

# ERP effects of change localization, change identification, and change blindness

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Change blindness is the failure to detect changes in visual scenes. Changes can elicit phenomenologically different perceptual experiences, possibly relating to different mechanisms: changes may be entirely missed, merely detected, located, or identified. We presented sequences of meaningful objects, one of which could change between the presentations. Changes had to be located and identified. Observers sometimes located the change without knowing which object had changed. However, effects of localization with and without identification were remarkably similar on a sequence of event-related potential components (including change-related positivity and N2pc). Only a late contralateral positivity was found exclusively for identified changes, indicating that change localization and change identification initially rely on a

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## Introduction

Change blindness is the failure to detect large changes in visual scenes when two versions of a scene are presented in a sequence separated by a brief disruption. In general, the full understanding of change detection, change blindness, and the nature of visual representations require to investigate how much information is represented when a change is not seen.

Several studies have investigated implicit change detection, that is, what information, if any, is processed even when observers are completely unaware of a change [1]. In addition, some studies have investigated visual processing when participants acquire only limited awareness of change without having a full experience of the changing object. For instance, observers sometimes report that they ‘sense’ the presence of a change without seeing the critical object changing [2–4]. In other cases, participants may have an intuition of ‘where’ approximately the change occurs without knowing ‘what’ is changing [5]. In this study, we investigated whether observers can localize changes without having a visual experience of the changing object, and whether localization and identification are associated with different electrophysiological markers.

## Methods

### Participants

Twenty participants volunteered after giving written informed consent before the experiment. Two participants were excluded from analysis because of poor behavioral performance. Eighteen participants remained

in the cohort (13 female, 5 male; mean age: 23.5 years; one left handed). All the participants had normal or corrected to normal vision. The study protocol conformed to local Ethics Guidelines and the Declaration of Helsinki.

### Stimuli and procedure

Stimuli were presented on a thin film transistor monitor operated at 60 Hz using Presentation software ([www.neurobs.com](http://www.neurobs.com)). Each trial comprised two displays containing a rectangular 4 × 4 matrix (7.5 × 5.3° visual angle) of colored objects (1.2° each) [6] and a central fixation cross (Fig. 1). An empty screen for 1700–2700 ms preceded each stimulus sequence. Display 1 was presented for 1000 ms after a blank screen for 35 ms. Display 2 was presented for 180 ms and could feature a change (one object replaced by a novel item) either on the left side, on the right side, or no change at all with equal probabilities. After display 2, a colored pattern mask was presented for another 200 ms. The mask served to disrupt processing of the display. Without the mask, even if observers localized the change initially without identifying it, they might direct the attention to the location of the change and report the identity of the object found there. Subsequently, participants were asked if a change had occurred to the left, to the right, or if no change had occurred at all. Then, six objects were presented and participants had to select the object that had changed by moving the mouse pointer to the respective object and clicking on it. These six stimuli always consisted of the critical object from display 1, the object to which it had changed in display 2, and two random unchanged objects, two from each side of the

Fig. 1

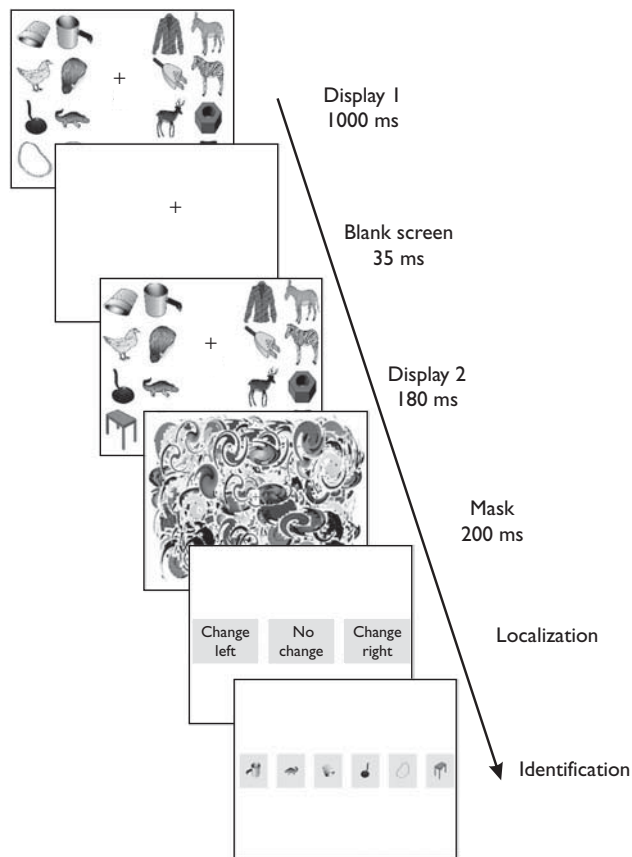


Illustration of the experimental paradigm. On each trial, a matrix of 16 meaningful objects was presented. A brief blank screen was presented in between the first and the second display. On change trials, one of the objects in the matrix changed from display 1 to display 2. Participants were then asked to first localize the change and subsequently to identify the object that had changed. Separate analyses were performed for changes that were only localized and changes that were additionally identified.

display. Participants were instructed to always maintain central fixation and to equally monitor both sides of the display.

### EEG data acquisition and analysis

Electroencephalogram (EEG) was recorded with a BrainAmp amplifier, (BrainProducts; Germany, Munich, Bavaria) from 64 electrodes placed according to the 10–10 system, with a nose-tip reference and ground between two fronto-central electrodes. To monitor for eye movements and blinks, the horizontal and vertical electro-oculogram was recorded. Electrode impedances were below 20 k $\Omega$ . The EEG was analog filtered between 0.02 and 200 Hz and digitized at a rate of 500 Hz. Data were additionally low-pass filtered offline at 120 Hz and down sampled to 250 Hz. Before averaging, independent component analysis was applied to the continuous raw data to correct for eye blinks and eye movements

using the MATLAB toolbox (The Mathworks, Natick, Massachusetts, USA), EEGLAB [7] and the extended infomax independent component analysis algorithm. Trials with remaining artefacts were rejected using visual inspection (5% on average).

### Statistical analysis

The analysis of change trials was comprised of four conditions: 'change blind' (no change reported), 'only localization' (correct report of the side of the change but no identification of the changing object), 'incorrect localization' (location reported on the side opposite to where the change really occurred), and 'change identified' (change was correctly localized and correctly identified). Identification of the critical object from display 1 or display 2 was both counted as correct responses. Two further conditions were analyzed for no change trials: 'correct rejection' (no change reported) and 'false alarm' (report of a change to the left or right).

For statistical analysis of the EEG data, selected channels were pooled into an anterior, central and posterior region of interest (ROI). All event-related potentials (ERPs) were time-locked to the onset of the second display. The visual awareness negativity (VAN) was quantified as mean amplitude in the time window from 250 to 350 ms relative to a 200 ms baseline. One analysis of variance (ANOVA) tested for the effects of change perception on change trials (change localized but not identified, change localized and identified, incorrect localization, change blind) and ROI (anterior, central, posterior). A second ANOVA tested whether similar effects are found for erroneous change localization on no change trials by analyzing the factors erroneous detection (false alarms vs. no change) and ROI. EEG asymmetries were computed as the voltage difference between homologous pairs of electrodes, taking into account the hemifield in which a change occurred. They were quantified as the mean amplitudes in the posterior ROI (with electrodes on the midline excluded) in the time windows from 120 to 190 ms (change-related positivity), 250 to 370 ms (N2pc), and from 480 to 600 ms [late posterior contralateral positivity; (LPCP)]. These components were analyzed with an ANOVA including the factors hemifield (left vs. right change), hemisphere (left vs. right electrodes), and change perception (change localized but not identified, change localized and identified, change blind, incorrect localization). Note that the presence of an event-related asymmetry manifests as a statistical hemifield  $\times$  hemisphere interaction. Huynh-Feldt corrections were used where appropriate. Significant effects of change perception were investigated with planned comparisons. The significance level for these tests was adjusted using the Bonferroni-Holm method [8] to maintain a family-wise type I error rate of 0.05. Only results that were significant according to this criterion were reported.

**Table 1 Behavioral performance**

|           | Loc. ident.       | Loc. <del>ident.</del> | Loc. <del>ident.</del> | Loc. <del>ident.</del> | Change blind |
|-----------|-------------------|------------------------|------------------------|------------------------|--------------|
| Change    | 39%               | 20%                    | 12%                    | 7%                     | 22%          |
|           | Correct rejection |                        | False alarms           |                        |              |
| No change | 45%               |                        | 55%                    |                        |              |

Incorrect change localization or identification is indicated by a cross out line. Note that incorrect localization refers to a report of a wrong location, whereas change blindness refers to reports of 'no change'.

## Results

### Behavioral results

The behavioral results are summarized in Table 1. Correct localization and identification of a change occurred twice as often as correct localization without identification. Although correct localization without identification might have occurred because of correct guessing, it was more frequent than incorrect localization without identification (which is also because of correct guessing) and this difference was statistically confirmed by a two-tailed *t*-test [ $T(17) = 11.9$ ;  $P < 0.001$ ]. This result confirms that changes can be localized without being identified.

False alarms on no change trials were as frequent as correct rejections [ $T(17) = -1.25$ ;  $P = 0.226$ ], reflecting a bias to report the presence of a change because of the high probability of changes (two-thirds of all trials).

### Electrophysiological results

#### Visual awareness negativity

VAN amplitudes were strongly affected by how the changes were perceived [change perception:  $F(3,51) = 8.268$ ;  $P = 0.002$ ], and this effect was strongest at posterior electrodes [change perception  $\times$  ROI:  $F(6,102) = 8.170$ ;  $P = 0.001$ ]. Planned comparisons showed that the posterior change perception effect was strongest when changes were both localized and identified [ $F(1,17) = 17.24$ ;  $P = 0.001$ ]. A trend for a VAN effect was observed even when changes were only localized, but this effect did not reach significance because of the adjustment for multiple testing.

#### Change-related positivity

This component was dependent on how the change was perceived [change perception  $\times$  hemisphere  $\times$  hemifield:  $F(3,51) = 4.84$ ;  $P = 0.017$ ]. Planned comparisons showed a change-related positivity when the changing object was localized and identified [hemisphere  $\times$  hemifield:  $F(1,17) = 70.48$ ;  $P < 0.001$ ] and when the change was only localized but not identified [ $F(1,17) = 7.68$ ;  $P = 0.013$ ], but not for incorrect localization or change blindness [all  $F(1,17) < 1$ ].

#### N2pc

The N2pc was influenced by how the change was perceived [change perception  $\times$  hemisphere  $\times$  hemifield:

$F(3,51) = 15.51$ ;  $P = 0.001$ ]. Planned comparisons showed an N2pc when the changing object was localized and identified [hemisphere  $\times$  hemifield:  $F(1,17) = 100.18$ ;  $P < 0.001$ ] or when the change was only localized [ $F(1,17) = 15.26$ ;  $P = 0.001$ ], but not for incorrect localization [ $F(1,17) = 2.83$ ;  $P = 0.111$ ] or for change blindness [ $F(1,17) < 1$ ].

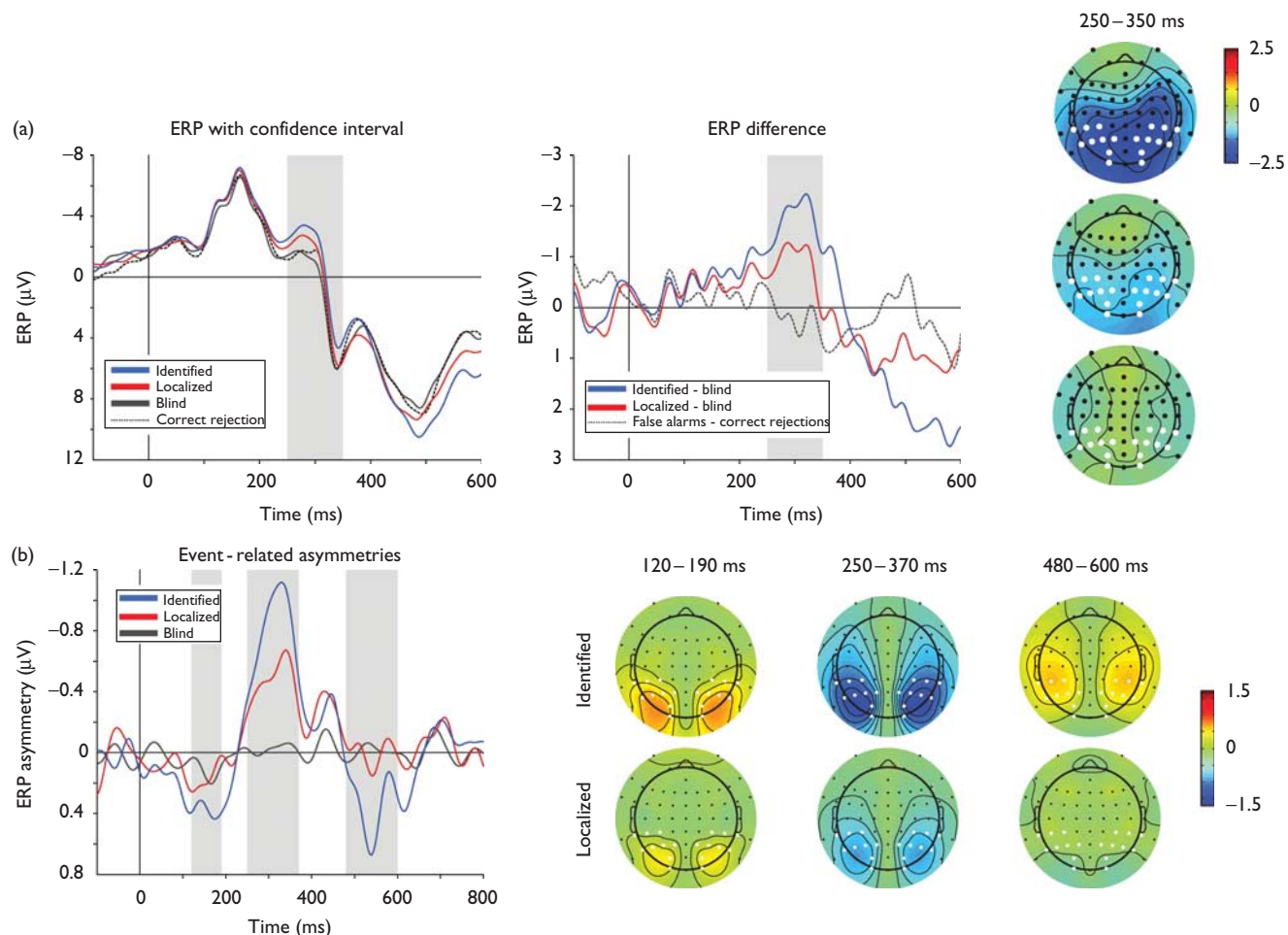
#### Late contralateral positivity

A second posterior contralateral positivity succeeded the N2pc in the time range from 480 to 600 ms (Fig. 2). The LPCP was influenced by how the change was perceived [change perception  $\times$  hemisphere  $\times$  hemifield:  $F(3,51) = 3.81$ ;  $P = 0.040$ ]. Planned comparisons showed LPCP only when the changing object was localized and identified [hemisphere  $\times$  hemifield:  $F(1,17) = 10.26$ ;  $P < 0.005$ ], but not when the change was merely localized, incorrectly localized or for change blindness [all  $F(1,17) < 1$ ].

## Discussion

Can observers localize changes without seeing the changing object, and are localization and identification subserved by different perceptual and neural mechanisms? Participants indeed localized changes without identifying them on a subset of trials, and this behavior could be distinguished from pure guessing. However, the effects of localization without identification (as compared with blindness) on the change-related positivity and the N2pc were very similar to the effects for fully identified changes. However, a LPCP after the N2pc was found exclusively for identified changes. Hence, unlike detection and identification [3], it seems unlikely that localization and identification are related to separate perceptual processes or even separate neuronal pathways. Rather, change localization and identification seem to act in a sequential manner: visual changes seem to be localized, but not identified, when the processing sequence leading to awareness and identification is interrupted too early.

Change localization and identification have been investigated recently in a psychophysical study [5]. Gabor elements with random orientations were rotated at  $45^\circ$ , and changes were masked by concomitant presentation of high-contrast distractors at variable times relative to change onset. Change localization was most impaired when the distractors followed the change, whereas change identification was impaired when the distractors preceded the change. Watanabe concluded that change localization and change identification are mediated by different perceptual mechanisms; while localization may depend on the focusing of attention, identification additionally depends on the formation of a stable representation of the changing item in visual working memory, and these functions may have separate neural substrates in the dorsal and the ventral visual pathway, respectively

**Fig. 2**

Grand averaged event-related potentials (ERPs). (a) ERPs time-locked to the second display for changes that were identified (and localized), localized (but not identified), change blindness and correct rejections on no change trials (left) and difference waveforms and topographies for identified (and localized) changes versus change blindness, localized (but not identified) changes versus change blindness, and false alarms versus correct rejections on no change trials (right). Time courses represent the average of selected posterior channels (white electrode markers in the topographies), which were used for statistical analyses. Shaded areas correspond to the time windows used for statistical analyses and for computing the topographies. (b) Event-related asymmetries (contralateral vs. ipsilateral difference). Conventions as in Fig. 2a.

[5,9]. In contrast to the study by Watanabe, the displays used in this study were far more complex and heterogeneous and involved a semantical change, whereas changes in the Watanabe study [5] can be described as a rotational motion. Second, although Watanabe investigated change localization and identification on separate experimental blocks, this study required localization and identification on each trial. Thus, the difference between these conditions in this study can be attributed to differences in the processing of changes, whereas blocked designs may show effects of different task sets required for locating and identifying changes.

The VAN has been found in change blindness and in masking paradigms [10,11]. It has been suggested that the VAN 'may correlate to neural processes occurring when the stimulus (change) enters phenomenal

visual awareness' [10]. However, it has been demonstrated that the VAN is also found when the presence of a change is detected but the changing object cannot be identified [3].

The change-related positivity has been reported in studies using paradigms that involve some sort of change and so trigger a memory based comparison between two successive displays [3,12,13]. In simple delayed matching to sample tasks, this change detection mechanism seems to operate independently of feature-selective or spatial attention [12]. Thus, it has been suggested that the change-related positivity operates regardless of the participants' conscious experience of a change [13]. This suggestion could not be confirmed in this study. Note, however, that the perceptual load in earlier studies was considerably lower compared with this study [12,13]. The

change positivity may depend on a minimum level of attention, and in simple stimulus displays attention may not be completely withdrawn from unattended locations or feature dimensions.

The N2pc reflects the allocation of attention to task-relevant stimuli [14–16] and it is found in change blindness paradigms when participants are aware of a change [3,16,17]. We found an N2pc when participants knew where a change occurred without being aware of what had changed. Thus, the N2pc cannot be a correlate of awareness as such. Rather, it seems to be involved in attentional processes, which are necessary but not sufficient for awareness.

The most pronounced difference between change localization and change identification was found on the LPCP, which was not observed at all when a change was only localized. No comparable component has been reported in earlier ERP studies of change blindness [3,16,17]. A considerable difference between the present paradigm and earlier change blindness studies was the presentation of a pattern mask after the second display. The onset of this mask may have acted as a probe stimulus. Unilateral probes presented at the spot of a target item evokes a posterior positivity contralateral to the target starting at 115 ms after probe onset [18]. The LPCP contralateral to identified changes found in this study might thus indicate attention that remained focused at the location of a change only when the change was identified, but was disengaged quickly when changes were only localized.

## Conclusion

Localization and identification of visual changes were investigated by comparing ERP effects of change localization, identification and change blindness. The sequence of ERP effects was very similar for localized and identified changes, differing only in magnitude, challenging the notion that change localization and identification are based on separate perceptual and neural mechanisms.

Only at later stages, a posterior contralateral positivity was found exclusively when changes were identified. Although phenomenologically different, knowing where a change occurs and seeing what is changing initially rely on a common processing sequence and differ only at later stages.

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