

Representation of Change: Separate Electrophysiological Markers of Attention, Awareness, and Implicit Processing

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Abstract

■ Awareness of change within a visual scene only occurs in the presence of focused attention. When two versions of a complex scene are presented in alternating sequence separated by a blank mask, unattended changes usually remain undetected, although they may be represented implicitly. To test whether awareness of change and focused attention had the same or separable neurophysiological substrates, and to search for the neural substrates of implicit representation of change, we recorded event-related brain potentials (ERPs) during a change blindness task. Relative to active search, focusing attention in the absence of a change enhanced an ERP component over frontal sites around 100–300 msec after stimulus onset, and in posterior sites at the 150–300 msec window. Focusing attention to the location of a change that

subjects were aware of, replicated those attentional effects, but also produced a unique positive deflection in the 350–600 msec window, broadly distributed with its epicenter in medio-central areas. The unique topography and time course of this latter modulation, together with its dependence on the aware perception of change, distinguishes this “awareness of change” electrophysiological response from the electrophysiological effects of focused attention. Finally, implicit representation of change elicited a distinct electrophysiological event: Unaware changes triggered a positive deflection at the 240–300 msec window, relative to trials with no change. Overall, the present data suggest that attention, awareness of change, and implicit representation of change may be mediated by separate underlying systems. ■

INTRODUCTION

Observers are sometimes very poor at reporting changes in their visual environment (Rensink, O'Regan, & Clark, 1997; Simons & Levin, 1997). Current theories of object and scene perception interpret such results as suggesting that focused attention is necessary for binding objects across both space and time (Rensink, 2000; Treisman, 1993). According to these theories, a change in an unattended object goes unnoticed because, in the absence of focused attention, the prechange and post-change representations are not integrated (Wolfe, 1999).

This dependence of awareness on focused attention renders it difficult to separately assess awareness of change from focused attention at the behavioral level. Nevertheless, these two processes may be separable at the neurophysiological level. That is, the neuronal response during awareness of change (with focused attention) may differ from the neuronal response during focused attention in the absence of change. Similarly, behavioral studies that use explicit reports are incapable of assessing whether, in the absence of focused atten-

tion, change can be implicitly represented. That is, the presence of a change may trigger a neuronal response even when subjects report being unaware of such a change. These questions are relevant to current theories of scene perception and, more generally, to neural theories of awareness (Kanwisher, 2001; O'Regan & Noe, 2001; Rees & Lavie, 2001; Rensink, 2000).

In recent years, the development of new behavioral paradigms and the use of neuroimaging techniques have begun to yield novel insights into the nature of perceptual awareness. One behavioral paradigm that has proven quite fruitful in this context is the flicker paradigm (Rensink, 2000). In this task, two versions of a complex scene are presented in alternating sequence, separated by a blank field. The two versions of the scene differ from one another only with respect to a single changing item. The change is well above threshold, and once it has been detected it is clearly visible, often appearing very “obvious” (see Figure 1). However, it usually takes several seconds for subjects to first notice the change, a phenomenon that has been labeled “change blindness” (for a review, see Rensink, 2002).

The crucial factor in making the change initially hard to detect is preventing attention from being captured by the local transients at the location of change. This can be accomplished in many ways, for instance, by introducing

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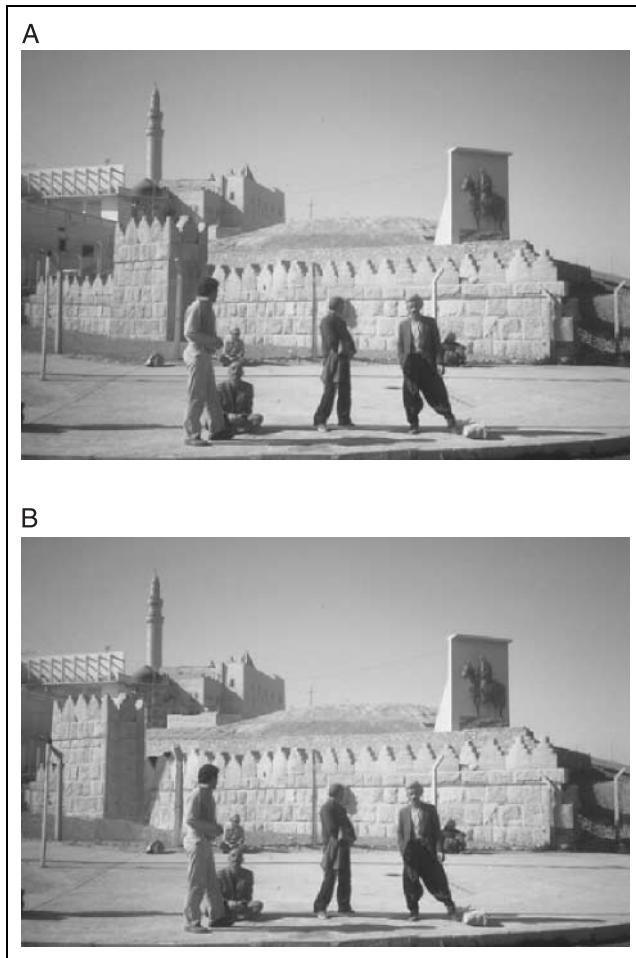


Figure 1. An example of a complex scene and its modified version. The tower in the left changes position. The pictures were displayed in color.

a global transient such as a blank field (O'Regan, Rensink, & Clark, 1999), displaying an orienting cue away from the location of change (Scholl, 2000), or introducing the change during a saccade (Bridgeman, Hendry, & Stark, 1975).

Neuroimaging of Perceptual Awareness

These findings highlight the importance of focused attention for awareness of change. However, behavioral studies can only provide information about the “effects” of attention on awareness, and thus are silent about the ways in which attention and awareness may interact in the brain. Neuroimaging methods can fill in this void. In recent years, several neuroimaging studies of attention and awareness have been conducted (for reviews, see Corbetta & Shulman, 2002; Kanwisher, 2001). Such studies can be broadly grouped into those that explore the mechanisms of attention, and those that study perceptual awareness.

Imaging studies of attention have investigated the areas that participate in the control of attention

(e.g., disengaging attention from a previously attended location, directing attention to a new location, etc.), and the effect of attention upon domain-specific areas (whether attention enhances the activity of areas involved in face perception, motion processing, etc.). This literature points to the existence of a network in right dorsal fronto-parietal areas, for the voluntary control of attention (Corbetta & Shulman, 2002; Kastner & Ungerleider, 2001; Hopfinger, Buonocore, & Mangun, 2000). It also reveals that focusing attention to a certain stimulus attribute (e.g., motion, face processing) enhances activity of the neural areas that participate in such information processing, such as area MT (O'Craven, Rosen, Kwong, Treisman, Savoy, 1997) and fusiform face area (O'Craven, Downing, & Kanwisher, 1999; Wojciulik, Kanwisher, & Driver, 1999), respectively (for a review, see Kanwisher & Wojciulik, 2000).

Imaging studies of perceptual awareness have revealed that activation in domain-specific areas correlates with perceptual awareness. A good example of this is a recent fMRI study of binocular rivalry, in which one eye was presented with face stimuli and the other with house stimuli (Tong, Nakayama, Vaughan, & Kanwisher, 1998). These rival stimuli led to increased activation of the face fusiform area, an area that responds selectively to faces, when subjects were aware of the face, relative to when they were aware of the house. The reverse was true for the parahippocampal place area (PPA), an area that responds selectively to outdoor scenes. Thus, even though the sensory stimuli were identical, the activity of domain-specific sites was dependent on the aware percept. Other studies have shown that the activation of other specialized brain areas similarly covaries with perceptual awareness. For example, activity in area MT, which is important for motion processing, is correlated with aware perception of motion (O'Craven et al., 1997), and activity in the “lateral occipital complex,” which is important for processing of information about objects, is correlated with aware object identification (Grill-Spector, Kushnir, Itzchak, & Malach, 2000; Tootell et al., 1996). Activity in area V4, which is important for processing of color, correlates with the perception of color aftereffects (Barnes et al., 1999).

Despite this evidence, it is unlikely that activation of domain-specific areas would in itself be sufficient for aware perception. For example, studies on implicit processing have revealed activation of domain-specific areas even in the absence of perceptual awareness (Dehaene et al., 2001). Furthermore, studies of aware perception have revealed activation of dorsal fronto-parietal areas, suggesting that these areas may also play an important role in perceptual awareness. For example, in another fMRI study of binocular rivalry, subjects were asked to report when their percept alternated. In the experimental condition, rivalrous stimuli (a face and a drifting grating) were presented to each eye, and subjects reported the perceptual transitions in their aware

experience (i.e., when they saw the face replacing the grating, and vice versa). In the control condition, the sequence was repeated but using monocular stimuli, thus eliminating the binocular rivalry. Relative to the control condition, transitions in the binocular rivalry condition led to activation of right fronto-parietal areas (inferior frontal, superior parietal, and inferior parietal areas) (Lumer, Friston, & Rees, 1998).

The claim that fronto-parietal areas are important for aware perception also receives support from an fMRI study of change blindness (Beck, Rees, Frith, & Lavie, 2001). This study combined a simplified flicker paradigm with an attentionally demanding baseline letter detection task. The change detection task involved reporting a change in two peripherally presented images of either faces or houses, which were flickered for only two cycles. The difficulty of the letter detection task was adapted for each observer to ensure that a roughly equal number of changes were missed as were detected. The main goal of the study was to test the hypothesis that faces and houses would activate domain-specific areas (FFA, PPA), but both types of stimulus would activate common fronto-parietal areas when subjects were aware of the change. The comparison was between trials in which a change was detected and trials in which the change was missed. Conscious detection of change led to activation of separate category-specific ventral regions (Epstein & Kanwisher, 1998; Kanwisher, McDermott, & Chun, 1997), but also of a common network of dorsal fronto-parietal areas.

Other studies have further shown a covariation in activity between the dorsal areas and the ventral areas across conditions of awareness (Dehaene et al., 2001; Vuilleumier et al., 2001; Lumer et al., 1998). The dorsal fronto-parietal activation in perceptual awareness tasks resembles the activation in those areas by tasks of selective attention (Kastner, DeWeerd, Desimone, & Ungerleider, 1998). This commonality of activation has led some researchers to propose that aware perception arises from the joint activity of an attentional network in dorsal fronto-parietal areas, and the category selective regions in the visual cortex that initially process the stimuli (Rees & Lavie, 2001; Kanwisher & Wojciulik, 2000).

A Confound of Perceptual Awareness and Focused Attention

The studies described above, and the theories that followed them, have turned what used to be an elusive question into a tractable scientific enterprise. They have also helped to make clear predictions about what patterns of activation should be expected in future studies of perceptual awareness. However, from these studies, it is not possible to assess whether the pattern of activation is due to attention, awareness, or both.

This difficulty stems from the intimate link between attention and perceptual awareness (Prinzmetal, Amiri,

Allen, & Edwards, 1998; Merikle & Joordens, 1997). This is best illustrated by studies of divided attention, in which attention is taken away from the main task by a secondary task, as in the study by Beck et al. (2001). While inattention reduces the neural activation in domain-specific areas, it also reduces perceptual awareness. In one of these studies, moving dots were displayed while subjects performed a linguistic task. Under a low attentional load, the presentation of task-irrelevant moving dots led to activation of area MT. This condition also produced an illusory motion aftereffect, which is a measure of perceptual awareness. When the attentional load of the secondary task was increased, activity in area MT was decreased, thus suggesting that MT activation was attention dependent. However, an increased attentional load also reduced the motion aftereffect, thus suggesting reduced perceptual awareness (Rees, Frith, & Lavie, 1997).

A similar problem arises with the neuroimaging studies of neglect patients (for a review, see Driver & Vuilleumier, 2001). Patients with right parietal lesion sometimes experience neglect and visual extinction, a lack of perceptual awareness to contralesional stimulus when displayed in combination to ipsilesional distractor. Visual extinction is thought to be caused by a biasing of attention towards the ipsilesional side. Despite their failure to reach awareness, neglected stimuli activate the primary visual cortex and the inferior temporal cortex, and trigger stimulus-specific event-related brain potential (ERP) responses (Vuilleumier et al., 2001; Rees et al., 2000). These studies provide strong evidence for the existence of implicit processing, and for the claim that activation of domain-specific areas is not sufficient for awareness. The results are also evidence for the claim that attention, via its fronto-parietal network, is a key ingredient for aware perception. However, what these studies cannot address is the separate contribution of attention and awareness to the pattern of brain activation, because in these studies, as in many others, awareness and attention are confounded.

A Solution to the Attention–Awareness Confound

The ideal paradigm to explore the contribution of aware perception to neuronal activation would measure the effect of awareness in the absence of attention. However, there is strong evidence that, in the absence of attention, aware perception is not possible (Driver, Davis, Russell, Turatto, & Freeman, 2001; Mack & Rock, 1998; Joseph, Chun, & Nakayama, 1997). Therefore, a different approach is needed. One possibility is to compare aware and unaware perception under conditions of focused attention. The problem here is that focused attention facilitates aware perception, thus making it difficult to modulate awareness while keeping the stimulus invariant. It is possible to add a mask to reduce awareness, but this modifies the properties of the physical stimulus, making comparisons across

conditions more difficult (Dehaene et al., 2001; Grill-Spector et al., 2000; Macknik & Livingstone, 1998). The flicker paradigm, in combination with ERPs, provides a good solution to this problem because it allows for comparisons across different awareness conditions using identical stimuli. In other words, response to the very same scene can be analyzed for a “change” trial, in which the preceding flicker was a modified version of the scene, and for a “no change” condition, in which the preceding flicker was the unmodified version. Given the excellent temporal resolution of ERPs, analysis can be limited to the identical stimuli, without worrying that neuronal responses to the preceding flicker would carry over. This is the approach taken for the present study.

Evidence for Implicit Processing of Change

In addition to exploring the relation between awareness of change and attention, a second goal of our study was to index the electrophysiological activity generated by implicit representation of change.

There is a long tradition of behavioral and clinical studies exploring the implicit processing of static stimuli (Shapiro, Driver, Ward, & Sorensen, 1997; Greenwald, Draine, & Abrams, 1996; Rafal, 1994; Merikle, 1992; Weiskrantz, 1986; Marcel, 1983). In recent years, neuroimaging studies have come to complement those findings (Dehaene et al., 2001, 1998; Luck, Vogel, & Shapiro, 1996). These studies have revealed that implicit processes are present at each level of information processing, up to the level of semantic encoding and motor response preparation.

In contrast, there is still much debate about the existence of implicit representation of change (Mitroff, Simons, & Franconieri, 2002; Thornton & Fernandez-Duque, 2002). Current theories of scene perception argue that in the absence of focused attention, mental representations are ephemeral and representation of change is impossible (O'Regan & Noe, 2001). However, studies taken as support for this view have relied entirely upon explicit reports, asking subjects to report a change when it occurs. In contrast, behavioral studies using implicit measures suggest that change can be represented beneath the level of conscious awareness and outside the focus of attention (Fernandez-Duque & Thornton, 2000; Smilek, Eastwood, & Merikle, 2000; Thornton & Fernandez-Duque, 2000).

Such studies have revealed that for simple displays, observers can report the location of an undetected change better than chance (Fernandez-Duque & Thornton, 2000). In a simplified flicker paradigm, an array of rectangles was presented twice, the second time with one of the items in a new orientation. The changed item and the item diametrically opposite were then cued, and the observer was asked to choose which one had changed. Even when observers reported seeing no

change, they were better than chance at selecting the changed item if forced to make a choice. Interestingly, this implicit localization of change does not appear to be mediated by a reallocation of attention, as control experiments revealed that undetected changes were ineffective at reorienting attention to the location of change. Unaware changes can also affect performance in an orientation discrimination task (“Is this rectangle horizontally or vertically oriented?”). Even when observers reported being unaware of the change, the change biased the pattern of response. For example, when an item changed from horizontal to vertical, observers were more likely to respond “vertical” to a horizontal probe, even when unaware of the change (Thornton & Fernandez-Duque, 2000).

Recent studies using the monitoring of eye movements provide further evidence for implicit representation of change. In one study, observers were asked to examine line drawings of complex naturalistic scenes for a later memory test (Hollingworth, Williams, & Henderson, 2001). Observers were also told that changes might be introduced to the scenes as they were scanning them, and that they should immediately report any detected changes by pressing a key. On some trials, objects were replaced as the eyes moved away from them. When the eyes returned to a changed object after several seconds, fixation durations were consistently longer than when no change was made to the object, even in the absence of explicit detection. Similar implicit effects on fixation duration have been found in other studies, even when explicit strategies for detection of change are discouraged by increasing task demands and low frequency of changes (Karn & Hayhoe, 2000; Hayhoe, Bensinger, & Ballard, 1998).

While the behavioral studies provide convincing evidence for implicit processing of change, as yet few neuroimaging studies have directly addressed this question (Beck et al., 2001; Huettel, Güzeldere, & McCarthy, 2001; Niedeggen, Wichmann, & Stoerig, 2001). Consequently, the current neuroimaging evidence for implicit representation of change is tentative at best. Absence of implicit effects would be consistent with current theories of scene perception, which pose that attention is needed for temporal integration (Rensink, 2000), but would be at odds with the behavioral evidence for implicit representation of change, and the neural evidence for implicit processing of static stimuli.

Goals of the Current Study

In the current study, we explored the possibility that unaware changes were implicitly processed. We also explored ERP responses to aware and unaware changes, as they relate to different attentional states. For these goals, we employed a change blindness paradigm that allowed us to compare different attentional conditions (focused vs. search), and different levels of awareness

(aware vs. unaware) both in the presence and in the absence of change.

Procedure

Table 1 summarizes the procedure. Scenes containing a location change and scenes containing a color change were randomly intermixed. Each scene sequence contained multiple epochs, in which the scene was displayed for 500 msec, separated by a 300-msec blank field. The long duration of the display and the interval was necessary for recording late components in the ERPs, and was justified by previous change studies, which have revealed similar effects across a wide variety of durations (Rensink, O'Regan, & Clark, 2000).

Each scene sequence started with several repetitions of an unmodified scene. This initial stage served to increase uncertainty about the onset of change, and to familiarize subjects to the novel stimulus. At some point (range: 12–22 flickers), a modified version of the scene was introduced. Original and modified versions alternated for 40 flickers or until the subject reported a change by pressing a key. Those flickers when the change was not being reported constituted the “unaware change” condition.

After the subject reported the change or 40 flickers of undetected change had passed, a semantic cue was displayed for 2.5 sec to help subjects identify the change. The semantic cue was displayed even if the subject had reported being aware of the change. In such cases, the cue served as feedback to confirm the subject’s experience. That the cues were highly effective in helping subjects recognize the change was evident in a preliminary pilot study in which subjects were asked to detect and describe the change after the semantic cue.

The semantic cue was followed by another message instructing the subjects to “respond when the change disappears.” During the subsequent 30 to 40 flickers, subjects focused attention at the location of the change

and pressed a key as soon as they noticed the removal of the modified scene (i.e., that only the original scene was being displayed). These flickers between the semantic cue and the removal of the change constituted the “aware change” condition.

Following the keypress to report the removal of the change, a message instructed subjects to “look for any change.” Subjects were instructed at the beginning of the experiment that this could be the reoccurrence of the first change or a completely new change. These instructions aimed to motivate subjects to search the scene in all its parts, rather than excluding the area where the first change had occurred. Despite the instructions to look for a change, in this stage only the original scene was displayed for a total of 26 flickers. Those flickers constituted the “attention search” condition.

To keep subjects motivated in performing the search, a change was introduced after the attention search condition, in 30% of the sequences. One-third of the changes were a reoccurrence of the change presented in the aware change condition, one-third were the disappearance of an object, and the remaining changes involved either a new translation or a new color, somewhere else on the screen. After the 26 flickers of the attention search condition, scenes with the change included six flickers in which the original and a modified version of the scene alternated. Following these six flickers, or at the end of attention search for scenes without the second change, subjects responded to a two-alternative forced-choice question asking whether they had detected a second change. Data from these modified versions were not included in the analyses.

Subjects were not informed that only 30% trials had a second change. By including a change in only a few trials, we tried to minimize subjects’ ability to learn that the change only occurred after several nonchange flickers (these nonchange flickers were necessary for assessing attention search in the absence of change). However,

Table 1. Conditions for Each Scene Sequence including their Major Features and Comparisons

<i>Condition</i>	<i>Flickers</i>	<i>Task is to Report</i>	<i>Change</i>	<i>Attention</i>	<i>Awareness</i>
Unaware change	Up to 40	Change	Present	Search	No
Aware change	30–40	Change removal	Present	Focused	Yes
Attention search	26	Second change	Absent	Search	No
Focused attention	20–30	Original change reoccurrence	Absent	Focused	No

Participants observed 20 scene sequences while maintaining fixation on a central fixation point. Scenes containing a location change and scenes containing a color change were randomly intermixed. A complex scene was repeatedly presented for 500 msec, separated by a 300-msec blank field. Each scene sequence contained multiple epochs and was divided into four stages. A sequence started with several repetitions of an unmodified scene (not shown in table). At some point, a modified version of the scene was introduced. Original and modified versions alternated for 40 flickers or until the change was reported (unaware change). A semantic cue was then displayed to help subjects identify the changing region. During the subsequent 30–40 flickers, subjects attended to the location of change while maintaining eye fixation in the center of the screen, and reported when the change was removed (aware change). Next, subjects searched for a second change in the same scene, usually absent (attention search). Finally, subjects focused attention at the location of the original change to report its reoccurrence (focused attention). A comparison of the first two conditions should reveal the combined effects of awareness and focused attention. A comparison of the other two conditions would reveal the pure contribution of focused attention. Comparing unaware change and attention search would assess implicit representation of change.

having the second change in only 30% of scenes and for only six flickers risked having subjects fail to detect any changes at all, thus compromising the goal that motivated the inclusion of those changes. For this reason, we chose changes that our pilot studies indicated were, as a group, somewhat easier to detect than the changes at the beginning of the sequence. No data were collected on subject's response to the second change during the ERP study.

After making their decision on whether they had noticed a second change, subjects were instructed to focus attention at the location of the original change, and respond as soon as the change reappeared. The next 20 to 30 flickers occurred without change and constituted the "focused attention" condition. Following those 20–30 flickers, the original change was introduced. Modified and original versions alternated for up to 16 flickers or until the subject responded. Following

this response, the subject rested ad libitum and, when ready, started a new sequence by pressing a key. Subjects were instructed not to move their eyes at any point during a scene presentation, but were allowed to move their eyes between scene sequences.

RESULTS

Behavioral Results and Inclusion Criteria for ERP Analysis

In agreement with previous studies of change blindness, there was great variability in the number of trials required to detect change and terminate the unaware change condition ($M = 24$ trials; $SD = 14$; range: 1–40). Scene sequences with fewer than 20 flickers were excluded from the ERP analysis because there were not enough trials with which to form an ERP average. In

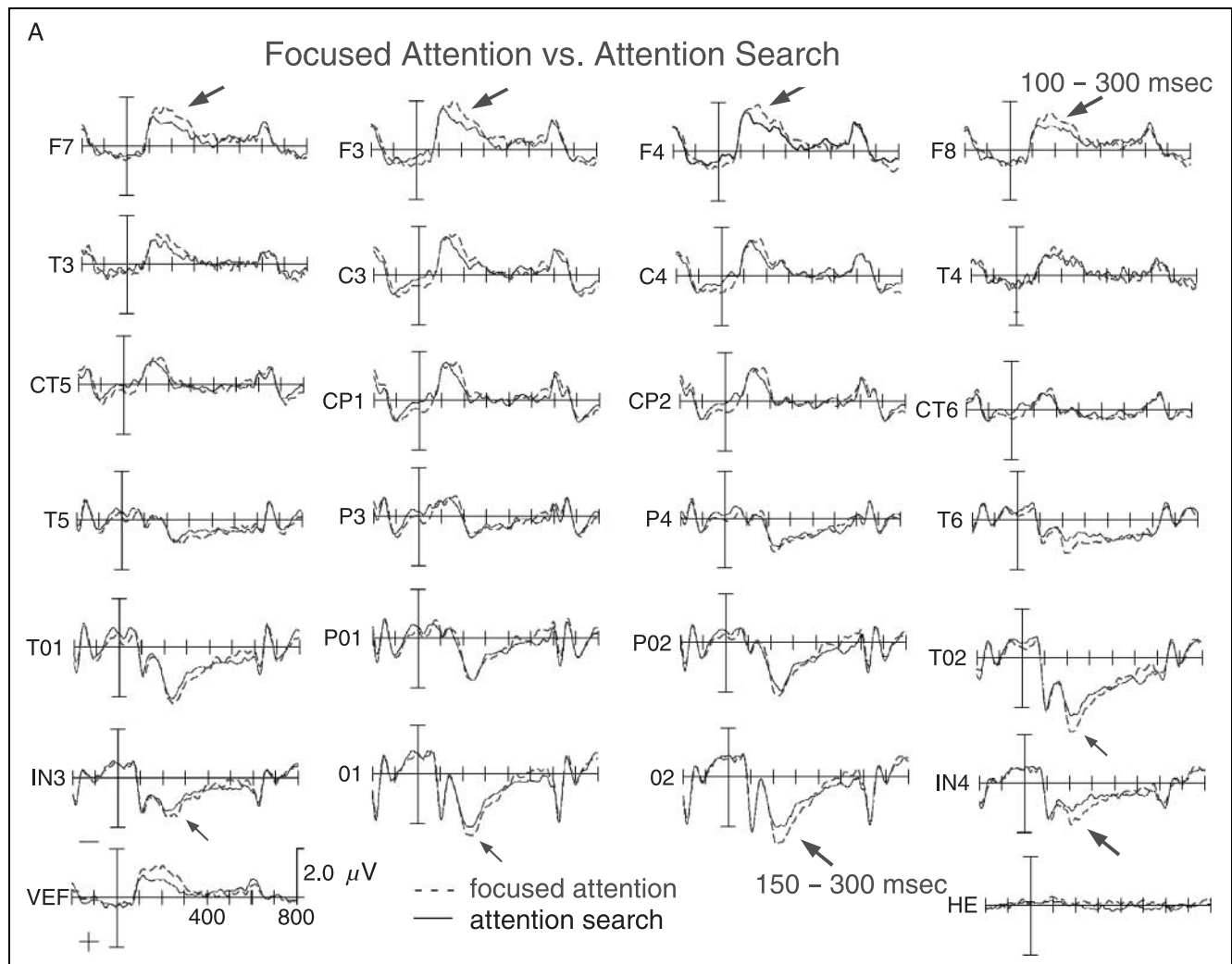
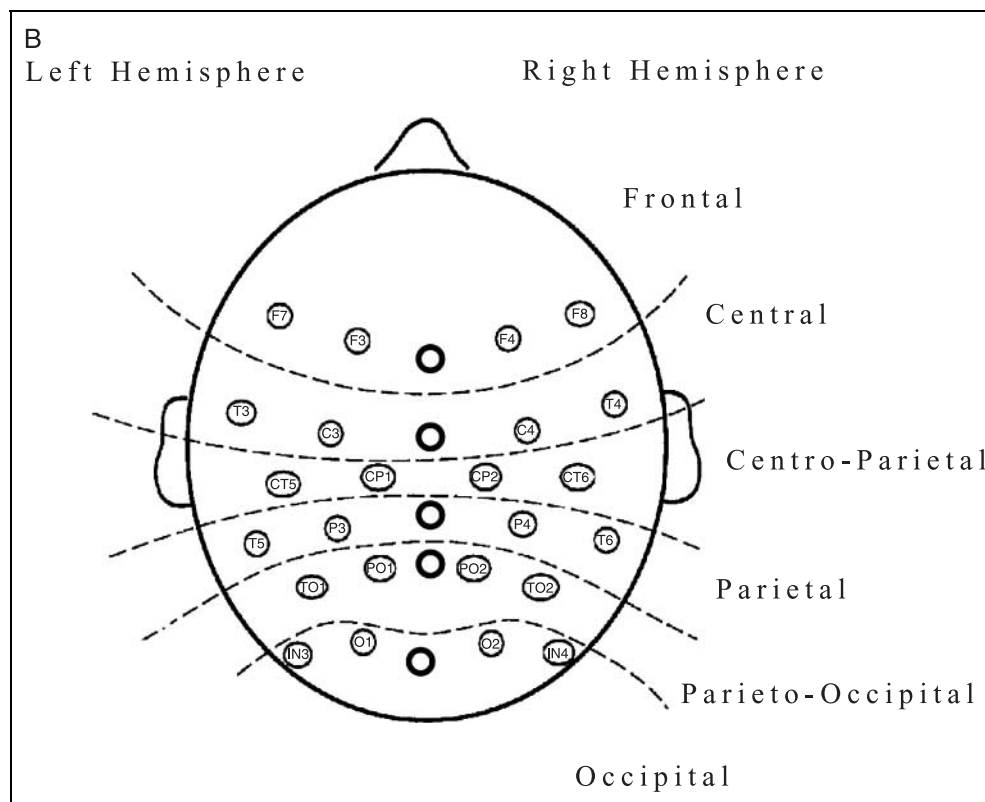


Figure 2. (A) Grand average ERP waveforms in the absence of change, for conditions of focused attention (dotted line) and attention search (solid line). The focused attention condition revealed an enhanced frontal negativity in the 100–300 msec window and an enhanced posterior positive deflection in the 150–300 msec window. There were no effects of focused attention in the centro-parietal sites during the 350–600 msec window. (B) Electrode sites for the main analyses are indicated on the head icon.

Figure 2. (continued)



those cases, data from the remaining stages of that scene were collected but were excluded from the data analysis. We also excluded from the analysis the 2400-msec preceding the report of a change (i.e., the last three flickers of the unaware change condition). This was done in order to prevent “aware” trials from contaminating “unaware” trials, as sometimes subjects might have taken longer than one flicker (800 msec) to report a change, either because they wanted to confirm the accuracy of their detection, or because of distraction. We also excluded the first two flickers of the aware change condition, as motor response and target detection might contaminate the “awareness” effects we were looking for in this stage. Flickers in which there were eye movements, muscular activity, or electrical noise were also excluded from the analysis.

Subjects easily detected the removal of a change at the end of the aware change condition and its reoccurrence at the end of the focused attention condition. For 94% of trials, subjects reported the change removal in seven or fewer flickers; for 96% of trials the change reoccurrence was detected in seven or fewer flickers. The remaining trials were largely due to one scene for which subjects reported having difficulties detecting the change. These findings replicate previous studies in which changes at the attended location are readily detectable (Scholl, 2000). It also confirms that subjects maintained focused attention during the aware change and the focused attention conditions, and that they were aware of the alternation between modified and

unmodified versions in the aware change condition. Scenes for which subjects failed to promptly respond at the end of the aware change condition or at the end of the focused attention condition were excluded from the ERP analysis.

Scenes with position changes were analyzed separately from scenes with color changes, but the findings were similar. For each comparison of interest, we first provide a detailed description for scenes with position change. Following, we offer convergent evidence from the scenes with color change, and point to some few differences brought about by the type of change.

ERP Results: General Approach to the Data

Data for each subject and each electrode were averaged by scene, experimental condition, and scene version (original, modified). Electrodes were grouped by anterior/posterior (six rows), laterality (medial, lateral), and hemisphere (right, left), in analyses of variance (ANOVAs) comparing conditions of interest. The interactions between experimental conditions and anterior/posterior electrode location were explored by follow-up analyses that looked at the anterior and posterior sites separately. For those analyses, the anterior sites were grouped into three rows (frontal, central, centro-parietal), and the posterior sites were grouped into the other three rows (parietal, parietal-occipital, occipital). Since main condition effects in the omnibus ANOVA are of little theoretical interest in the presence of interactions

with anterior/posterior sites, in those cases we limit our report to the follow-up analyses.

To allow testing for hemispheric differences, midline channels were excluded from the initial analyses. However, we occasionally included those channels when exploring effects that had bilateral distribution and epicenter in the midline sites. This was performed to provide a more complete description of the effect and increase the statistical power. Those specific cases will be noted in the Results section.

Separate analyses were run for scenes with position change and scenes with color change. Effect onsets were established by the presence of a significant effect in the ANOVA of three consecutive 20-msec bins. The Greenhouse–Geisser correction index was applied to all within-subject measures with more than one degree of freedom.

Effects of Focused Attention versus Attention Search

To assess the effect of focused attention relative to attention search, we compared conditions with identical physical stimuli and no change. That is, we compared focused attention to attention search (see Figure 2). These conditions differ in many respects, including whether attention is distributed over the whole scene or is focused at one location, and whether there is active search or not. The goal of this comparison was to describe such condition differences, so that they could then be subtracted from the key comparisons of interest (i.e., between aware and unaware change).

Given that no change is in fact taking place, one might expect similar effects whether the observer is waiting for the reoccurrence of a location change or waiting for the reoccurrence of a color change. Alternatively, preparatory attention may have a different modulatory effect in the electrophysiological response depending on whether the subject is expecting a change in position or a change in color (Kastner et al., 1998).

Position. An anterior/posterior main effect and its interaction with experimental condition in the overall ANOVA were further explored in follow-up analyses that separated sites into anterior and posterior rows. The analysis of the three anterior rows revealed that the complex scenes used in our paradigm elicited a bilateral frontal negativity in the 100–300 msec window, with larger amplitudes in the medio-frontal sites, and decreasing amplitude in more posterior and lateral sites [anterior/posterior effect: $F(2,26) = 20$, $p < .0003$; lateral/medial effect: $F(1,13) = 7$, $p < .02$]. This frontal component was evident in both the focused attention and the attention search condition, but was enhanced during the condition of focused attention. This amplitude enhancement by focused attention was bilateral and was largest at the most anterior sites, much like the component itself [condition effect:

$F(1,13) = 4.3$, $p < .05$; Condition \times Anterior/Posterior interaction: $F(2,26) = 13$, $p < .0002$ (see Figure 2)]. The effect of focused attention reached significance at 120 msec after stimulus onset, and remained significant until 300 msec after stimulus onset, temporally overlapping with the component. The similarity in waveform and topography between attention conditions argues against the presence of artifacts such as eye drift and differences in foveation. Foveal presentations trigger waveforms of different topography and time-course than parafoveal stimuli, and no such differences were apparent in the comparison between these two conditions.

The analysis of the posterior sites revealed that the complex scenes elicited a positive deflection in the 150–300 msec window for both the attention search and the focused attention conditions, with an epicenter in the occipital and the posterior-occipital sites [anterior/posterior effect: $F(2,26) = 14$, $p < .0002$; Lateral/Medial \times Anterior/Posterior interaction: $F(2,26) = 14$, $p < .0001$]. This positive component was enhanced by focused attention relative to the attention search condition. Furthermore, the effect of focused attention, like the component itself, was largest at most posterior sites where it reached statistical significance [condition effect: $F(1,13) = 3.8$, $p < .07$; Condition \times Anterior/Posterior interaction: $F(2,26) = 9$, $p < .001$; condition effect in posterior sites: $F(1,13) = 16$, $p < .001$]. The influence of focused attention in posterior sites became significant 170 msec after stimulus onset (see Figure 2).

Color. The color scene trials replicated the frontal and posterior components, as well as their modulation by focused attention.

The color scenes elicited a bilateral frontal negativity in the 100–300 msec window, with decreasing amplitude in more posterior and lateral sites [anterior/posterior effect: $F(2,26) = 13$, $p < .002$; lateral/medial effect: $F(1,13) = 21$, $p < .0004$]. The component was bilaterally enhanced during focused attention, particularly at the anterior sites [condition effect: $F(1,13) = 9$, $p < .01$; Condition \times Anterior/Posterior interaction: $F(2,26) = 5.7$, $p < .03$]. The effect of focused attention reached significance at 150 msec after stimulus onset, and remained significant until 330 msec after stimulus onset.

There was also a positive component with epicenter in the occipital and the posterior-occipital sites during the 150–300 msec window [anterior/posterior effect: $F(2,26) = 13$, $p < .0002$; Lateral/Medial \times Anterior/Posterior interaction: $F(2,26) = 12$, $p < .0002$]. This component was enhanced by focused attention, in particular, at the most posterior sites where it reached statistical significance [condition effect: $F(1,13) = 2.4$, $p < .15$; Condition \times Anterior/Posterior interaction: $F(2,26) = 5$, $p < .01$; condition effect in posterior sites: $F(1,13) = 6$, $p < .02$]. The influence of focused attention

in posterior sites became significant 160 msec after stimulus onset.

Effects of Aware Change versus Unaware Change

Commonality with the focused attention versus attention search comparison. The main purpose of comparing the conditions of aware change and unaware change was, obviously, to assess the effect of awareness of change. However, we first wanted to establish whether the attentional effects found in the absence of change were replicated in the presence of an aware change. Using the same statistical approach as in the previous analyses, we compared the unaware change condition, in which subjects were searching for an as-yet-undetected change, and the aware change condition,

in which subjects were aware of the change and focusing attention to its location.

For scenes with change in position, the findings replicated those observed in the absence of a change. This included an enhancement of the frontal and posterior components by awareness of change (see Figure 3). In scenes with color change, the frontal effect was also enhanced by the awareness of change, but the posterior component was not. Following, we describe these findings in more detail.

POSITION. There was a bilateral frontal negativity in the 100–300 msec window, with largest amplitude in the most anterior sites [anterior/posterior effect: $F(2,26) = 13, p < .003$]. The enhancement of this component by aware trials was largest for the most anterior sites [Condition \times Anterior/Posterior interaction: $F(2,26) = 6,$

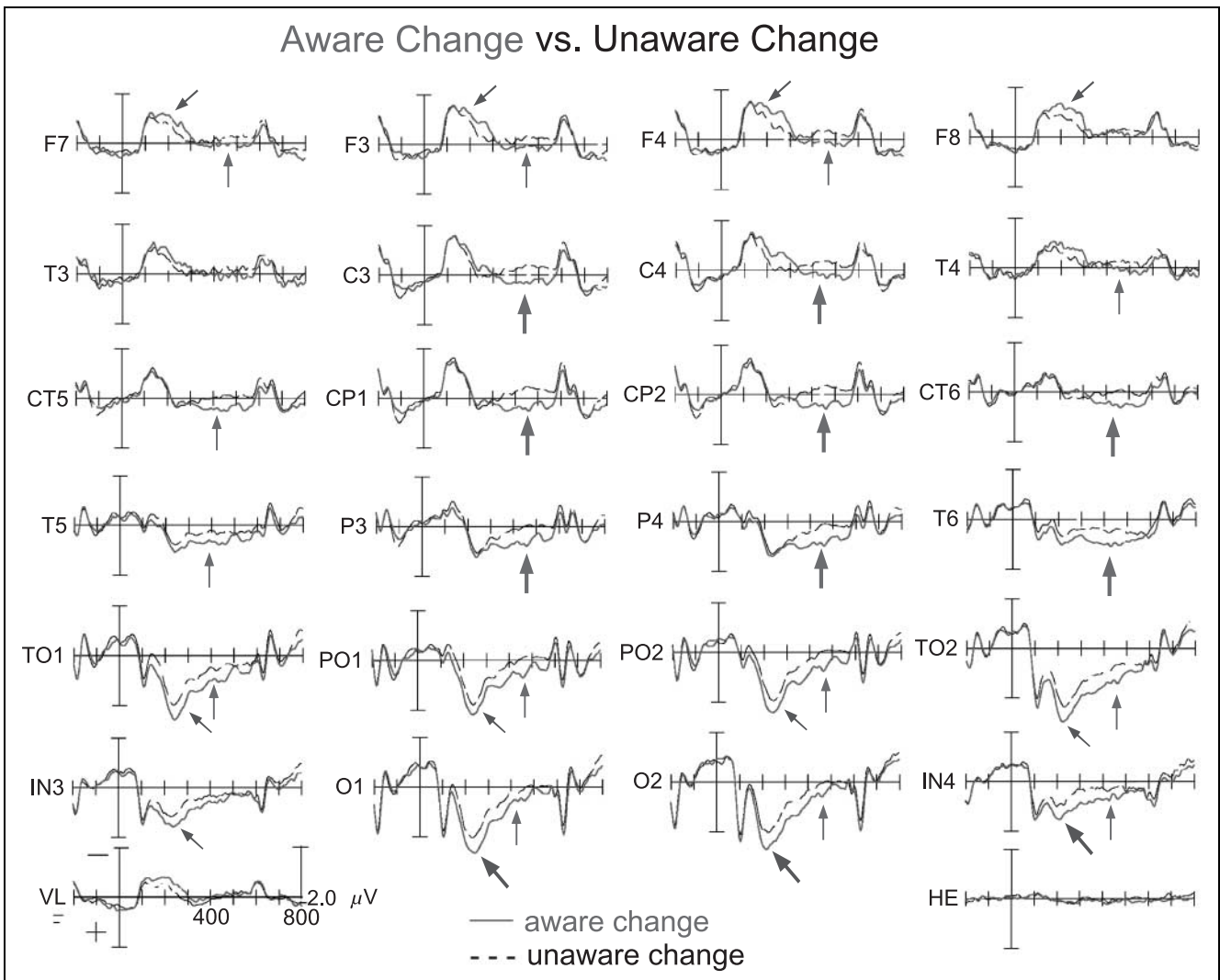


Figure 3. Grand average ERP waveforms in the presence of change, for conditions of unaware change (dotted line) and aware change (solid line). Aware change enhanced the frontal negativity in the 100–300 msec window, and enhanced the posterior positive deflection in the 150–300 msec window, resembling the effects of focused attention of the previous comparison (oblique arrows, see Figure 2). In addition, aware change produced a broadly distributed positivity in the 350–600 msec window, which was evident even in central sites that were unaffected by focused attention (vertical arrows, see Figure 2).

$p < .006$]. In those sites, the modulation reached significance 120 msec after stimulus onset and remained significant until 310 msec poststimulus.

The ANOVA of posterior sites revealed a positive component, with a posterior/anterior distribution [$F(2,26) = 15, p < .0001$], which was enhanced during the aware condition relative to the unaware condition [$F(1,13) = 11, p < .005$]. That enhancement reached significance at 150 msec after stimulus onset and, like the component itself, was largest at the most posterior sites [Condition \times Anterior/Posterior interaction: $F(2,26) = 5.7, p < .03$].

The similarities in topography and time course strongly suggest that these particular differences between the aware and unaware conditions were not due to awareness of change but were due instead to differences in attention. To test this idea directly, we compared the difference waves across levels of awareness of change (focused attention minus attention search vs. aware change minus unaware change). As expected, this comparison revealed no significant differences in the 100–300 msec window in the frontal sites [$F(1,13) = .05, ns$] nor in the 150–300 msec window in the posterior sites [$F(1,13) = 2.6, ns$].

To further test that the frontal and occipital modulations by aware change were the same as the modulations by focused attention, we ran another analysis. This analysis compared the condition in which subjects focused attention to the location of change and were aware of it (aware change), to the condition in which subjects focused attention to the same location but no change was displayed (focused attention). To make the physical stimuli across conditions identical, we excluded responses to the modified scene in the aware change condition, and limited the comparison to the unchanged scene. The effect of aware change on the anterior component (in the 100–300 msec window) was indistinguishable from the effect of focused attention [$F(1,13) = 1, ns$]. The comparison on the posterior effect (150–300 msec) tells a similar story. The effect of aware change is not different from focused attention [$F(1,13) = 0.8, ns$]. These results reveal that the modulation of frontal and occipital effects by the awareness of change were similar to the modulation by focused attention, not only qualitatively in terms of polarity, spatial, and temporal distribution, but also quantitatively, in terms of the magnitude of the modulation. This provides further evidence that same effects were triggered in frontal and occipital sites by the focused attention and the aware change conditions.

COLOR. The comparison of aware and unaware change in scenes with color changes revealed, as in the case for position changes, a bilateral frontal negativity in the 100–300 msec window, with largest amplitude in the most anterior sites [anterior/posterior effect: $F(2,26) = 9, p < .007$]. The amplitude of this component was enhanced by awareness of change [condition: $F(1,13) = 7,$

$p < .01$] and there was a nonsignificant trend for that enhancement to be largest in the most anterior sites [Condition \times Anterior/Posterior interaction: $F(2,26) = 2.4, p < .13$]. The modulation by aware trials reached significance 140 msec after stimulus onset and remained significant until 320 msec poststimulus. So again, the effect was slightly delayed for color scenes relative to position scenes. The ANOVA of posterior sites revealed a positive component with a posterior/anterior distribution [$F(2,26) = 15, p < .0001$] but, unlike the scenes with position change, this component was not enhanced by awareness of change [$F(1,13) = 0.1, ns$].

Unique effects of awareness of change. We next assessed the effects on the ERPs of awareness, comparing conditions of aware and unaware change. The analyses revealed a 350–600 msec effect, bilateral, broadly distributed, with epicenter in medial sites, slightly more anterior for color changes than for position changes.

POSITION. As seen in Figure 3, ERPs in conjunction with awareness of change elicited a greater positive deflection in the 350–600 msec window than in the condition of undetected change [$F(1,13) = 19, p < .0001$]. The effect was bilateral and broadly distributed, with the largest amplitude in the medial sites [$F(1,13) = 12, p < .004$], where it reached significance at 350 msec after stimulus onset. A separate analysis looking at the midline sites also revealed a main effect of awareness of change [$F(1,13) = 28, p < .0001$], which interacted with anterior/posterior [$F(1,13) = 7, p < .0001$]. Single electrode analysis revealed a significant effect of awareness of change in Fz, Cz, Pz, and Ipz (but not in Inz).

These analyses reveal the electrophysiological differences between being aware of a change and not being aware. It is unlikely that the 350–600 msec effect was an attention effect because we found no effects in that time window in the attention comparison (see Figure 2). This temporal dissociation gives credibility to the claim that the effect is a unique marker for awareness of change. However, to explore this question more thoroughly, we reanalyzed the data using only the two central rows of electrodes, which are the sites that showed no condition effect in the attention comparison (Figure 2). Since previous analyses revealed a midline epicenter and lack of hemispheric differences, we included the midline sites in the analysis to increase its statistical power.

This analysis, which was limited to the central rows, also served to explore the true onset of the awareness effect. Although the analysis that included the frontal sites revealed an awareness effect 350 msec after stimulus onset, it is possible that such an effect started earlier but was masked, in the frontal sites, by the effect of focused attention that rises on top of it. If that were the case, the central sites, which are not affected by attention, should reveal an earlier onset of the awareness effect.

Consistent with the hypothesis that the effect was due to awareness of change and not to attention, the analysis of the central rows revealed that aware change elicited a greater positive deflection in the 350–600 window than during unaware change [$F(1,13) = 20, p < .0001$]. The effect was bilateral and broadly distributed, with the largest amplitude in the medial sites [$F(1,13) = 12, p < .004$]. Its onset was at 350 msec, confirming the results obtained in the previous, overall analysis.

An alternative interpretation of the above results could be that the difference between aware and unaware change stems not from the aware perception of change, but from the surprise brought about by the discovery of the change (Neville, Snyder, Woods, & Galambos, 1982). To rule out this alternative explanation, we reanalyzed the data using only the second half of the aware change trials. For this analysis, we included all electrode sites except the midline (including the midline sites, or limiting the analysis to the central rows did not change the

pattern of results). As the duration of the aware change condition ranged from 30 to 40 flickers, the onset of the second half occurred 15 to 20 flickers after the initial introduction of the change. By then, the change had already flickered several times, had been committed to memory, and had presumably lost its surprise effect. Nevertheless, the comparison between aware and unaware change conditions still revealed a significant effect [$F(1,13) = 11, p < .005$], with identical topography and time course as the previous analysis. Thus, even after several flickers, when the change had become highly familiar and it was not the target of response, its aware perception continued to elicit an electrophysiological response distinct from the response generated by unaware change.

Another index of awareness of change can be obtained by comparing difference waves. The conditions of focused attention and attention search are different from each other only with regard to attention. In contrast,

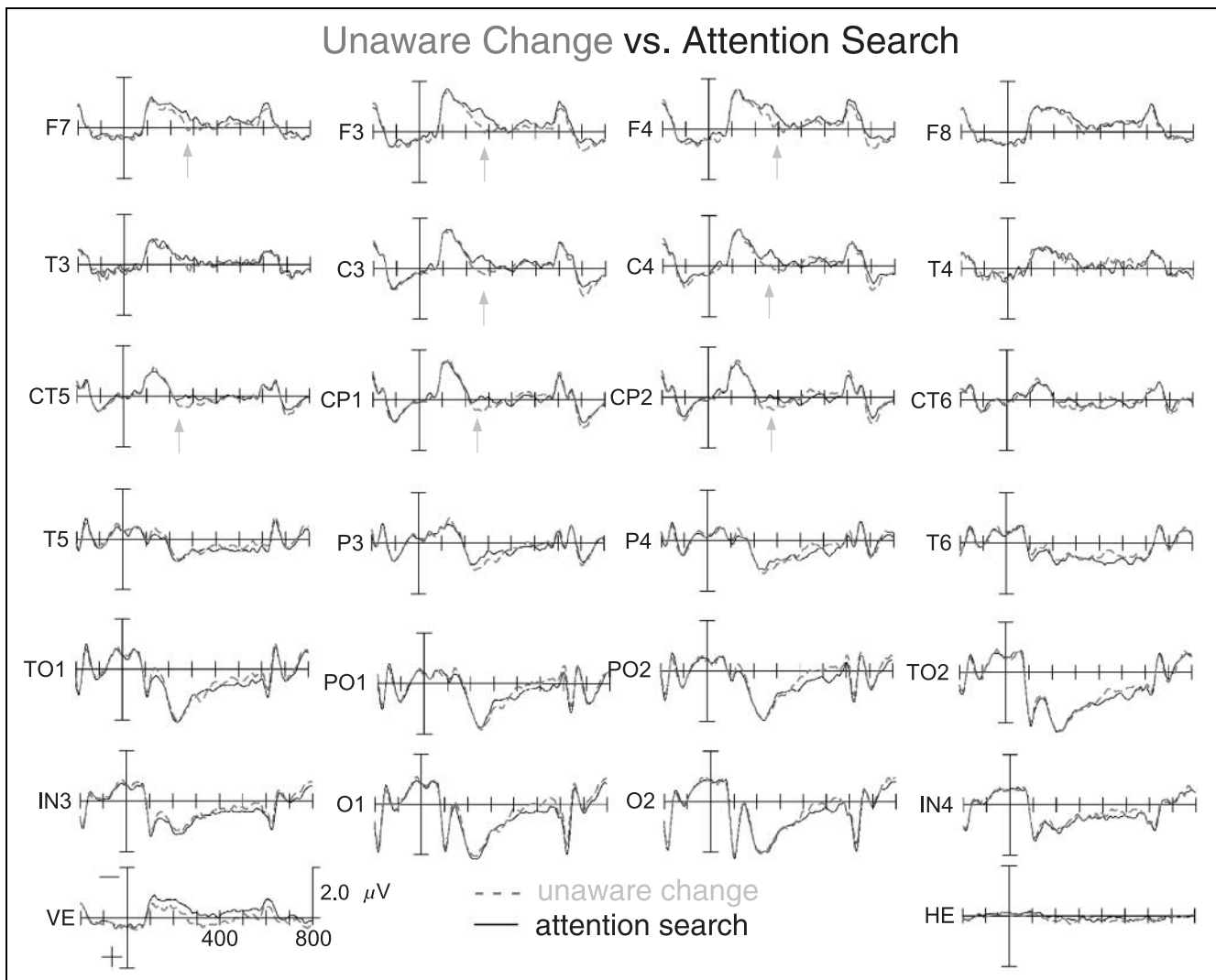


Figure 4. Grand average ERP waveforms for conditions of attention search (solid line) and unaware change (dotted line). Although in neither case was there awareness of change, there were ERP differences in the frontal and central sites in the 240–300 msec window, consistent with an implicit representation of change. To keep physical stimuli identical between conditions, only unmodified scenes were included in the ERPs averages.

the conditions of aware and unaware change are different from each other both with regard to attention and with regard to awareness of change. Relative to the difference wave between focused attention and attention search, the difference wave between aware and unaware change showed a positive deflection in the 350–600 msec window [$F(1,13) = 16, p < .002$]. This result contrasts with the absence of a difference waves effect for the frontal and occipital modulations, described in the previous section.

COLOR. Similar to the scenes with position change, awareness of a change in color elicited positive deflection in the 350–600 msec window. The effect was bilateral and had the largest amplitude in the medial sites [Condition \times Lateral/Medial interaction: $F(1,13) = 5, p < .05$], but showed a more anterior distribution, as revealed by an interaction between condition and anterior/posterior sites [$F(5,65) = 5, p < .01$]. The follow-up ANOVAs revealed the effect for the anterior sites [$F(1,13) = 5.3, p < .04$] but not for the posterior ones [$F(1,13) = 0.2, ns$]. The effect was also found in an analysis of the midline sites, particularly in mid-frontal and mid-central sites [Condition \times Anterior/Posterior interaction: $F(4,52) = 6, p < .006$; Fz: $F(1,13) = 8, p < .01$; Cz: $F(1,13) = 6, p < .03$].

Similar to scenes with position changes, the awareness effect for color changes was present even during the second half of aware change, eliciting an effect of identical distribution and time course to the one elicited by the aware change in its integrity [Condition \times Lateral/Medial interaction: $F(1,13) = 4.3, p < .05$; for medial sites: Condition \times Anterior/Posterior interaction: $F(5,65) = 3.3, p < .05$; a follow-up analysis looking at the three most anterior rows of medial sites, Condition: $F(1,13) = 5.8, p < .03$].

The more anterior distribution of the awareness effect in color scenes precluded an analysis of this effect in the central sites, which would have assessed the unique contribution of awareness. This limitation notwithstanding, the opposite polarity of the 100–300 msec frontal effect and the 350–600 msec “awareness” effect protects against a possible artifact, as “contamination” by the frontal focused attention effect would only reduce the likelihood of finding the “awareness” effect.

Effect of Implicit Representation of Change (Unaware Change vs. Attention Search)

To assess the neurophysiological substrates of implicit representation of change, we compared the condition in which subjects were unaware that a change was taking place (unaware change condition) to the condition in which there was no change (attention search condition). In order to compare ERPs elicited by identical physical stimuli for both conditions, we excluded the modified scenes of unaware change in the ERPs averages.

Position. Although the physical stimuli and the state of awareness (i.e., unaware of change) were identical across conditions, the existence of a change elicited a bilateral positive deflection in the anterior sites (see Figure 4) [Condition \times Anterior/Posterior interaction in overall ANOVA: $F(5,65) = 6, p < .01$; follow-up ANOVA including three anterior rows, Condition: $F(1,13) = 6, p < .03$]. The effect reached significance at 240 msec and remained significant until 300 msec. There was a trend toward an interaction with laterality, with a tendency for the effect to be larger in medial sites than in lateral sites [$F(1,13) = 3.6, p < .08$]. An ANOVA of the midline sites revealed a significant effect of implicit detection of change in sites Fz and Cz [$F(1,13) = 5.3, p < .04$].

Color. A similar but smaller effect was found at the 240–300 msec window in scenes with color change. Relative to the scenes with position change, the implicit effect for color change was limited to the medial sites [Condition \times Lateral/Medial interaction in overall ANOVA: $F(1,13) = 7.4, p < .01$]. It also had a more posterior distribution than the effect in scenes with position change, without interaction with anterior/posterior sites [Condition \times Anterior/Posterior interaction in overall ANOVA: $F(5,65) = 1.3, ns$]. A separate ANOVA of the midline sites revealed a marginally significant effect of implicit detection of change [$F(1,13) = 4.2, p < .06$].

DISCUSSION

Previous research suggests that it is only within the focus of attention that we have a detailed, stable, and conscious representation of the visual world. In other words, being aware of a change necessitates the focusing of attention at the location of change. Despite this tight coupling, change awareness and focused attention may be distinct processes that rely on non-identical neural substrates. The current study reveals that these processes are indeed indexed by neurophysiological responses that differ in their topography and time course. At the neurophysiological level, being aware of a change is associated with two distinct events: an early activation (around 100 msec) of systems important in focused attention, followed by an activation around 350 msec distinct in topography, and that appears to index activity related to the awareness of change.

The modulations of the early frontal and occipital effects by awareness of change were indistinguishable from to the modulations by focused attention.¹ This result suggests that such modulations were not due to awareness of change, but instead were related to focused attention. The enhancement of frontal effects may relate to attentional control mechanisms (Hopfinger et al., 2000; Kastner et al., 1998; Rees, Frackowiack, & Frith, 1997). The enhancement of the posterior

component by focused attention is consistent with previous findings of attentional modulation of extrastriate areas (Martínez et al., 1999; Kastner et al., 1998).

Besides the frontal and posterior effects, awareness of change triggered an effect starting around 350 msec, which was broadly distributed, with its epicenter in the medial centro-parietal sites. This effect was unique to awareness of change, and was absent when subjects were focusing attention to “no change” scenes. Its topography was consistent with previous findings from fMRI studies that revealed parietal activation in relation to aware perception (Beck et al., 2001; Lumer et al., 1998; Rees, Frackowiack, et al., 1997; Rees, Frith, et al., 1997). Thus, the finding is broadly consistent with claims by several researchers about the importance of dorsal areas for aware perception (Driver & Vuilleumier, 2001; Kanwisher, 2001; Rees & Lavie, 2001).

A general problem of previous studies of aware perception has been their confounding of awareness and attention, which has made it difficult to interpret the pattern of activation associated with perceptual awareness. Our design allowed awareness of change (under focused attention) to be compared with focused attention in the absence of change. The results argue that the centro-parietal activation cannot be explained by focused attention alone, and instead depends on the subjective experience of seeing a change. However, this is not to say that attention is inconsequential for such an effect. Our study controlled for many aspects of attention, including attention to space, attention to objects, and attention to the rhythm of flickering. Nevertheless, in order to become aware of a change, subjects need to deploy attention that integrates frames across time. Thus, it remains a possibility for future investigation that the observed electrophysiological response may stem from an interaction between this temporal form of attentional deployment and visual processing of change. Such an interaction would be yet another demonstration of the integral role that attention plays in facilitating awareness of change.

Studies of aware perception showing fronto-parietal activation frequently confound perceptual awareness and target detection, because the aware percept is also the target for response (e.g., Beck et al., 2001). In a recent ERP study, subjects were asked to report the detection of a changing item in an array of alphanumeric characters that flickered for up to five cycles (Niedeggen et al., 2001). Awareness of the change was accompanied by a large positive deflection in the 200–800 msec range, which was most pronounced over central and parietal sites. It is certainly possible that this waveform was related to the experience of perceiving a change. However, it is more likely that such an effect was triggered by the detection of the target, a well-known finding in the ERP literature. This P300 component typically accompanies the detection of low-probability targets (Johnson,

1986), and is thought to reflect a range of cognitive processes, including the updating of working memory, the making of binary decision, as well as various forms of recognition and identification judgements (for review, see Donchin & Coles, 1988).

A noteworthy exception to this confound of awareness and target detection comes from a study of binocular rivalry by Lumer et al. (1998). In this study, subjects first saw a binocular rivalry condition, in which rivalrous stimuli were presented to each eye and the subjects had to report the perceptual transitions in their aware experience (i.e., when they saw the face replacing the grating, and vice versa). Next, the exact same sequence was repeated using monocular stimuli, thus eliminating the binocular rivalry but retaining to-be-detected transitions. The binocular rivalry condition with target detection revealed activation of right fronto-parietal areas relative to target detection alone.

Our study addressed the confounding between awareness of change and target detection by presenting the change repeatedly after it was first reported. Even after several flickers, when the change had become highly familiar and was not the target of response, its aware perception continued to elicit an electrophysiological response distinct from the response generated by unaware change. This finding rules out the possibility that the effect was merely due to novelty.

Previous research has explored which brain areas correlate with perceptual awareness, and more recently, which areas are necessary and which sufficient for aware perception. In comparison, the dynamics of awareness have triggered little interest (Super, Spekreijse, & Lamme, 2001; Dennet & Kinsbourne, 1992; Castiello, Paulignan, & Jeannerod, 1991; Libet, Wright, Feinstein, & Pearl, 1979). The results from our study reveal a rather late onset for the component of awareness of change. The possibility that awareness of change triggered an earlier onset that was masked by other effects cannot be completely ruled out. However, the similar onset of the effect for sites modulated by attention and sites not modulated by attention gives credibility to the claim that ERP differences due to awareness of change truly started 350 msec after stimulus onset.

The late development of the awareness effect is broadly consistent with the “type–token” hypothesis of perceptual awareness (Kanwisher, 1987, 2001). According to this theory, what distinguishes perceptual awareness is “the individuation of that perceptual information as a distinct *event*... Conscious perception requires the attribution of perceptual information to a *spatio-temporal* ‘source’” (italics added; p. 107, Kanwisher, 2001). Focused attention not only integrates perceptual attributes (e.g., “redness,” “triangleness”) into coherent objects (e.g., “red triangle”), but it also individuates those objects in time. Aware percept depends on that episodic aspect of the representation

(e.g., “*this red triangle*”). According to this view, the domain-specific areas of the ventral path provide the content of awareness (e.g., the redness, the triangle-ness), but perceptual awareness (i.e., the content-independent aspects of perceptual awareness) is dependent on the interaction of the attentional network in dorso-frontal-parietal areas with the ventral pathway, in a process that takes a few hundred milliseconds to be established (Kanwisher, 2001). This is consistent with the current findings from our study showing that the focused attention effects temporally precedes the awareness effect, and that the awareness effect develops relatively late and has a broad dorso-parietal distribution.

On a more speculative note, it has been argued that perceptual awareness is “temporally” distributed, and that there is no single point in time at which the representation becomes aware (Dennet & Kinsbourne, 1992). If awareness really stems from a collection of many temporally asynchronous micro-stages distributed across the brain, then it is no surprise that the effect of awareness develops relatively late with a long duration and broad distribution, as in our study.

Another question for which we can only provide a tentative answer is whether the mechanisms of “awareness of change” are qualitatively different from the mechanisms underlying awareness of other visual properties, such as color or shape. Certainly, everyone would agree that the contents of aware perception will differ for each type of stimulus, and that activation of domain-specific areas is likely to vary accordingly. However, it is also true that awareness of change shares with other types of visual awareness many features, most importantly, its dependence on focused attention. Due to its dependence on temporal integration, representation of change may be particularly useful in the study of perceptual awareness if, as some theories suggest, a key feature of visual awareness is the individuation of stimulus into distinct events (Kanwisher, 2001). On the other hand, subjects in our study were always aware of the visual display (or at least they were aware of the part of the visual display to which they were attending). Thus, the comparison of awareness of change relative to focused attention in this study might be saying more about the unique attributes of awareness of change than about perceptual awareness in general. Finally, awareness of change depends on a comparison of two scenes over time, and therefore it may tap into working memory processes that are not required for the perceptual awareness of static stimuli.

A second goal of the current study was to investigate the electrophysiological substrates of implicit representation of change. Although the existence of implicit processing of static stimuli is well established, with evidence from behavioral (Marcel, 1983), neuroimaging (Dehaene et al., 2001), and clinical data (Driver & Vuilleumier, 2001), there is still much debate about

the existence of implicit representation of change (Mitroff & Simons, 2002; Mitroff et al., 2002; Simons & Silverman, in press). In recent years, behavioral and eye movement studies have begun to provide evidence for unaware representation of change (Fernandez-Duque & Thornton, 2000; Smilek et al., 2000; Thornton & Fernandez-Duque, 2000). However, neuroimaging studies have been less reliable in demonstrating such implicit processes (Beck et al., 2001; Huettel et al., 2001; Niedeggen et al., 2001).

The fMRI study of change blindness by Beck et al. (2001) showed evidence of implicit processing, but only for certain stimulus type and only for a subset of subjects. Another study used ERPs to measure implicit change detection in a change blindness paradigm in which arrays of alphanumeric characters were flickered for up to five cycles (Niedeggen et al., 2001). The comparison between trials in which a change was present but not reported and trials in which a change was absent, failed to reveal any differences. However, this null result may be due to a lack of power, as only in 15% of trials was the change undetected. Furthermore, subjects in this task were allowed to move their eyes freely. This, combined with the quite long stimulus displays (1500 msec), may have masked implicit effects as ERPs are exquisitely sensitive to eye movements, and in the presence of eye movements, other signals are hard to detect.

In contrast, our study uncovered electrophysiological evidence for the implicit representation of change using naturalistic complex scenes. Consistent with previous behavioral findings, our observers were unaware of the changes that occurred in the visual scene; nevertheless, those changes were clearly indexed in the neuronal response. This effect exhibited a different distribution and time course than the effects of attention and awareness of change, suggesting that the substrate of implicit perception of change is organized within different neural systems than those mediating focused attention and awareness of change.

Previous neuroimaging studies have revealed domain-specific activations in extrastriate area in relation to implicit processes (Dehaene et al., 2001; Vuilleumier et al., 2001), leading to the prediction that implicit representation of change would be evident mostly in posterior sites and at early onsets. Nevertheless, the late onset and more anterior location of the effect in our study is consistent with the claim for full processing of implicit stimuli proposed by other neuroimaging studies (Dehaene et al., 1998; Luck et al., 1996). Future studies using imaging techniques with better spatial resolution and simplified versions of the change blindness paradigm may help to resolve this issue. More generally, the use of these and other measures of performance, in the context of change-over-time tasks, promises to shed new light on the visual processes involved in the perception of dynamic events.

METHODS

Participants

Data from 14 subjects (10 women; mean age: 26; range: 18–38) naïve to the purpose of the study were included in the analyses. All subjects were neurologically normal and had normal or corrected-to-normal vision. Data from two additional subjects were excluded due to (1) excessive blinking, and (2) insufficient number of unaware trials.

Apparatus and Materials

Stimuli were presented on a Power Mac G3 attached to a 19-in. color monitor 17.75-in. viewable, with a frame rate of 75 Hz and a screen resolution of 1152 by 870 pixels. Viewing distance was 145 cm (eyes-to-monitor) and the testing booth was dimly illuminated. The images were displayed centrally and subtended 3.2° by 4.4° visual angle, with a black board physically covering the remainder of the screen. Instructions were displayed centrally in 24-pt Geneva. A central fixation dot was present at all times.

The stimuli consisted of 20 complex scenes and their modified versions, taken from the Cambridge Basic Research image database, and selected from a pilot study in which a broad range of changes was tested. Half of the modified versions consisted of a position change, and half a color change. Changes were equally distributed across both visual fields, and across central/peripheral locations.

ERP Methods

EEG recordings were made from 29 electrodes mounted in an elastic cap (Electro-Cap), according to an extended International 10–20 System. The extended version includes a denser array of electrodes over the back of the head, allowing better spatial resolution across visual areas. An electrode was placed beneath the right eye to monitor blinking and vertical eye movements, and two electrodes were placed at the outer canthus of each eye to monitor horizontal eye movements. On-line recordings were referenced to the right mastoid and re-referenced to averaged mastoids in the final data averaging. The EEG was amplified with Grass 7P511 amplifiers (3 dB cutoff, bandpass of 0.01–100 Hz) and digitized on-line at a sampling rate of 250 Hz. An epoch of 800 msec poststimulus was considered for statistical analyses, using a baseline of 300 msec prestimulus. Trials characterized by eye movements, muscular activity, and electrical noise were excluded from the analyses.

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Note

1. The only exception to such a result was the posterior component of the color scenes, which was modulated by focused attention condition but not by awareness of change. Nevertheless, that pattern of results is consistent with the claim that awareness of change did not affect the frontal and posterior sites beyond the effect of focused attention.

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