

Electrophysiological Evidence for Different Types of Change Detection and Change Blindness

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Abstract

■ Numerous studies have demonstrated that observers often fail to notice large changes in visual scenes, a phenomenon known as change blindness. Some experiments have suggested that phenomenological experience in change blindness experiments is more diverse than the common distinction between change detection and change blindness allows to resolve. Recently, it has been debated whether changes in visual scenes can be detected (“sensed”) without a corresponding perception of the changing object (“seeing”) and whether these phenomena build on fundamentally different perceptual processes. The present study investigated whether phenomenologically different perceptual processes such as sensing and seeing rely on different or similar neural processes. We studied ERP effects of visual change processing (as compared to change blindness) when observers merely detected the presence of a change (“sensing”) and when they identified the changing object in addition to detec-

tion (“seeing”). Although the visual awareness negativity (VAN)/selection negativity was similar for detection with and without identification, a change-related positivity and the N2pc contralateral to changes were found exclusively when the change was fully identified. This finding indicates that change identification requires perceptual and neural processes that are not involved in mere detection. In a second experiment, we demonstrated that the VAN and N2pc effects are similar to effects of selective attention in a visual search task. By contrast, the change-related positivity was specific for conscious processing of visual changes. The results suggest that changes can be detected (“sensed”) without perception of the changing object. Furthermore, sensing and seeing seem to rely on different neural processes and seem to constitute different types of visual perception. These findings bear implications for how different categories of visual awareness are related to different stages in visual processing. ■

INTRODUCTION

In everyday situations, vision provides us with a seemingly effortless, detailed, and stable visual experience of the world. It is intuitive to believe that this experience results from stable and detailed internal representations. In recent years, several authors have argued that, in contrast to introspection, the brain does not build up such detailed and stable internal models of a visual scene, or that at least the access to scene details is limited (Rensink, 2002; Thornton & Fernandez-Duque, 2002; Simons, 2000). This argument is, in part, based on the finding that under appropriate conditions, observers often fail to notice substantial changes in a visual scene. Under normal viewing conditions, it is usually easy to notice when a visual object suddenly changes color, location, or other attributes because such changes are accompanied by strong motion transients (Simons, Nevarez, & Boot, 2005). However, when these transients are masked by simultaneous visual disruptions, such as blank screens (Simons, 2000;

Rensink, O’Regan, & Clark, 1997), mudsplashes (Schankin & Wascher, 2007; O’Regan, Rensink, & Clark, 1999), eye blinks (Henderson & Hollingworth, 1999), or saccades (O’Regan, Deubel, Clark, & Rensink, 2000), change detection is strongly impaired—a phenomenon known as change blindness (for reviews, see Rensink, 2002; Simons, 2000). Based on these results, some authors have even formulated a new skepticism, which states that we have radically false beliefs about what our visual experience is like (Blackmore, Brelstaff, Nelson, & Troćianko, 1995).

In studies requiring observers to report the presence or absence of change, it is often assumed that change detection (reporting that a change has occurred) is also accompanied by a phenomenological experience of the changing object’s identity. However, observers’ reports point to the possibility that detection and identification of a change may, in fact, be different perceptual processes (Rensink, 2004; Agostinelli, Sherman, Fazio, & Hearst, 1986). Some changes are accompanied by a vague feeling of “sensing that something has changed somewhere” whereas on other trials change perception is accompanied by a clear and crisp experience of “seeing” the identity of the changing object. Recently, two studies have focused on the question whether “sensing” and “seeing” rely on the same or on different perceptual processes. Rensink (2004)

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has postulated the existence of two distinct modes of conscious visual perception in a change blindness paradigm: seeing involving the subjective visual experience of the changing object and a preattentive mechanism responsible for sensing of changes without a visual experience. This hypothesis was investigated in a flicker paradigm in which two slightly different versions of a visual scene are separated by a blank screen and are alternated in the sequence. Participants were instructed to press one response key when they “sensed” a change and another key when they “saw” the change (i.e., they had a visual experience of the object and could verbally localize and describe it). Rensink found that some participants gave a “sense” response several scene alternations prior to their “see” responses. The onset of sensing and the onset of seeing were not correlated. Moreover, the average time for seeing relative to sensing in trials when it occurred was the same as the average time for seeing when sensing did not occur. Rensink argued that this pattern of response times suggests that sensing and seeing do not simply correspond to different thresholds or signal strengths, but instead are based on different perceptual mechanisms. Furthermore, the incidence of sensing was not affected when a bright yellow flash was presented in between two scene presentations, indicating that sensing is not simply based on the registration of the transient signal caused by a change. The existence of a separate perceptual mechanism, which enables sensing without requiring focused attention and which does not result in a conscious perception of the changing object, might point to a novel and yet poorly investigated mode of visual processing (Simons & Rensink, 2005; Rensink, 2000). However, this interpretation has been vigorously rejected by Simons et al. (2005), who offered a more parsimonious explanation for the temporal lag between sense and see responses. They argued that only a single mechanism for change processing exists. Different response times for sensing and seeing can be explained by participants’ tendencies to guess without processing visual information at all when giving the sensing response. Moreover, some participants may simply take time to verify their initial detection of the change. This verification of the change would have caused a lag between the sense and saw responses, as well. Thus, sensing and seeing may rest upon the same perceptual process, but the two response types could be given with a different response criterion.

Sensing may be operationally defined as the correct conscious detection of change (reporting that something has changed) without correct identification of what has changed. It is important not to confuse sensing with implicit change detection—the subliminal processing of changes that observers are completely unconscious of (Laloyaux, Destrebecqz, & Cleeremans, 2006; Mitroff, Simons, & Franconeri, 2002; Thornton & Fernandez-Duque, 2000). Seeing may be defined as detection plus correct identification (reporting the identity of the changing object). The debate can then be rephrased as the question of whether the difference between change detection and change iden-

tification is, as was suggested by Rensink (2004), a difference in quality or, according to Simons et al. (2005), merely a difference in quantity (or no difference at all). A difference in quality would be revealed if there were perceptual or neural processes associated with identifying a change that are not involved at all in detecting a change. The distinction between qualitative and quantitative differences is difficult to make based solely on behavioral experiments. In the flicker paradigm (Rensink, 2000; Simons, 2000), where the stimulus display is continuously alternating between the two versions of the scene, the only index for sensing is the time lag between the initial sense response and the subsequent see response. Even if sensing and seeing were, in fact, dissociable mechanisms, the paradigm may encourage participants to scrutinize their perception. Unfortunately, there is no way in a behavioral experiment to directly investigate the processing that occurs between stimulus presentation and the behavioral responses. Moreover, preattentive change detection without identification can be unveiled only to the extent that it has an effect on an overt response. In contrast, electrophysiological experiments yield a continuous signal that can be used to directly observe neural activity associated with stimulus processing at the time this processing occurs. Here, the differential timing of different behavioral response types (e.g., sense and see responses) is not of special importance, and EEG effects can be compared between experimental conditions even when the overt responses do not differ (e.g., comparisons between trials without any change and trials where a change was not reported). However, previous EEG studies were not suited to investigate the difference between sensing and seeing because they did not differentiate between different types of change processing. Participants were usually instructed to detect changes by responding in a two-alternative forced-choice task (change/no change), but they were not asked for their perception of the changing object. In addition, most of these studies (with the exception of Fernandez-Duque, Grossi, Thornton, & Neville, 2003) used very simple stimulus arrays, such as oriented bars or letters, or used a very narrow set of stimuli (faces). Previous EEG experiments have identified three major event-related potential (ERP) components that are differentially affected by change detection and change blindness. Successful change detection has been demonstrated to elicit a negative amplitude modulation at posterior electrodes starting about 200 msec after stimulus onset and a later broadly distributed enhanced positivity (P3) for detected changes (Pourtois, Preto, Hauert, & Vuilleumier, 2006; Eimer & Mazza, 2005; Koivisto & Revonsuo, 2003). It has been suggested that the posterior negativity is an electrophysiological correlate of phenomenal visual awareness (thus termed the “visual awareness negativity,” VAN), whereas the subsequent P3 was linked to later postperceptual response-related decisions (Eimer & Mazza, 2005; Koivisto & Revonsuo, 2003). Furthermore, the N2pc (a posterior ERP negativity contralateral to the side of a change) in the

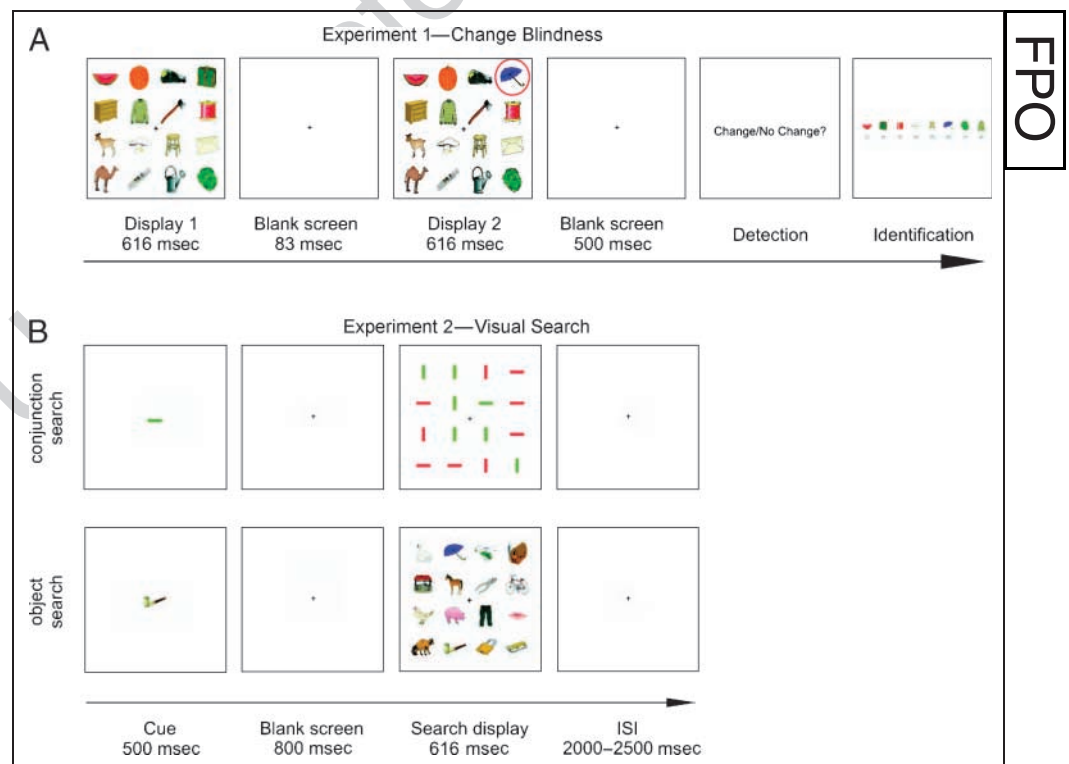
time range of 200–300 msec, has been demonstrated for detected changes (Schankin & Wascher, 2007; Eimer & Mazza, 2005). In the visual search literature, the N2pc is usually interpreted as an index of a shift of attention toward task-relevant locations (Woodman & Luck, 2003). Schankin and Wascher (2007) suggested that in a change detection task, the N2pc reflects an attentional process that is necessary, but not sufficient, for conscious change detection, rather than reflecting awareness per se.

Experiment 1 investigated effects of change detection with correct identification and detection without identification as measures of seeing and sensing, respectively (see Figure 1A). In Experiment 2, these effects were compared to effects of selective attention in two varieties of a visual search task, using simple feature conjunctions and meaningful objects, respectively (see Figure 1B). In sum, we could demonstrate that some EEG effects are shared between detection with and detection without identification. However, event-related EEG asymmetries were found exclusively when the change was correctly identified. This finding indicates that seeing a change does not simply represent a stronger form of sensing a change. Instead, seeing seems to involve neural processes that are not involved at all when changes are merely sensed. These results suggest that sensing and seeing constitute different perceptual processes (Rensink, 2000).

EXPERIMENT 1

In Experiment 1, we recorded ERPs in a change blindness paradigm in which two displays were presented successively. Observers had to report at the end of each trial whether or not they detected any change, irrespective of whether or not they were aware of the object's identity (see Figure 1A). Subsequently, participants were to identify the changing object. Although the detection task can be solved purely based on sensing the presence of a change, the identification task additionally requires that the observer had consciously perceived the changing object (i.e., that the change was “seen” in Rensink's and Simons' terminology). We sought for effects of change processing by comparing ERPs on change trials, depending on whether this change was unnoticed, detected but not identified, or detected and correctly identified. These three types of trials are equivalent with respect to the physical presence of a change, but differ with respect to the participants' reported perception. In the remainder of this article, we refer to these conditions as “change blind,” “detected,” and “identified,” respectively. There are at least three hypotheses about what might be found in an EEG experiment, in which change blindness, detection, and identification are investigated. First, effects of detection with correct identification and detection without identification (as opposed to

Figure 1. Illustration of the experimental paradigms used in Experiment 1 and Experiment 2. (A) In the change blindness experiment, a matrix of 16 meaningful objects was presented. A brief blank screen was presented in between the first and the second displays. On half of the trials, one of the objects in the matrix changed from Display 1 to Display 2. (Note that the red circle serves only for illustration purposes and was not presented during the experiment.) Participants were then asked to first detect the presence of a change and, subsequently, identify the object that was changed. Separate analyses were performed for changes that were detected only and changes that were additionally identified. (B) In the visual search task, participants were cued on each trial for a target stimulus to search for. Targets were present on half of the trials. Size and duration of the displays were identical to Experiment 1. Stimuli were either simple conjunctions of color and orientation or images of meaningful objects.



change blindness) might be similar for all ERP components, differing only in magnitude. This *quantitative* difference would be compatible with the interpretation that sensing and seeing rely on the same perceptual processes (Simons et al., 2005). Second, all effects that are found for detection with correct identification might be completely absent for detection without identification. This could point to the fact that detection without identification represents merely correct guessing without any perceptual processing of the change. Third, effects of detection with and without identification might differ in quantity only for some EEG components, whereas other EEG effects are found exclusively for changes that are correctly identified. Such a *qualitative* difference would be consistent with the notion that sensing and seeing are fundamentally different perceptual processes (Rensink, 2004).¹

Methods

Participants

Twenty volunteers participated in Experiment 1. Participants gave written informed consent before the start of the experiment. All participants had normal or corrected-to-normal vision and had no recorded history of neurological or psychiatric disorders. The study protocol conformed with local ethics guidelines and the Declaration of Helsinki. Two participants had to be excluded due to severely noise contaminated EEG data. Two further participants were excluded due to behavioral performance at chance level, leaving 16 participants for behavioral and EEG analysis (mean age = 23 years; 12 women; all right-handed).

Stimuli and Procedure

Each trial comprised two displays each of which consisted of a rectangular 4×4 matrix of colored and shaded images of objects (a detailed description is given in Rossion & Pourtois, 2004). The displays were presented in sequence centrally at a size of 7° visual angle. A single item had a size of 1.25° visual angle. A fixation cross at the center of the screen was visible during the entire sequence, and participants were required to always maintain their gaze focused on the fixation cross. Each stimulus sequence started with an empty screen for 1700–2700 msec, followed by the first of two displays for a duration of 616 msec. This display was interrupted by a blank screen for 83 msec after which the second display was presented for another 616 msec. Following the offset of the second display, the screen remained empty for 500 msec. On 50% of all trials, one of the 16 items in a matrix changed its identity from the first to the second display. On the other half of the trials, the first display was identical to the second one (no change trials; see Figure 1 for an example). The change could occur with equal probability at each position of the matrix. Following the stimulus sequence, participants were required to answer up to two questions. The first question

asked for whether or not they detected any change, and three response options were provided. Participants were instructed to respond with “detected a change” whenever they perceived or felt a difference between the two displays, even if they were unsure of the identity of the changing object. They were required to respond “no change detected” if they were sure that there was no change between displays. Participants were instructed not to guess, but to respond with “not sure” in case they felt uncertain. Subjects were encouraged to respond according to their “hunch” and to give a “not sure” answer only when they were completely undecided. On change trials on which the change was detected, a second question asked for the identity of the modified object. Eight objects were presented on the screen, and participants had to choose the object that had changed. These eight stimuli always comprised the object of the first display and the object to which it changed in the second display plus six unchanged objects from random positions of the object matrix. Again, participants were instructed to respond with “not sure” rather than guessing. Upon debriefing, none of the participants reported any problems to distinguish these response categories. Participants were told to respond as accurately as possible, but no instruction for speed was given. Subjects were not required to maintain central fixation while responding to the questions. Feedback was given after each response. The experiment comprised six blocks of 192 trials each, resulting in a total of 576 change trials and 576 no-change trials.

Data Acquisition and Analysis

The experiment was conducted in an electrically shielded and sound-attenuated cabin. The monitor was placed outside this cabin behind an electrically shielded window. All devices inside the cabin were battery operated to avoid interference of the line frequency. EEG was recorded with a BrainAmp amplifier (Brain Products, Munich) using 64 sintered Ag/AgCl electrodes mounted in an elastic cap (EasyCap, Falk Minow Services, Munich) and placed according to the 10–10 system, with a nose-tip reference and ground electrode between Fz and Cz. To monitor for eye movements and blinks, the horizontal and vertical electrooculogram was recorded. Electrode impedances were below 20 k Ω . Data were sampled at 500 Hz and analog filtered between 0.01 and 250 Hz during recording.

Data were additionally filtered off-line with a 120-Hz low-pass FIR filter and down-sampled to 250 Hz. Before averaging, independent-component analysis (ICA) was used to correct for eye blinks and lateral eye movements (Jung et al., 2000) using the MATLAB toolbox EEGLAB (Delorme & Makeig, 2004) and the extended infomax ICA algorithm. The ICA method uses spatial filtering to decompose multichannel EEG data into spatially fixed and temporally independent components. ICA can derive independent, separable components for these artifactual potentials and extract them from the EEG signal because

sources of artifacts have a spatial distribution and time course, which is independent of EEG activity. Sporadic artifacts (e.g., strong electrode drifts or EMG bursts, but not the consistent artifacts such as blinks) were manually rejected from the data before ICA training in order to obtain “clean” ICA components, including those accounting for blinks and lateral eye movements. These components were then removed from the data. Excessive eye artifacts were found mostly after the offset of the displays. The ICA-corrected data were very similar to the uncontaminated raw data, suggesting that ICA correction did not distort the original brain electrical signal. Trials with remaining artifacts were rejected using visual inspection.

The experiment consisted of five experimental conditions, which were analyzed according to the presence or absence of a change on a given trial and on the participants’ response. The analysis of change trials comprised three conditions. In the “change blind” condition, participants reported that they had not noticed any change at all. When the detection question was answered with “not sure,” that particular trial was not analyzed further. In the “change detected” (but not identified) condition, the presence of a change was veridically detected, but either the wrong object was chosen or the identification question was answered with “not sure.” In the “change identified” condition, a change was correctly detected and the object was correctly identified. Identification of the critical object from the prechange and the postchange displays were both categorized as correct responses. Two further conditions were analyzed for no-change trials. In the “correct rejection” condition, participants veridically reported that they did not notice any change, whereas in the “false alarm” condition, the presence of a change was erroneously reported. Behavioral performance was quantified by the nonparametric performance measure A' , which essentially expresses the ratio of hits (correctly detected changes with and without correct identification) and false alarms (erroneous detection in no change trials). This parameter typically ranges from 0.5, which indicates chance performance, to the value of 1, indicating perfect performance (Stanislaw & Todorov, 1999, Equation 2). The response bias was quantified with the parameter C (Stanislaw & Todorov, 1999, Equation 7). Negative values reflect a subjects’ tendency to respond with “yes” in the detection question (a liberal criterion), whereas positive values reflect the tendency to respond with “no change” (a conservative criterion).

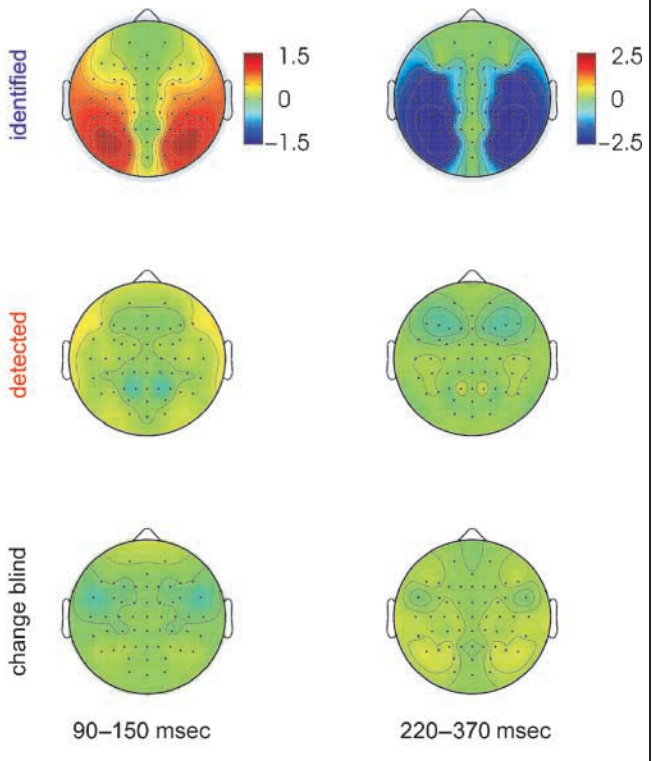
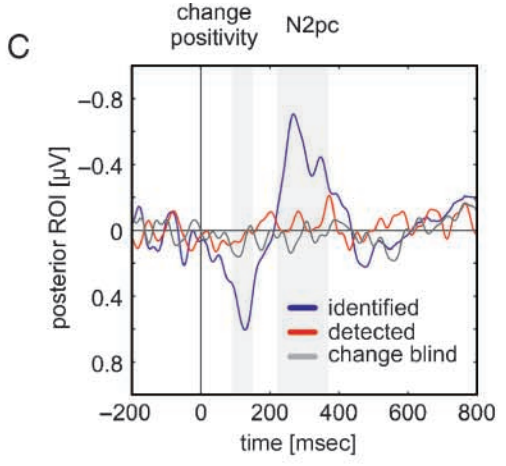
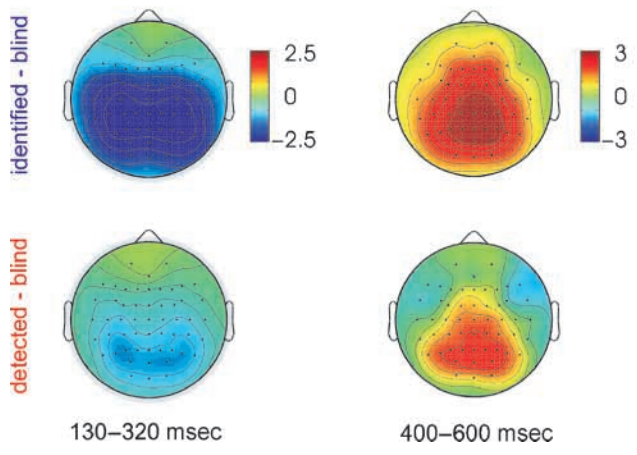
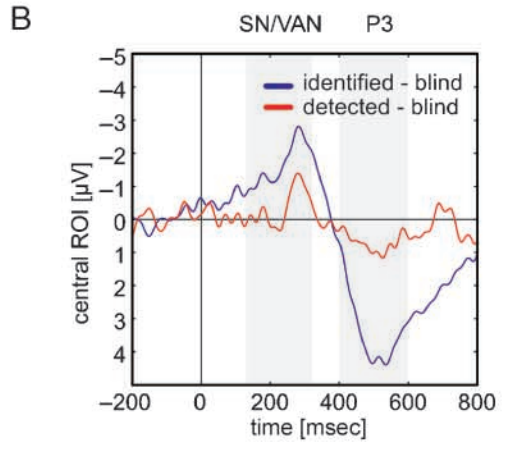
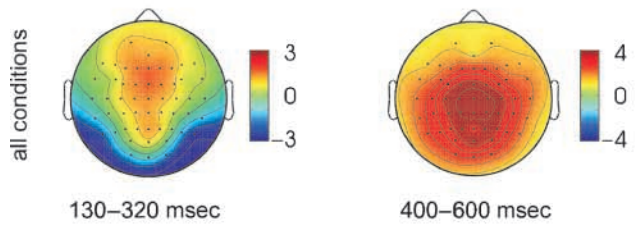
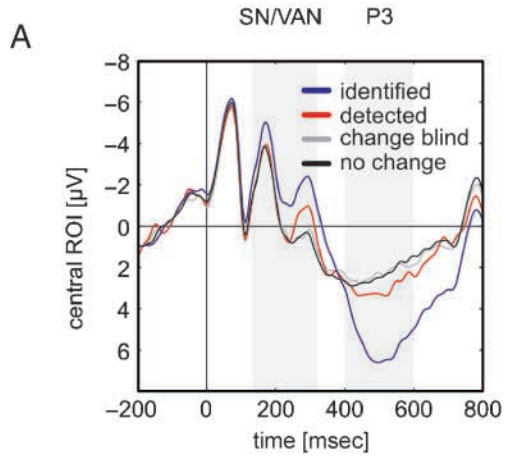
Statistical analysis of the EEG data in these conditions was performed after selected channels were pooled into a frontal (Fp1, Fp2, F7, F3, Fz, F4, F8), a central (FC1, FC2, C3, Cz, C4, CP5, CP3, CP2, CP4), and a posterior (P7, P3, Pz, P4, P8, O1, O2) region of interest (ROI). Nonlateralized EEG components were quantified as mean amplitudes in the time windows from 130 to 320 msec (selection negativity [SN]/VAN) and 400 to 600 msec (P3), all relative to a 200-msec baseline preceding the second display. These components were analyzed with three separate analyses of variance (ANOVAs). One ANOVA tested for effects of

change detection and identification and included the factors change processing (change identified, change detected, change blind) and ROI (anterior, central, posterior). A second ANOVA tested whether similar effects are found for erroneous change detection on no-change trials by analyzing the factors erroneous detection (false alarms vs. no change) and ROI. These two ANOVAs each compared types of trials that are equivalent with respect to the physical presence or absence of a change, respectively, but differ with respect to participants’ reported perception of the change. A third ANOVA tested for effects of implicit change processing by investigating the factors implicit processing (change blind vs. no change) and ROI (anterior, central, posterior). This third ANOVA thus compared two types of trials that differ with respect to the presence or absence of a physical change, but are equivalent with respect to participants’ reported perception. Separate analyses were performed for event-related EEG asymmetries. Event-related asymmetries are essentially difference waveforms computed by subtraction of homologous electrodes (e.g., electrodes P7 and P8). Therefore, the lateralization toward the left hemisphere in response to a change in the right hemifield is averaged with the lateralization toward the right hemisphere in response to a change in the left hemifield, thereby reducing the number of waveforms per condition by half. For display purposes, scalp distributions of event-related asymmetries were mirror reversed relative to the midline in order to yield conventional topographies in Figures 2C and 3C (see Oostenveld, Stegeman, Praamstra, & van Oosterom, 2003, for an elaborate discussion of this approach). Event-related asymmetries were quantified as the mean amplitudes in the posterior ROI in the time windows from 90 to 150 msec (change-related positivity) and 220–370 msec (N2pc), all relative to a 200-msec baseline. These components were analyzed with an ANOVA including the factors hemifield (left change vs. right change), hemisphere (left electrode sites vs. right electrode sites), and change processing (change identified, change detected, change blind). Note that the presence of an event-related asymmetry such as the N2pc manifests as a statistical Hemifield \times Hemisphere interaction. Note that effects of implicit change processing and false alarms cannot be tested for these components because event-related asymmetries are not defined for no-change trials. Huynh–Feldt corrections were used to adjust for violations of the sphericity assumption for repeated measures factors with more than two levels (Dien & Santuzzi, 2004). Corrected p values and uncorrected degrees of freedom are reported along with the ϵ value.

Results

Behavioral Results

Participants correctly detected the presence of a change on 68% of all change trials (29% change blind; 3% not sure). The identity of these detected changes was correctly



reported in 37% of all change trials (16% incorrect; 15% not sure). The absence of a change was correctly reported on 74% of all no-change trials (24% false alarms; 2% not sure). The proportion of trials that were detected but not identified was significantly larger than the proportion of false alarms [$F(1, 15) = 7.22, p = .017$]. Average detection accuracy A' was .80.

EEG Results

Quantitative differences between change detection and identification. *VISUAL AWARENESS NEGATIVITY.* Detection of a change as well as identification of a change amplified the magnitude of the VAN compared to change blindness [change processing: $F(2, 30) = 23.24, p < .001, \epsilon = .83$; see Figure 2A and B]. Follow-up ANOVAs confirmed that change identification resulted in a magnification of the VAN compared to change blindness [$F(1, 15) = 65.247, p < .001$]. Most importantly, a similar, albeit smaller, effect was found for the comparison of change blindness with changes that were only detected [$F(1, 15) = 5.21, p = .036$]. This effect was strongest at central recording sites [Change processing \times ROI: $F(4, 60) = 7.54, p = .001, \epsilon = .64$]. Importantly, the comparison of false alarms and correct rejections in no-change trials revealed no such effect for erroneous change detection [$F(1, 15) < 1$].

P3. P3 amplitudes were also modulated by perception of a change [change processing: $F(2, 30) = 40.75, p < .001, \epsilon = .77$; see Figure 2A and B]. Follow-up ANOVAs revealed that P3 amplitudes were larger for identified changes as compared to change blindness [$F(1, 15) = 42.23, p < .001$], but no effects were found between detected changes and change blindness when all electrodes were considered [$F(1, 15) = 1.51, p = .238$]. However, the magnitude of change perception effects differed between recording sites [Change processing \times ROI: $F(4, 60) = 11.12, p < .001, \epsilon = .55$]. Effects of change processing were most pronounced at central [$F(2, 30) = 41.27, p < .001, \epsilon = .75$] and posterior electrodes [$F(2, 30) = 38.15, p < .001, \epsilon = .73$]. In the posterior ROI, identified changes evoked larger P3 amplitudes compared to change blindness [$F(1, 15) = 40.93, p < .001$]. A similar but smaller effect was found here for changes that were only detected compared to change blindness [$F(1, 15) = 4.87, p = .043$]. However, a similar magnification of P3 amplitudes was also found for false alarms as compared to correct rejections in no-change trials [$F(1, 15) = 5.50, p = .033$]. This P3 ef-

fect for erroneous change detection also differed between recording sites [Erroneous detection \times ROI: $F(2, 30) = 7.67, p = .004, \epsilon = .86$] and was maximal over frontal electrodes [$F(1, 15) = 10.00, p = .006$].

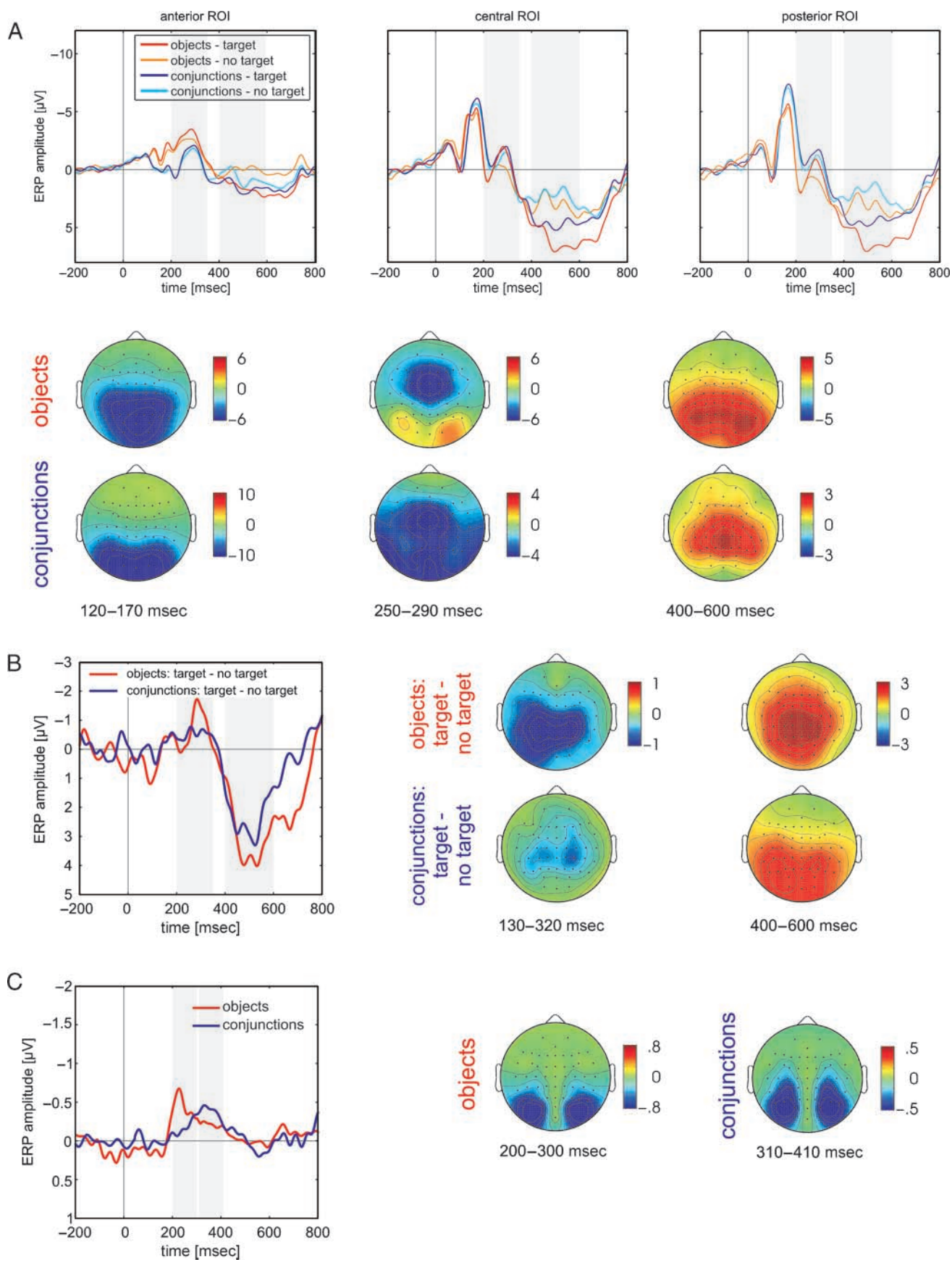
Qualitative differences between change detection and identification. *CHANGE-RELATED POSITIVITY.* Presentation of a change was associated with a positive ERP component contralateral to the side of the change in the posterior ROI [Hemifield \times Hemisphere: $F(1, 15) = 19.30, p = .001$; see Figure 2C]. The magnitude of this change-related positivity was dependent on the perception of the change [Change processing \times Hemifield \times Hemisphere: $F(2, 30) = 9.09, p = .001, \epsilon = .99$]. Follow-up ANOVAs revealed that a change-related positivity, as manifested by a Hemifield \times Hemisphere interaction, was evoked only when the change was identified [$F(1, 15) = 21.04, p < .001$]. No change positivity was observed when the change was only detected [$F(1, 15) = 2.24, p = .16$] or when participants were change blind [$F(1, 15) = 3.14, p = .10$].

N2pc. A similar pattern emerged for a negative posterior ERP component contralateral to a change (the N2pc; Figure 2C). The N2pc was observed in the posterior ROI [Hemifield \times Hemisphere: $F(1, 15) = 16.42, p = .001$], and the magnitude of this component was also dependent on how the change was perceived [Change processing \times Hemifield \times Hemisphere: $F(2, 30) = 18.72, p < .001, \epsilon = .80$]. Follow-up ANOVAs revealed that an N2pc was evoked only when the change was identified [$F(1, 15) = 34.67, p < .001$], but not when the change was only detected [$F(1, 15) < 1$] or under change blindness [$F(1, 15) = 1.04, p = .32$].

Effects of implicit change processing. The comparison of no-change trials and change blindness did not yield effects of implicit change processing on any of the EEG components investigated. The issue of implicit change processing will thus not be treated any further.

Relationship of false alarm rate and ERP effects. It has been argued that sensing and seeing do not differ in terms of the perceptual processes involved. Instead, the difference may lie in the response criterion—sensing responses may reflect a liberal criterion, whereas subjects are more conservative when they report seeing the change (Simons

Figure 2. Summary of the grand-averaged ERP data obtained in the change blindness task in Experiment 1 time-locked to the onset of the second display. Time windows used for statistical analyses are shaded. Topographies show scalp distributions in the time windows used for statistical analyses. (A) ERPs (SN/VAN and P3) for change trials in which changes were only detected, detected and identified, or completely missed (change blind) and for correct rejections at the central ROI. (B) Difference potentials at the central ROI in the SN/VAN and P3 time range derived by subtracting waveforms for change blindness from detected changes and identified changes, respectively. (C) Event-related asymmetries at the posterior ROI: Change-related positivity and N2pcs were computed by subtracting the ERPs at electrodes ipsilateral to a change from electrodes contralateral to a change.



et al., 2005). In line with this argument, Simons et al. (2005) found a higher false alarm rate in subjects with a higher incidence of sensing. Similarly, in the present paradigm, one might suspect that change detection without identification reflects a liberal response criterion and lucky guessing rather than a particular perceptual process. To investigate this, we split our subject sample into two halves and compared subjects with low and high false alarm rates, respectively (19% vs. 28%). A more conservative response criterion C was found in the group with lower false alarm rates (0.22 vs. -0.02). As expected, the incidence of change detection without identification was lower in the subgroup with lower false alarm rate (26% vs. 35%). These results indicate that more guessing occurred in the group with the highest false alarm rate.

If detection without identification is, indeed, a perceptual process rather than a product of lucky guessing due to a liberal response criterion, one would expect ERP effects for detection without identification to be strongest in subjects who guessed the least. We thus compared ERP effects between the two subgroups in an ANOVA using the same within-subjects factors as above with an additional between-subjects factor group (low vs. high false alarm rate).

VISUAL AWARENESS NEGATIVITY. The effect of change processing on the VAN in the central ROI was more pronounced in the group with lowest false alarm rate [Change processing \times Group: $F(2, 28) = 4.01, p = .035, \epsilon = .89$]. A post hoc comparison revealed a significant effect for change detection without identification versus change blindness only in the group with low false alarm rate [$F(1, 7) = 10.11, p = .015$], but not for subjects with high false alarm rates [$F(1, 7) < 1$]. No similar effects were found when false alarms were compared to correct rejections (all $F < 1$). Thus, in contrast to the account that sees sensing as the result of a liberal response bias, we actually found the electrophysiological correlate of sensing (detection without identification) only in subjects with a conservative response criterion.

P3. The analysis confirmed the effect of change processing [$F(2, 28) = 39.60, p < .001, \epsilon = .81$] but did not reveal a significant difference between the two groups [Change processing \times Group: $F(2, 28) = 2.80, p = .09, \epsilon = .81$].

CHANGE-RELATED POSITIVITY. The analysis confirmed that the magnitude of the change-related positivity was dependent on the perception of the change [Change processing \times

Hemifield \times Hemisphere: $F(2, 28) = 16.28, p < .001, \epsilon = .99$]. However, no interaction with the group factor was found [$F(2, 28) = 1.13, p = .338, \epsilon = .99$].

N2pc. The analysis confirmed that the magnitude of the N2pc was dependent on the perception of the change [Change processing \times Hemifield \times Hemisphere: $F(2, 28) = 7.95, p = .003, \epsilon = .90$]. However, no interaction with the group factor was found ($F < 1$).

Discussion

In Experiment 1, we sought to identify electrophysiological responses associated with detection and identification of visual changes. We were primarily interested in whether or not EEG data would support the claim that sensing of changes and conscious perception of the changing object are based on fundamentally different perceptual processes. Two types of change trials were in the focus of the present analysis. Trials in which a change was detected but could not be identified served as an index of sensing, whereas seeing of a change was inferred when the change was both detected and also identified. A comparison of effects for detection of a change and identification of a change (as opposed to change blindness) revealed both similarities and fundamental differences between these conditions.

We found that on some trials, participants correctly detected the occurrence of a change, but could not identify the changing object. Detection without identification was associated with the VAN—a posterior ERP negativity. A very similar effect was found (with larger magnitude) when the changing object was correctly identified. No such effect was observed for false alarms. As laid out above, finding such a similarity between change detection with correct identification and detection without identification is essential for arguing that detection without identification is, indeed, a perceptual process, and can be distinguished from correct guessing. It has been suspected that change detection without identification might be due to correct guessing and a liberal response criterion (Simons et al., 2005), but our results suggest otherwise. We compared subjects with low and high false alarm rates. We confirmed the finding by Simons et al. (2005) that subjects with higher false alarm rates (and who were supposedly guessing the most) showed a higher incidence of change detection without identification. However, the electrophysiological correlate of sensing—the VAN for detection without identification—was found only in subjects with low false alarm rates, who were supposedly guessing the

Figure 3. Summary of the grand-averaged ERP data obtained in the visual search task in Experiment 2 time-locked to the onset of the search display. Time windows used for statistical analyses are shaded. Topographies show scalp distributions in the time windows used for statistical analyses. (A) ERPs for target-present and target-absent trials for conjunction stimuli and meaningful objects. Time courses are shown at the three ROIs. (B) Difference potentials at the central ROI in the SN and P3 time range for conjunctions and objects derived by subtracting waveforms for target-present and target-absent trials. (C) The N2pc (shown here at the posterior ROI) was computed by subtracting the ERPs at electrodes ipsilateral to a target from electrodes contralateral to a target.

least. This result confirms that ERP effects of sensing do not simply reflect guessing and a liberal response criterion. Furthermore, the difference between subjects with low and high false alarm rates confirms the finding of Rensink (2004) that subjects differ widely in how frequently they experience sensing or how reliably they can report this experience.

ERP asymmetries contralateral to a change (the change-related positivity and the N2pc) were found exclusively for change trials in which the identity of the changing object could be reported. No change-related positivity or N2pc was observed when the change was only detected or when observers were change blind. As laid out above, finding a qualitative difference between detection with and without identification indicates that sensing and seeing are distinct perceptual processes (Rensink, 2004). Furthermore, if detection without identification was due to misclassified identified trials, similar effects should be observed in the detection without identification condition as well, which was not the case. This dissociation thus indicates that reports of different ways of perceiving a change do not result only from differential response biases or are made up only in retrospect. Rather, the results indicate that, in the case of change perception, phenomenologically different experiences are brought about by separable perceptual and neural processes.

In the remainder of this section, we will discuss each of the ERP results in more detail. The ERP effect that was found for sensing resembles the ERP component that has been called VAN. Several studies demonstrated that in change blindness and in masking paradigms, this component is largest in conditions in which observers report perceptual awareness as compared to conditions in which stimuli are not perceived or not reported (Wilenius-Emet, Revonsuo, & Ojanen, 2004; Koivisto & Revonsuo, 2003). It has been suggested that in a change detection paradigm, the VAN “may correlate to neural processes occurring when the stimulus (change) enters phenomenal visual awareness” (Koivisto & Revonsuo, 2003). A central finding in the present experiment is that the VAN was mainly associated with the awareness of a change, but it was not dependent on the identification of the changing object. The earliest effect of change detection with correct identification in the present study was found on the lateralized change-related positivity with a mean peak latency of approximately 120 msec. This ERP component has been reported previously in studies of simple delayed matching-to-sample tasks (Kimura, Katayama, & Murohashi, 2005a, 2005b). The change-related positivity is overlapping with the P1 or N1 component of the ERP and its topography varies according to the changing feature dimension (Kimura et al., 2005b) and appears contralateral to the change in lateralized stimulus displays (Kimura et al., 2005a). This component has been interpreted as an automatic memory-based change detection mechanism, which compares representations of different feature dimensions independently (Kimura et al., 2005a, 2005b). According to this interpreta-

tion, the absence of this component under change blindness and detection without identification may indicate that a requirement of successful change identification is the memory-based comparison of representations of pre- and postchange information (Mitroff, Simons, & Levin, 2004). Previous studies found that this change detection mechanism seems to operate independently of whether the changing feature belongs to the task-relevant feature dimension (Kimura et al., 2005b) and is also independent of whether or not the change occurs at an attended location (Kimura et al., 2005a). This feature of the change positivity may also be important for the interpretation of the present results. The absence of a change-related positivity under change blindness and detection without identification might imply that the failure to see the change cannot be attributed simply to a failure of attention because a lapse of attention should not make a difference for a preattentive change detection process as indicated by the change-related positivity. It should be noted, however, that the perceptual load in the present study was considerably higher compared to the simple designs employed by Kimura et al. (2005a, 2005b). Moreover, Kimura, Katayama, and Ohira (2008) found no change-related positivity in a change blindness paradigm in the comparison between change blindness and no-change trials. It is thus conceivable that the change positivity does, in fact, depend on a minimum level of attention, and that attention is not completely withdrawn from unattended locations or feature dimensions in paradigms with low perceptual load. An important aspect of our findings is that the earliest effect for changes that were detected, but not identified, was found on the VAN/SN with a mean latency of 270 msec. This is considerably later than the earliest effect found for identification on the change positivity. This result implies that sensing a change does not seem to be a necessary prerequisite for seeing a change. In this case, the earliest effect for detection without identification should have preceded the earliest effect for detection with correct identification, which was not the case. Of course, this interpretation presumes that we did not simply fail to detect any earlier effects of sensing due to the limited sensitivity of the ERP technique. Moreover, this result argues against the interpretation that detection and identification rely on the same perceptual process at early stages, whereas later stages of that process are executed only for identification. In this case, effects that occur only for identification (i.e., the change-related positivity) should not precede effects that occur for both detection with correct identification and detection without identification (the VAN). Rather, this finding is in line with the study by Rensink (2004), who found that in those trials where sensing occurred, the average onset of sensing is later than the average onset of seeing in trials where sensing did not occur.

A second effect that was unique for change identification was found on the N2pc component. N2pcs were only found for changes that were detected and identified, but no N2pcs were elicited when changes were only detected

or not perceived at all. Possibly, the perceptual process underlying sensing of change occurs at a stage of visual processing that does not provide the spatial information required for the focusing of selective attention, which is reflected by the N2pc. The N2pc has been predominantly investigated in visual search tasks (Luck & Hillyard, 1994). The function of this component has been a matter of debate, and different (but not necessarily exclusive) interpretations have been put forward. The N2pc has been found to be larger for targets surrounded by distracting context elements (Luck & Hillyard, 1994). Hence, it has been concluded that the N2pc reflects a spatial filter, which suppresses irrelevant distractor items (Luck & Hillyard, 1994). In contrast, Eimer (1996) found N2pcs even with stimulus arrays comprising only a single distractor element for which the need to filter out irrelevant or conflicting information was minimized. Thus, an alternative interpretation states that the N2pc reflects the allocation of attention to targets, and this allocation is guided by a top-down mechanism sensitive to the presence of task-relevant features (Eimer, 1996). This interpretation is close to other accounts that envisage the N2pc as indicating the focusing of attention (Hopf et al., 2000) or a shift of attention within the search display (Woodman & Luck, 2003). Generators of the N2pc have been found in parietal and occipito-temporal cortex (Hopf, Boelmans, Schoenfeld, Luck, & Heinze, 2004; Hopf et al., 2000). It has been suggested that the parietal source reflects the initiation of spatial shifts of attention to target locations (Hopf et al., 2000), whereas the occipito-temporal subcomponent reflects a mechanism that implements the selection of relevant information once attention has been shifted (Hopf, Boelmans, Schoenfeld, Heinze, & Luck, 2002). The parietal source of the N2pc seems to overlap with part of the fronto-parietal network that has been found active when changes are detected (as opposed to change blindness) (Beck, Rees, Frith, & Lavie, 2001). The significance of spatial shifts of attention for identification (but not detection) of changes is discussed in more detail in the General Discussion. Our results are in accordance with a study that reported N2pcs for detected but not for undetected changes (Eimer & Mazza, 2005). We could thus not replicate the effects reported by Schankin and Wascher (2007), where small N2pcs were found even for change blindness.

P3 amplitudes were largest for correctly identified changes, but small P3 effects were also found for merely detected changes and also for false alarms, replicating effects reported in previous studies (Eimer & Mazza, 2005; Koivisto & Revonsuo, 2003). These results are in accordance with the interpretation that P3 amplitudes reflect observers' response confidence rather than a perceptual process involved in processing of change (Eimer & Mazza, 2005).

EXPERIMENT 2

Experiment 1 sought to identify ERP correlates of change detection and identification and change blindness. Three

major EEG parameters were related to these conditions: an early posterior negativity (the VAN), the contralateral change-related positivity, and the N2pc. Some of these EEG phenomena are known as correlates of selective attention. The SN, a posterior negative effect closely resembling the VAN, has been described as a correlate of feature selective attention in visual search studies (Hillyard & Anllo-Vento, 1998). In addition, the N2pc component is frequently found in visual search tasks contralateral to targets, especially when the target is defined by a feature conjunction (Woodman & Luck, 2003; Hillyard & Anllo-Vento, 1998). In Experiment 2, we wanted to compare the ERP effects found in the change blindness paradigm of Experiment 1 to well-known effects in a visual search task. We asked whether any of the effects found for change detection/identification (as opposed to change blindness) is specific for the change blindness paradigm, or whether they are all similar to effects of attention, which also manifest as target-present/target-absent effects in a visual search paradigm. These questions cannot be unequivocally answered based on existing literature. Most previous ERP studies of visual search employed very basic stimuli such as bars or simple geometric shapes, whereas we presented images of real-world objects in Experiment 1. To our knowledge, no systematic comparison of these stimulus types has been conducted to date. Therefore, we conducted a visual search experiment under two conditions: search for a conjunction of color and orientation with simple bars, and search for a specific meaningful object among distractor objects (see Figure 1B). Parameters of the stimulation were held as similar as possible to the change blindness paradigm.

Methods

Participants

Eight volunteers participated in the study (mean age = 26 years; 4 women; 7 right-handed). Participants gave written informed consent before the start of the experiment. All participants had normal or corrected-to-normal vision and had no recorded history of neurological or psychiatric disorders. The study protocol conformed with local ethics guidelines and the Declaration of Helsinki.

Stimuli and Procedure

Experiment 2 employed a visual search task with two different types of stimuli: simple colored bars and the set of complex objects (Rossion & Pourtois, 2004), which was also employed in Experiment 1 (see Figure 1 for an illustration). The two stimulus types were presented blockwise, and the order of blocks was counterbalanced across participants. The experimental task was identical for both types of stimuli. A trial began with a cue stimulus presented for 500 msec. This cue informed participants about the identity of the target that had to be searched for in this trial.

In the block featuring simple bars, the target was always defined as a particular conjunction of color (red or green) and orientation (vertical or horizontal). A different target was chosen on each trial. After a short interstimulus interval of 800 msec, the search display was presented for 616 msec. Search displays consisted of a matrix of 4×4 items. The displays subtended 7° visual angle, and a single item had a size of 1.25° visual angle. The displays in Experiment 2 were thus identical with respect to size and duration to the displays in Experiment 1. The target was present in the display on 50% of the trials. Participants were instructed to always maintain central fixation and to indicate the presence or absence of the target item as fast and accurately as possible by pressing one of two response keys. The mapping between experimental condition (target present vs. target absent) and response keys was also counterbalanced across participants. The following trial began after a variable intertrial interval of 2000–2500 msec after the button press. Three hundred eighty-four trials (192 target-present trials) were presented for each stimulus type.

Data Acquisition and Analysis

The recording and general analytic procedures were the same as those used in Experiment 1. Response times of correct responses and the percentage of correct responses were analyzed with an ANOVA comprising the factors stimulus type (conjunction stimuli vs. complex objects) and target presence (target present vs. target absent). Statistical analyses of EEG data were based on trials with correct answers only. Nonlateralized EEG components were defined as mean amplitudes in the following time windows: 200–350 msec (SN) and 400–600 msec (P3). Nonlateralized EEG components (SN, P3) were analyzed with an ANOVA comprising the factors stimulus type, condition, and ROI. Event-related asymmetries were defined as the mean amplitudes in target-present trials in the following time windows: 310–410 msec (N2pc in the conjunction search block) and 200–300 msec (N2pc in the object search block). N2pcs were analyzed in the posterior ROI with an ANOVA comprising the factors stimulus type, hemifield (left target vs. right target), and hemisphere (left vs. right recording sites). Note that asymmetries are not defined for trials in which no target was presented.

Results

Behavioral Results

Behavioral responses were faster to objects (650 msec) than to the simple conjunction stimuli [718 msec; stimulus type: $F(1, 7) = 9.46, p = .018$]. Responses on target-present trials (646 msec) were faster, irrespective of stimulus type, than on target-absent trials [723 msec; target presence: $F(1, 7) = 18.27, p = .004$]. There was no statistical interaction between stimulus type and target presence

[$F(1, 7) < 1$]. More correct responses were found in the object search task than in the conjunction search task [89% vs. 85%; stimulus type: $F(1, 7) = 6.75, p = .036$]. Furthermore, performance was superior on target-absent trials than on target-present trials [target presence: $F(1, 7) = 37.11, p < .001$]. The difference between conjunction and object stimuli concerned primarily target-present trials (objects: 88%; conjunctions: 79%), whereas the proportion of correct responses on target-absent trials was similar for the two stimulus types (objects: 91%; conjunctions: 92%). Target detection accuracy A' was slightly better for object stimuli ($A' = 0.95$) than for conjunction stimuli ($A' = 0.91$; $F(1, 7) = 7.92, p = .026$). These effects indicate that the stimulus material primarily exerted an effect on how often target stimuli were missed, and they were missed more often when the search display contained simple conjunction stimuli. This conclusion was supported by a Stimulus type \times Target presence interaction [$F(1, 7) = 13.92, p = .007$].

EEG Results

The topography of ERPs differed vastly between simple conjunction stimuli and meaningful objects (Figure 3A). Conjunctions evoked a stronger negative ERP component around 150 msec with a midline topography, and this component was less pronounced and more laterally distributed for complex objects. A second peak of the ERP waveform was larger and had a stronger dipolar distribution for meaningful objects at around 270 msec (Figure 3A).

Selection Negativity

Presentation of a target stimulus elicited stronger negativity of the ERP as compared to target-absent trials [target presence: $F(1, 7) = 6.79, p = .035$], and this negative deflection was most pronounced over central channels [Target presence \times ROI: $F(2, 14) = 36.56, p < .001, \epsilon = .93$]. The topography of this target effect was similar for conjunctions and meaningful objects, even though the ERPs on which it was superimposed clearly had different topographical distributions (Figure 3B).

P3

P3 amplitudes were larger for meaningful objects than for conjunction stimuli [stimulus type: $F(1, 7) = 5.60, p = .050$] and larger for target-present than for target-absent trials [target presence: $F(1, 7) = 47.42, p < .001$]. The target effect was also larger for meaningful objects than for conjunction stimuli [Stimulus type \times Target presence: $F(1, 7) = 5.65, p = .048$] and this effect was most prominent over posterior recording sites [Stimulus type \times Target presence \times ROI: $F(2, 14) = 25.86, p < .001, \epsilon = .89$; Figure 3A and B].

ERP Asymmetries

No change-related positivity was found in this search task, as indicated by a nonsignificant Hemisphere \times Hemifield interaction in that time window in which a change positivity was found in Experiment 1 (Figure 3C). In a later time range, N2pc components were found [Hemifield \times Hemisphere: $F(1, 7) = 23.87, p = .002$; Figure 3C]. N2pcs for meaningful objects had shorter latencies than N2pcs for conjunction stimuli [objects: 224 msec; conjunctions: 348 msec; $t(14) = 0.01$, two-tailed t test]. Furthermore, N2pcs were larger for meaningful objects as compared to conjunction stimuli [Hemifield \times Hemisphere \times Stimulus type: $F(1, 7) = 7.05, p = .033$].

Discussion

In Experiment 2, we compared the effects of change detection and change identification found in Experiment 1 to attentional effects in a classical visual search paradigm. In order to assure the equivalence of the change blindness paradigm and the visual search experiment, the visual search task was conducted with simple colored bars, which is a very typical stimulus set in this line of research, as well as with the complex objects that were employed also in Experiment 1. This comparison enables us to draw conclusions about the identity of the EEG components found in the change blindness paradigm. In addition, we sought to determine EEG components that are genuine for change processing on the one hand, and components that represent general effects of visual attention on the other. This comparison revealed several similarities, but also striking differences.

Target stimuli evoked a negative ERP component at around 200 msec. This component represents the so-called SN, which is typically found in this paradigm (Hillyard & Anllo-Vento, 1998). The SN found in the visual search task can thus serve as a benchmark to which similar effects in the change blindness paradigm can be compared. The central/posterior negativity that was found for detected and for identified changes (as opposed to change blindness) in Experiment 1 had a highly similar latency, morphology of the waveform, and also scalp topography (compare Figures 2B and 3B). Hence, it is reasonable to assume that the so-called VAN in the change blindness paradigm is closely related or even identical to the well-known SN. In a series of experiments using masking paradigms, Koivisto, Revonsuo, and collaborators have demonstrated that the VAN can be dissociated from effects of attention, even though ERP effects of awareness and attention may seem similar at first glance. Attentional manipulations employed in these studies comprised the global/local scope of attention in hierarchical stimuli (Koivisto, Revonsuo, & Lehtonen, 2006), detection of masked target letters (Koivisto, Revonsuo, & Salminen, 2005), and cueing of spatial attention (Koivisto & Revonsuo, 2007). The central finding in these studies has been that one class of ERP com-

ponents (the VAN) is found for consciously perceived (as opposed to unperceived) stimuli, whereas a separate class of attention-related ERPs (presumably the SN) is found for attended as opposed to unattended stimuli. In contrast to this work, we found ERP effects of change detection and identification in a change blindness paradigm to be very similar to effects of feature-selective attention on the SN component in a visual search paradigm. It is important to note, however, that the experimental manipulations leading to awareness and unawareness in the present study differ significantly from the masking paradigms used by Koivisto et al.. Masking reduces stimulus detectability by disrupting early visual processing of the stimulus (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Breitmeyer & Ogmen, 2000; Di Lollo, Enns, & Rensink, 2000). By contrast, most researchers agree that the reasons for change blindness are limitations of attention and working memory, which are necessary to build up, maintain, and compare object representations (Dehaene et al., 2006; Simons & Rensink, 2005; Mitroff et al., 2004; Rensink, 2002). If the difference between change blindness and change detection is essentially an attentional difference, completely dissociating ERP effects of awareness from ERP effects of attention may not be possible in the first place. It would be worthwhile to combine a change detection task with a target detection task in the same paradigm to further distinguish awareness-related and attention-related ERP components. For the time being, the relationship between VAN and SN in the change blindness paradigm remains an open issue.

Furthermore, targets evoked a negative component contralateral to the hemifield in which the target was presented. This N2pc component was most pronounced and peaked earlier for targets that were complex objects as compared to the simple colored bars. The latency difference between the complex objects and the simple bars paralleled the differences in response times between these two conditions. These results can be regarded as conflicting with the interpretation that the N2pc reflects a neural correlate of a filter process that serves to suppress distractor items surrounding a target item (Luck & Hillyard, 1994). In Experiment 2, the number of distractor items was identical in both search tasks. Moreover, when search displays consisted of simple colored vertical and horizontal bars, distractors were more similar to the target item, resulting in stronger competition between target and distractors. This competition was confirmed also by the behavioral data that showed longer RTs and a larger number of errors compared to search for complex objects. Yet, although the stimuli actually necessitate stronger filtering of distractors, the N2pc was less pronounced in this condition. A further interesting finding was that N2pc topographies were not different for the two sets of stimuli (Figure 3C), although topographies of early visual components suggest that complex objects and simple bars were processed in different brain areas (Figure 3A). Thus, the N2pc does not seem to be specific for the content of what

is being attended. This conclusion is in line with accounts that see the function of the N2pc as selecting relevant stimuli through deployment of attention to task-relevant locations (Woodman & Luck, 2003; Hopf et al., 2000; Eimer, 1996). The N2pc component found for identified changes in Experiment 1 was almost indistinguishable from the N2pc found in the visual search paradigm (compare Figures 2C and 3C). Thus, searching for a change can be assumed to involve similar cognitive processes as searching for a task-relevant target.

A major difference between the results of Experiments 1 and 2 concerned the visual change-related positivity, which indeed was only found in the change blindness paradigm of the first experiment. Thus, this component does not generally reflect visual attentional processes. Instead, it appears to reflect a genuine change detector that performs memory-based comparisons between consecutive stimuli (Kimura et al., 2005a, 2005b).

GENERAL DISCUSSION

Sensing and Seeing as Different Perceptual Processes

The main objective of the present study was to investigate whether visual changes can be detected without also being identified, and whether the difference between change detection and change identification is a difference of quantity or quality. In other words, do detection and identification of a change rely on similar or fundamentally different perceptual processes? This investigation was motivated by the finding reported by Rensink (2004) that some observers on some trials can sense the presence of a recurring change before they can explicitly identify (see) it and without having a visual experience of the changing object. However, according to an alternative interpretation, the feeling of sensing a change without a corresponding experience of the changing object is either not based on a perceptual process at all (i.e., lucky guessing) or sensing responses are based on the same perceptual process as seeing, but are given with a more liberal response criterion after observers have scrutinized their detection (Simons et al., 2005). This conclusion was based on the finding that the occurrence of sensing was correlated with the occurrence of false alarms. However, it cannot be excluded that this paradigm might have encouraged participants to scrutinize their perception of a change or simply guess when no change is found in the display. In addition, by requiring participants to base their responses on their feeling and seeing, respectively, the instructions might have introduced confusion on what these response categories actually constitute and which subjective response criteria should be assigned to each of the response alternatives. In the present study, sensing was not measured as a certain time lag between a sensing response and a seeing response. Moreover, the difference between sensing and seeing was not inferred from the

patterns of response times as in the Rensink study. Instead, it was inferred from different electrophysiological response patterns. In the present study, participants were forced to give answers to two questions immediately after a single presentation of the change displays, with one question requiring only the mere detection of a change and the second question requiring identification. Sensing was inferred when a change could be veridically detected, but not identified. We found that merely detecting the presence of a change differs systematically from conscious perception of the changing object, which is required for identification. Although detection with correct identification (seeing) and detection without identification (sensing) exerted similar effects on some ERP components, effects for identification on the change-related positivity and the N2pc were completely absent for changes that were only detected. This result is in line with a fundamental difference between sensing and seeing (Rensink, 2004). Further support for the distinction between sensing and seeing has been provided by a study of comparative visual search by Galpin, Underwood, and Chapman (2008). In their study, participants had to search for a difference between two simultaneously presented natural scenes. Two different response keys had to be pressed when a difference was sensed or seen. They found that response confidence was stronger for sensing when there actually was a difference between the two images compared to false alarms when the images were identical. Moreover, the type of change and the homogeneity of the displays had dissociable effects on sensing and seeing. Similar to the present study, Galpin et al. (2008) found that subjects made a large number of false alarms. This finding indicates that real sensing can be easily confused with random internal noise. However, sensing clearly does not represent random guessing. In the study (Galpin et al., 2008), eye movements were sensitive to the location of the difference when this difference was sensed, but not seen. In the present study, a VAN/SN effect for changes that were detected but not identified was found only in subjects who made few false alarms and who had a conservative response criterion. Also, a VAN/SN effect was not found for false alarms.

The findings bear important implications for the design and interpretation of studies on change detection and change blindness. Task instructions in such studies should be as specific as possible about whether response alternatives correspond to the perceived presence or absence of a change (a detection task) or whether they correspond to the perception of the changing object (an identification task). Possible conflation of change detection and change identification complicates the interpretation of studies, in which the change blindness paradigm has been used to investigate the so-called neural correlates of visual awareness (Eimer & Mazza, 2005; Koivisto & Revonsuo, 2003; Beck et al., 2001). Furthermore, the present results suggest that studies investigating neural correlates of conscious visual perception can benefit from employing complex and diverse stimulus material (i.e., a large set of different

meaningful objects or scenes instead of a limited set of simple bars or geometric figures or a narrow class of objects). For instance, asking observers to report on their perception of the changing object is hardly meaningful when all objects come from the same stimulus category or the stimulus display contains a very narrow set of elements (e.g., only either horizontal or vertical bars).

Another consequence of our finding of a fundamental difference between sensing and seeing of a change concerns the design of future studies on change detection and change blindness and their neural correlates. We demonstrate the advantage of offering subjects a response format that allows them to differentiate between different ways of perceiving a change over a simple “change/no change” decision (see Gaillard, Vandenberghe, Destrebecqz, & Cleeremans, 2006, for a similar line of reasoning). More fine-grained measures of awareness and phenomenological approaches have been successfully employed in studies of the attentional blink (Sergent, Baillet, & Dehaene, 2005; Sergent & Dehaene, 2004) and visual masking (Overgaard, Nielsen, & Fuglsang-Frederiksen, 2004; Overgaard & Sørensen, 2004). This approach is largely accepted in other fields of research. For instance, several studies have investigated phenomenologically different ways of long-term memory retrieval: vaguely “knowing” that something is from the past (familiarity) versus “remembering” detailed information from the study episode (recollection). By differentiating between “remember” and “know” judgments, numerous studies have found evidence that familiarity and recollection can be dissociated, supporting dual-process models of recognition memory (Jäger, Mecklinger, & Kipp, 2006; Yonelinas, 2002). In sum, experimental paradigms should take into account that “visual experiences seem much more complicated than what is captured by using just the two categories ‘clear, vivid experiences’ and ‘nothing at all’” (Ramsøy & Overgaard, 2004, p. 4).

Change Blindness and Attention

By comparison with results in the visual search task, we could ascertain that some effects of change detection and identification appear also as target-present/target-absent effects when identical stimuli are used. Such target effects have been employed as measures of feature selective attention (Hillyard & Anllo-Vento, 1998; Luck, Girelli, McDermott, & Ford, 1997). Most accounts of change blindness have highlighted the importance of attention for detection of changes (see Simons, 2000, for an overview). Attention could facilitate the encoding of information or protect visual representations from being overwritten by the subsequent display (Landman, Spekreijse, & Lamme, 2003; Becker, Pashler, & Anstis, 2000; Rensink et al., 1997). However, change blindness can also be brought about by a failure of working memory (Wilken & Ma, 2004), when information from the prechange scene is not stored or not compared with information from the postchange scene (Mitroff et al., 2004; Hollingworth, 2003), at least when

meaningful stimuli or natural scenes instead of simplistic stimuli are investigated (Landman et al., 2003). Although the role of working memory for change detection and identification was not directly investigated in the present study, the results suggest that detection and identification of change do not exclusively rely on attentional mechanisms. To begin with, the change-related positivity was found only for identified changes in the change blindness paradigm but not for target stimuli in a visual search paradigm. This finding implies that this mechanism of change processing cannot simply be regarded as the attentional selection of a task relevant stimulus. Second, no event-related asymmetries contralateral to the site where the change was about to occur were found before the onset of the second display (data not shown), suggesting that attention was not necessarily deployed at the location of the change prior to the change. Thus, we could not confirm previous studies that found differential activity between detected changes and change blindness preceding the change (Pourtois et al., 2006; Koivisto & Revonsuo, 2005). In sum, these results suggest that although attention is tightly linked to and most probably necessary for detection and identification of change, neither feature-selective nor spatial attention appears to be sufficient for change detection and identification. Similar conclusions have been derived from studies that found change blindness even for objects that are fixated or at the focus of attention (Caplovitz, Fendrich, & Hughes, 2007; O’Regan et al., 2000; Levin & Simons, 1997).

Sensing, Seeing, and Object Recognition

Our findings may seem to be at odds with recent studies on rapid object recognition. Building on earlier studies that revealed that high-order representations can be accessed very rapidly from natural scenes presented at rapid succession (Potter, 1976), several authors have argued that recognition of objects in natural scenes is accomplished very rapidly without requiring attention. It has been demonstrated that observers can recognize the category of objects in briefly presented natural scenes while simultaneously performing an attentionally demanding primary task (Li, VanRullen, Koch, & Perona, 2002). By comparison, observers were unable to discriminate abstract stimuli under the same conditions (Li et al., 2002). The authors concluded that object recognition proceeds in the near absence of attention. Moreover, Grill-Spector and Kanwisher (2005) have demonstrated that mere detection of the presence of an object and recognition of the object’s basic category (e.g., car or face) requires the same amount of stimulus information and processing time while more processing time and stimulus information is required for identification of the object’s identity at the subordinate level (e.g., Volkswagen Beetle or Harrison Ford). In contrast to these studies, we found that detection of a change does not warrant the recognition of the changing object. Furthermore, the electrophysiological effect that was most specific for identification (the N2pc) is regarded as

a correlate of spatial selective attention. Why might spatial attention be necessary for the *identification* of a change, but not or much less for *detection* of change? A clue to a possible answer is provided by a study that found evidence against rapid and parallel recognition and access to high-level object representations in the absence of attention (Evans & Treisman, 2005). This series of experiments demonstrated that object identification can be impaired despite superior detection performance when targets in a rapid serial visual presentation sequence were intermixed with distractor stimuli containing shared features. The authors concluded that, in a recognition task, participants rapidly and in parallel detect sets of unbound features that are diagnostic for the target category (such as the round shape of the eyes when the task requires detection of an animal). These unbound features can then be used to discriminate between scenes that do or do not contain the target category, but they do not allow precise identification of the object. Thus, rapid feature analysis enabling detection may be followed by identification and localization only after attention-demanding feature binding (Evans & Treisman, 2005). This account may also provide an answer to the question of the nature of the sensing phenomenon and change detection without identification of the changing object. The present results show that change detection without identification (sensing a change) is associated with the SN, which indicates the involvement of feature-selective attention (Baas, Kenemans, & Mangun, 2002; Hillyard & Anllo-Vento, 1998). Hence, some features of the changing object seem to be processed in the visual system, but this processing is insufficient for identification of the object and for a conscious visual perception. Correct identification (seeing), but not mere detection, was additionally associated with a neural correlate of a shift of attention (the N2pc). Possibly, the mechanism responsible for sensing is the registration of a change on a map of unbound features representing a scene. This registration enables the detection that something has changed, but it is insufficient for identification because object recognition requires that features be bound into a coherent or integrated object representation through deployment of selective spatial attention (Wolfe, 2003; Rensink, 2000; Treisman & Gelade, 1980). Galpin et al. (2008) arrived at a similar conclusion based on data in a comparative visual search task. They suggested that sensing occurs when a comparison process detects a mismatch in feature information, but is unable to identify the corresponding object because the features have not been bound correctly. In sum, we suggest that sensing occurs when feature-selective attention is engaged by a change without an accompanying shift of attention to the locus of the change, rendering object features unbound, which precludes their integration into a coherent object representation.

Conclusion

We investigated whether observers can sense a visual change (detect that something has changed) without see-

ing it (identifying what has changed) and whether these two types of change perception rely on different perceptual and neural processes. Detection without identification (but not false alarms) was associated with increased ERP negativity around 200–300 msec (VAN/SN). Changes that were detected and correctly identified did not merely evoke a stronger ERP effect of that type, but elicited several additional EEG effects both before and succeeding the time at which sensing effects were found: an early change-related positivity and an N2pc contralateral to the change. The results suggest a fundamental difference between sensing and seeing as postulated by Rensink (2004).

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Note

1. Note that the present study investigated *explicit* detection and *explicit* identification of changes. The study was not concerned with residual identification performance in the absence of awareness of a change (i.e., implicit change processing).

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