between S1 offset and S2 onset in our one-shot technique.

Our ERP result for change blindness (compared with conscious change detection) parallels that found for another form of induced blindness in normal observers, the ‘attentional blink’ (AB). For a rapid stream of successive visual stimuli, AB comprises an impaired identification of a second target (T2) when presented in a temporal window within 300 ms from a detected preceding target (T1). As compared to when the only task is to detect T2, the corresponding P300 is suppressed when AB occurs (Vogel et al., 1998). This resembles the present finding of an eliminated P300 for change blindness, and suggests that these two forms of attention-related induced blindness may be functionally similar.

Our ERP results also showed that even when the scene modification was invariably reported correctly (i.e. for cued conditions), background and foreground changes were processed somewhat differently, with higher positivity for cued background changes than foreground changes. Interestingly, some of this difference was found even before the change took place (i.e. prior to S2), which points to preparatory effects when anticipating a particular type of change on cued trials.

A critical new result concerns the timing and cortical distribution of the ERP components associated with conscious change detection versus change blindness. As emerges from inspecting scalp activity maps (Fig. 3), and as confirmed by our analyses of 200–300 and 300–400 ms time windows, differential P300 effects were first apparent at frontal sites (already evident 250 ms after S2 onset) and then spread back to parietal sites 100–150 ms later. While a recent fMRI study (Beck et al., 2001) associated diffuse frontal-parietal activity with conscious detection, the present ERP findings suggest that the role of frontal sites may precede that of parietal sites.

The difference between detected versus missed (background) changes depended here primarily on instructions/cues indicating that background changes were possible. One might therefore suggest that frontal effects preceding parietal effects could somehow be due to top-down influences associated with attentional instruction, rather than a specific temporal pattern related to conscious change detection. However, it should be noted that the present P300 effects were time-locked to S2, and absent in earlier time windows. Moreover, as apparent in scalp activity maps (Fig. 3), frontal effects preceded their parietal counterparts even in the uncued foreground condition, where they cannot be due to instruction.

In sum, we found two main results. First, change blindness is much more pronounced for backgrounds than figures, even when background changes are physically stronger. Second, ERPs revealed that the P300 component was absent for missed as compared to consciously detected changes at frontal and parietal sites. This may accord with recent fMRI findings of frontal and parietal activation associated with conscious change detection (Beck et al., 2001). Our results go further in revealing the temporal order of effects over these sites. The observation of an initial effect over prefrontal sites, followed around 100 ms later by parietal involvement, seems nontrivial, as traditional feedforward hypotheses (i.e. posterior-to-anterior; see Driver, 1995; Driver & Mattingley, 1998) would predict the reverse.

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