Conscious and Non-Conscious Visual Processing of Shape and Color Depends on Task-Oriented Attention

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Abstract

Advancements in neuroscience have substantially improved understanding of the biological mechanisms responsible for mental processes. However, the neurological correlates of consciousness remain poorly understood. This thesis used electroencephalography (EEG) to examine the neural correlates of visual experience. Two questions motivated the investigation: 1) Could the proposed correlates of visual awareness instead reflect task-related processes? 2) Can task-oriented attention influence the processing of 'invisible' stimuli?

Comparisons were made between brain activity (ERPs) elicited by a stimulus in conditions in which it is consciously perceived and ERPs elicited by the same stimulus when it is not perceived. Awareness of the stimuli was manipulated by backward masking, a technique in which a stimulus is presented for a very brief time before the onset of a "mask." Latency of the mask onset was determined by a behavioral experiment conducted before the main EEG study. Participants performed alternating discrimination tasks between two shape stimuli or two color stimuli. All four stimuli were presented across both tasks, and stimulus task-relevancy was regulated by the target stimulus during each task.

Results suggest that a negative peak at posterior recording sites occurring around 200 ms post-stimulus presentation may be a marker of a purely phenomenal visual experience because it was not affected by task-relevancy. Other proposed correlates were found to be manipulated by stimulus task-relevancy, suggesting that these components reflect task-related post-perceptual processing. In addition, an effect of stimulus task-relevancy was found for 'invisible' stimuli, suggesting an effect of task-oriented attention in non-conscious processing.

Chapter 1: An Introduction to the Neural Correlates of Consciousness

> “If you want to find the secrets of the universe, think in terms of energy, frequency, and vibration.” -Nikola Tesla

The relationship between the subjective experience of consciousness and brain activity has long been debated. Technological developments have only recently allowed for rigorous study of the interaction between mind and brain; however, the nature of consciousness still largely remains a mystery. One promising paradigm toward enhancing our understanding involves comparing the brain activity associated with a consciously perceived stimulus to brain activity when the same stimulus is presented but not perceived. This is the method utilized in the main experiment presented in this manuscript. In order to contextualize and understand the experiment, an overview of foundational information is first offered.

In this chapter, I review philosophical and empirical perspectives and other theoretical considerations relevant to the study of consciousness. In doing so, I present operational definitions for terms used throughout this manuscript. I then briefly discuss electroencephalography, the technique utilized in my thesis project. Finally, I present my research question involving the study of conscious and non-conscious visual processing.

1.1 Background

The nature of consciousness and the brain has been discussed for centuries. René Descartes famously addressed the mind-body problem in his assertion of dualism, a distinct separation between consciousness and the brain without reduction to each other in any way. This notion has long since been abandoned by the scientific community, but the apparently causal and certainly correlational relationship between mental activity and physical events in the brain remains no less remarkable now than it was hundreds of years ago.

Empirical science has done much to enhance our understanding of the neural correlates of functions and behaviors, but the how and why underlying phenomenal experience is unknown. This question is known as 'the hard problem of consciousness,' and some believe that it will forever remain a mystery due to the nature of qualia, or subjective experience (Chalmers, 1995). In other words, cognitive neuroscience can satisfactorily explain the neural basis for function but is inadequate to explain why we experience life as we do. In contrast, some argue that subjective experience itself is encoded in the same neural substrate as cognitive functions and is the product of several such functions co-occurring (Cohen & Dennett, 2011).

Empirical study has the potential to inform this controversy through elucidation of the neural correlates of consciousness (NCCs). Christof Koch defined this as "the minimal set of neuronal events that gives rise to a specific aspect of a conscious percept" (Crick & Koch, 2003). In other words, NCCs are the necessary and sufficient neuronal events that engender any subjective experience. This manuscript focuses on the NCCs of visual perception, and theoretical considerations of the study are outlined below.

1.2 Consciousness and Related Terms

Consciousness and related words have an array of colloquial associations, but precise definitions must be used in empirical study. To be aware of a stimulus is to experience it consciously. To be consciously experienced is synonymous with being consciously perceived. Consciousness can also refer to various states such as coma, dreamless sleep, dreaming, wakefulness, etc.; however, such usage is irrelevant in the scope of this thesis. Perception refers to the identification and organization of some sensory input. In contrast, sensation refers to the low-level biochemical events when receptor cells detect a stimulus. In other words, perception interprets what sensation detects. Perception is usually understood to be consciously processed, but there is also evidence of unconscious perception influencing behavior. For example, unconscious perception has been shown to influence reaching and grasping motor movements (Franz, Fahle, Bülthoff, & Gegenfurtner, 2001; Dassonville & Bala, 2004; McIntosh & Lashley, 2008; Bruno & Franz, 2009; Brogaard, 2011).

Attention refers to the set of processes that controls the flow of information through the nervous system (Luck & Kappenman, 2012). It determines a subset of available information to which focus is oriented for enhanced processing. When this selection is produced volitionally (e.g. searching for a target), it is said to be "top-down attention." When attention is captured automatically (e.g. from a loud crash), it is considered "bottom-up."

Attention and awareness, while related, are distinct and dissociable. The two systems often interact on the behavioral level, however, the underlying neural mechanisms have been shown to be divided (Tallon-Baudry, 2012). Attention has been shown to be a prerequisite of awareness, but it alone is not necessarily sufficient for conscious perception. Inattentional blindness refers to the inability to consciously perceive unattended stimuli or objects because attention is occupied elsewhere, even if the unattended stimulus is directly in the center of one's view (Simons & Levin, 1998; Simons & Chabris, 1999). A disturbing real-life example of this is the inability to locate a fire extinguisher that is walked by daily but never attended to (Castel, Vendetti, & Holyoak, 2012). Additionally, several studies have found evidence for attentional selection despite the lack of awareness (Lamme, 2003; Koch & Tsuchiya, 2007; Schmidt & Schmidt, 2010; Posner, 2012). The opposite, awareness without attention, has been suggested for certain types of percepts such as the "gist" of a scene, but this has not been demonstrated conclusively (Li, VanRullen, Koch, & Perona, 2002; Cohen, Alvarez, & Nakayama, 2010, 2011; Cohen, Cavanagh, Chun, & Nakayama, 2012). In other words, the current consensus is that attentional selection can occur without awareness, but awareness cannot occur without some form of attention.

1.3 Theoretical Considerations

Bernard Baars posited that consciousness integrates brain functions that are otherwise distinct and independent, proposing the Global Workspace Theory (GWT) as a model for this unification process (Baars, 1988). Each of the unconscious processes is considered highly efficient in their own tasks and together these processes shape and direct the contents of consciousness. Selective attention limits the resulting contents that reach awareness and can be conceptualized as an "attentional spotlight." The model has since been refined as the Global Neuronal Workspace Theory (GNWT), which incorporates longitudinal cortical connections between regions that support cognitive processes (Newman, Baars, & Cho, 1997; Dehaene, Kerszberg, & Changeux, 1998; Dehaene & Naccache, 2001; Dehaene, Sergent, & Changeux, 2003).

In accordance with the GNWT, conscious perception is not thought to occur in degrees; rather, evidence suggests that perceptual awareness is an all-or-none phenomenon (Sergent & Dehaene, 2004). It seems that a threshold must be passed in processing stimuli in order for the 'ignition' of conscious awareness, although limited processing may occur in the absence of awareness (Sergent, Baillet, & Dehaene, 2005; Fisch et al., 2009). Recurrent processing between regions in the visual pathway has been proposed as a critical component for visual awareness (Lamme & Roelfsema, 2000; Lamme, 2003). The initial 'feed-forward sweep' of processing following presentation of a stimulus has been recorded in anesthetized animals; however, recurrent processing is suppressed under anesthesia (Lamme, Zipser, & Spekreijse, 1998; Lamme, 2003).

While conscious awareness seems to be an all-or-none result of processing, various subtypes of both conscious and non-conscious processing have been offered. Stanislas Dehaene proposes the taxonomy of conscious, preconscious, and subliminal processing (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006). He posits that conscious processing involves a stimulus with sufficiently strong bottom-up strength (i.e. detectable and perceptible) that is coincident to the orientation of top-down attention. As a result, widespread activation involving parietal-frontal networks occurs, and the stimulus is consciously reportable.

Preconscious (or, potentially conscious) processing is defined by the absence of top-down attention toward a stimulus that has sufficiently strong bottom-up strength to yield the possibility of perception. This level of processing is proposed to be confined to sensori-motor cortical regions and involves recurrent looping. While preconsciously processed stimuli can lead to priming[1] at multiple levels, there is no reportability until a stimulus attains top-down attention.

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[1] Priming refers to the effect a stimulus has on later responses or behavior due to implicit (nonconscious) memory. It is thought to result from the prior activation of a neural pathway.

Finally, subliminal processing is defined by the inaccessibility of processed information due to the bottom-up strength of a stimulus being either too weak or interrupted. While subliminal processing is by definition never reportable, top-down attention can still modulate the neural response to a subliminal stimulus. If (and only if) attended, some amount of feed-forward activation may occur before quickly dissipating (Del Cul, Baillet, & Dehaene, 2007). Short-lived priming can also occur from subliminal processing (Kiefer & Brendel, 2006; Naccache, Blandin, & Dehaene, 2002; Kiefer et al., 2011).

Philosopher Ned Block suggests a further differentiation made between the correlates of conscious processing: a bifurcation between ‘core’ and ‘total’ NCCs (Block, 2005). Importantly, he proposes the sub-types of *phenomenal* NCCs and *access* NCCs. Phenomenal-consciousness is defined by the content of an experience unique to that conscious state; it is the ‘core’ NCC to an experience. Access-consciousness refers to the ability to report on or otherwise utilize the perceived information. Conscious *access* is said to occur when information is sent to the cognitive systems responsible for memory, reasoning, voluntary direction of attention, and more generally, control of action. Together, phenomenal- and access-consciousness are encoded by the ‘total’ NCC.

Another consideration noted by Jaan Aru is the isolation of core NCCs from the prerequisites for and consequences of conscious perception, abbreviated as NCC-pr and NCC-co, respectively (Aru, Bachmann, Singer, & Melloni, 2012). While an individual NCC-pr may not alone be sufficient or even necessary in producing a conscious experience, some combination of NCC-pr might be necessary in triggering the processes responsible for the core NCCs. Examples of NCC-pr include the recurrent processing underlying conscious and potentially-conscious processing as well as the spontaneous and stochastic fluctuations in the excitability of neurons that encode a fluctuating threshold for visual detection (Busch, Dubois, & VanRullen, 2009). Consequential processes (NCC-co) reflect activity beginning immediately after or at the same time as the core NCC, but by definition, an NCC-co is not a part of the minimally sufficient mechanisms underlying a conscious experience. An example of an NCC-co is the maintenance of information in memory to allow decision-making and verbal report. Note that the neural basis of access-consciousness are also consequences of consciousness.

Synthesis of these proposals suggests that at least some NCC-co can be components of access-consciousness. In reference to the GNWT, access-consciousness is the information “broadcasted” through the global workspace at any given time, and phenomenal-NCCs compete for the singular “spotlight” of access-consciousness. It seems likely that the longitudinal projections of the GNWT are only involved in the cognitive processes secondary to the experience of perceptual awareness, or “core NCC.”

It is also worth noting that, although similar, preconscious processing is distinct from phenomenal-NCCs. Preconscious processing is not yet conscious; rather, the potential for reaching consciousness exists and is contingent on attention. In contrast, all phenomenal-NCCs are consciously processed at some level due to receiving some amount of attention.

There is a significant risk of pollution from NCC-pr, NCC-co, and access-conscious processing when only the minimal neural basis for a conscious experience is sought. Care must be taken to avoid these possible confounds when designing studies of consciousness, particularly when isolation of any ‘core’ NCC is attempted.

1.4 Brief Discussion of the EEG Technique

Neuronal events are the fundamental mechanisms underlying the brain’s activity. Action potentials occur within an individual cell when a cascade of gated ion channels sends a voltage spike down the axon to the axon terminal, where neurotransmitters are kept for signaling other neurons. Action potentials are initiated or inhibited by postsynaptic potentials, which are the changes in voltage following neurotransmitter binding to a postsynaptic neuron’s membrane. These electro-chemical events are the foundation for every process occurring within the brain, including the production of consciousness.

There are several methods to study brain function. One such method is electroencephalography (EEG), and this is the technique utilized in the present study. EEG involves the recording of the electrical activity along the scalp with the use of several electrodes sewn into a cap. Due to the timing of action potentials and the arrangement of axons, action potentials are rarely detected by surface electrodes and instead typically cancel each other out. Synaptic potentials, however, last for longer durations, summate, and are frequently able to be recorded from the scalp (Luck, 2005).

EEG recording can measure event-related potentials (ERPs), which are stereotyped electrophysiological responses (summated post-synaptic potentials) to a stimulus (Luck & Kappenman, 2012). ERP waveforms consist of a series of positive and negative voltage deflections, referred to as components. ERP components display stable time relationships to a definable reference event, such as the onset of a stimulus' presentation (Luck, 2005). EEG records thousands of simultaneously ongoing brain processes, only a fraction of which are directly related to the 'event' of interest (e.g. a sensory stimulus or a motor response). ERPs are derived by taking the average of the raw EEG waveforms corresponding to a stimulus presented across several (>100) trials. This averaging cancels out much of the 'random' ongoing electrical activity in the EEG and achieves a stronger signal-to-noise ratio allowing one to associate ERP components to various stages of processing involved in sensory and motor functions.

EEG and ERPs offer several advantages over alternative recording methods. EEG has excellent temporal resolution, on the order of milliseconds rather than seconds. This is especially advantageous in the study of consciousness because the scale of perceptual processing is also in milliseconds. In addition, EEG is useful because it allows for the detection of covert processing without requiring a response, and it affords some degree of monitoring for lapses of attention and the development of fatigue (Mulholland, 1973). Finally, EEG is non-invasive as well as inexpensive relative to other recording methods.

While there are many favorable aspects of electroencephalography, there are also some disadvantages worthy of consideration. Notably, EEG has poor spatial resolution, which makes localization of a component's source difficult if not impossible. In addition, EEG cannot detect activity in all parts of the brain. If neurons are not arranged in parallel then their electric fields may cancel more than summate, which leads to no signal at the scalp. Several structures (such as the thalamus and cerebellum) contain non-parallel cellular architecture and thus cannot be recorded using EEG. Finally, the use of EEG is time-intensive, due to both the precise set-up required and the necessity for repetition of trials. Despite these limitations, EEG proves itself as an excellent tool in the study of consciousness.

1.4.1 Experimental EEG Paradigms for NCC Research

As mentioned before, a classic paradigm of studying the neural correlates of consciousness is to compare the brain activity, such as ERPs, elicited by a stimulus that is consciously perceived with brain activity elicited by the same stimulus when it is not consciously perceived. There are several methods to effectively manipulate awareness without changing the stimulus, including the use of inattentional blindness (Pitts, Martínez, & Hillyard, 2012; Shafto, 2013), the attentional blink (Vogel, Luck, & Shapiro, 1998), multistable stimuli (Pitts, Nerger, & Davis, 2007), and backward masking (Breitmeyer & Ogmen, 2000; Enns & Di Lollo, 2000). The present study utilizes backward masking to preclude conscious awareness of some stimuli. This technique involves the brief presentation of a stimulus before the onset of a "mask," which is another image spatially coincident with the stimulus. The latency between the presentation of a stimulus and its substitution by a mask is commonly referred to as the stimulus onset asynchrony (SOA).

In most masking studies, stimuli are always attended (task-relevant) targets. Studies of consciousness typically involved subjects pushing one of two buttons to indicate whether or not a stimulus was perceived. However, this methodology is vulnerable to confounding NCC-co's and NCC-pr's with the core NCC. For example, when a stimulus is not perceived, it cannot be held in memory nor can it be accessed for perceptual report. When the same stimulus is perceived, this information is maintained in working memory and accessed for report, and the neural correlates of these processes (NCC-co's) are difficult to distinguish from the core NCCs. Similarly, when a stimulus is presented at masking threshold, trial-by-trial fluctuations in attention may determine whether the stimulus was consciously perceived on any given trial, and the neural correlates of this waxing and waning attention (NCC-pr) may be confused with the core NCCs.

The current experiment is unique because in addition to measuring ERPs elicited by attended (task-relevant) stimuli, ERPs associated with task-irrelevant stimuli were also assessed, thereby allowing a possible separation of NCC-co's and NCC-pr's from the core NCC.

1.4.2 Proposed Markers of Conscious Perception

Several ERP components have been proposed to be signatures of conscious perception. The question of whether conscious perception occurs earlier or later remains controversial, as some early processing occurs for all stimuli despite perceptual awareness (Pins & Ffytche, 2003; Del Cul et al., 2007; Gaillard et al., 2009; Koivisto et al., 2008; Railo, Koivisto, & Revonsuo, 2011; Aru et al., 2012).

Five components were chosen for analysis in the present study. First, components reflecting early sensory processing were assessed for each of the stimuli types. In the shape stimuli, presence of the contour integration negativity (CIN) was examined. The CIN is an early negative peak observed between 150 and 250 msec after stimulus onset in occipito-temporal electrodes as a result of perceptual integration (Kovács, Zimmer, & Kovács, 2005). A color vertex positivity (CVP) was assessed in the color stimuli between 140 and 180 msec at the crown of the head. A similar positivity has previously been reported for ERPs elicited by color versus non-color stimuli (Schoenfeld et al., 2003). The second component considered was the visual awareness negativity (VAN). The VAN is a negative-going component observed at occipito-parietal sites around 200-300 msec and, as its name suggests, it has previously been linked to visual awareness (Koivisto et al., 2008). The selection negativity (SN), a correlate of attentional selection, is a third component assessed in the present study. The SN has been found in bilateral occipital electrodes around 240-300 msec in response to task-relevant target and non-target stimuli. For non-target stimuli SN amplitude varies as a function of how similar the stimulus is to the target (Pitts et al., 2012). A late occipital positivity (LOP), occurring after 270 ms has also been proposed as a correlate to awareness although the characteristics of this component are not well understood (Del Cul et al., 2007). Finally, the P3b has been proposed as a marker of awareness in numerous studies (Sergent et al., 2005; Dehaene & Changeux, 2011). The P3b is a broadly distributed late positivity between 300 and 600 msec post-stimulus onset and is argued to be the most consistent correlate of perceptual visibility (Dehaene & Changeux, 2011). Notably, this component’s wide distribution is also consistent with the Global Neuronal Workspace Theory of consciousness.

1.5 The Present Study

The present study investigates the neural correlates of visual awareness. In doing so, explanations for two narrower questions are sought: Which ERP components correlate with awareness per se, and which components correlate more strongly with post-perceptual processing related to carrying out the reporting task? In other words, are the proposed components more closely associated with task-oriented attention or awareness? Secondly, can task-oriented attention influence processing of ‘invisible’ stimuli?

Elucidation of the ‘core’ NCCs (underlying phenomenal-consciousness) rather than the ‘total’ NCCs (encoding both phenomenal- and access-consciousness) is attempted by manipulating task-relevancy of the stimuli and primarily analyzing responses to non-target stimuli. As a result, possible confounds of extraneous activity reflecting motor preparation and execution as well as task-oriented attention are thereby controlled for.

Colored and shaped stimuli were used. By using two stimuli categories, this study effectively includes a degree of internal replication. Stimulus perception was manipulated by backwards masking, a technique in which a stimulus is presented for a very brief time (here, 16.6 ms) before the onset of a “mask” (here, a random array of line segments). A behavioral study was first conducted to determine the optimal stimulus onset asynchrony (SOA) that effectively masks the stimuli used in the main experiment.

Chapter 2: Behavioral Experiment

2.1 Methods

2.1.1 Participants

Twelve healthy adults participated in the behavioral study. Participants had normal or corrected to normal vision, as confirmed by a brief eye exam conducted before experimentation. Data from one participant were excluded due to aberrance from task instructions. All participants gave informed consent prior to participation. The Reed College Institutional Review Board approved all procedures.

2.1.2 Stimuli

Participants viewed a computer monitor displaying a 20 X 20 grid of white lines (visual angle = 9.728°) while seated approximately 70 cm from the screen. The orientation of each line changed every 1000-1200 milliseconds. For one-third of the presentations, a random configuration of white lines alternated to form an outlined square pattern (10 line segments per side). On another third of the presentations four of the white lines changed to red, and each red line was located in the rows and columns spatially coincident to the four contours of the square. The final third of presentations were simply another random configuration of white line segments. (See Fig. 2.1 for stimuli examples.) Each stimulus array was created separately and never repeated. To subjects, the changes in line orientation appeared as brief rotations or "twitches." Stimuli were created and displayed using Presentation software (Neurobehavioral Systems Inc., Albany, CA).

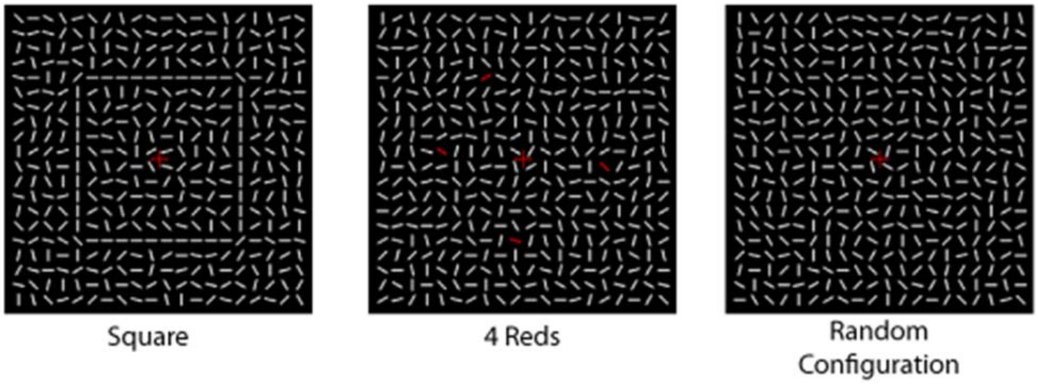


Figure 2.1 Examples of the behavioral study stimuli

2.1.3 Procedure

Each of the three stimulus types (randoms, 4 reds, and squares) was presented 100 total times across five time durations (approximately 16ms, 33ms, 50ms, 67ms, and 300ms) in a random order. Thus, there were 15 combinations of stimulus-type and stimulus-duration, and each combination was shown 20 times. Participants were instructed to push a button with their right index finger whenever four red lines or a square was consciously perceived (CEDRIS button pad, Model RB-830). A practice session was conducted immediately prior to data collection.

2.2 Results and Discussion

The shape stimulus was more readily masked than the color stimulus. Squares were virtually never perceived in the 16ms condition (1.8%) and rarely detected in the 33ms (17.7%) and 50ms (38.6%) conditions. (See Figure 2.2 for detection accuracy of the shape stimulus.) It is possible that some responses were false alarms, particularly for the shorter durations. For example, two people each responded once to the square presented for 16ms, and it seems more likely that these reflected accidental button presses rather than transient perceptual capacities.

The color stimulus was considerably more resistant to backward masking. Almost all of the participants detected the stimulus in most of the SOAs tested. The detection threshold seems to lie somewhere between a latency of 16ms (13.6%) and 33ms (83.6%). (See Figure 2.3 for detection accuracy of the color stimulus.) Closer inspection of participants' performance in the 16ms duration revealed a bimodal distribution of accuracy. The majority of participants (N=7) never perceived the stimulus in this condition. However, four subjects detected the 16ms colored stimulus in a quarter or more of the trials. This finding motivated the inclusion of a manipulation check for perceptual awareness in the main EEG study.

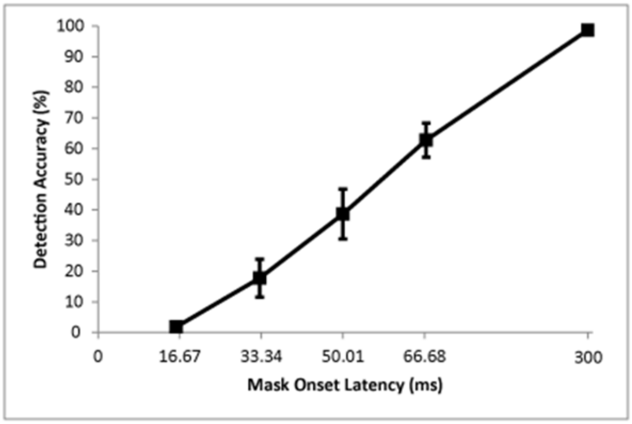


Figure 2.2 Detection of the shape stimulus as a function of mask SOA
Mean results for detection of squares are plotted over tested SOAs. Error bars reflect the standard error of the mean. The intervals of the horizontal axis reflect the actual presentation durations.

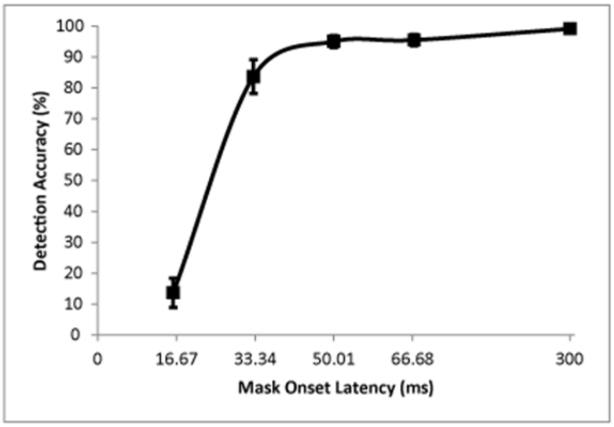


Figure 2.3 Detection of the color stimulus as a function of mask SOA
Mean results for detection of 4 Reds are plotted over tested SOAs. Error bars reflect the standard error of the mean. The intervals of the horizontal axis reflect the actual presentation durations.

Condition	*Mean*	*SD*	*SEM*
C16	0.1364	0.1518	0.0480
C33	0.8364	0.1719	0.0544
C50	0.9500	0.0632	0.0200
C67	0.9545	0.0568	0.0180
C300	0.9909	0.0302	0.0095
S16	0.0182	0.0337	0.0107
S33	0.1773	0.1954	0.0618
S50	0.3864	0.2580	0.0816
S67	0.6273	0.1780	0.0563
S300	0.9864	0.0234	0.0074

Table 2.1 Detection performance in behavioral study
Descriptive statistics of detection performance are shown above. A condition's letter refers to its stimulus type, and the number refers to its duration in milliseconds.

Chapter 3: Methods

3.1 Participants

Twenty-six healthy adults (ages 18-27; 65% female) participated in the EEG study. Participants with (corrected) visual acuity of less than 20/40 or history of neurological damage or disorder were excluded. Data from five participants were excluded due to failures in the awareness manipulation (see below). Data from two participants were also excluded due to excessive artifacts in their electrophysiological recordings (e.g., due to blinks and other muscle movements.) Data from one additional participant was excluded in ERP analyses due to aberrance from task instructions. The final group consisted of 18 participants (mean age = 21 years; 66.67% female). All participants were recruited as volunteers and gave informed consent prior to participation. The Reed College Institutional Review Board approved all procedures.

3.2 Stimuli

Participants viewed a computer monitor displaying a 20 X 20 grid of white lines (visual angle = 9.728°) while seated approximately 70 cm from the screen. The orientation of the lines shifted approximately once per second and appeared to briefly rotate or "twitch." Some configurations included color or a shape. More precisely, following the brief presentation of a random array of lines for 1000-1200ms, another random configuration would appear in its place. Sometimes the second array contained 3 red lines, 4 red lines, a diamond, or a square. As in the behavioral study, the location of the color lines and shape edges were kept spatially coincident. The red lines did not appear in the same location each time, but they always appeared in the same row or column as a contour of the square stimuli. (See Fig. 3.1 for example stimuli.) After a stimulus onset asynchrony (SOA) of either 16.67ms (hereafter "16ms") or 300ms, another random configuration of line segments was presented. This random configuration served as a “mask” for the short (16ms) color and shape stimuli. (See Fig. 3.2 for a diagram of the sequence of an individual trial.) The stimulus duration of 16ms was selected based on the findings of the behavioral experiment. Each stimulus array was made separately and never repeated. The order of the stimuli was randomized for each block of trials. Participants were instructed to maintain focus on a central red cross-hair present in all stimuli. Stimuli were created and displayed using Presentation software (Neurobehavioral Systems Inc., Albany, CA).

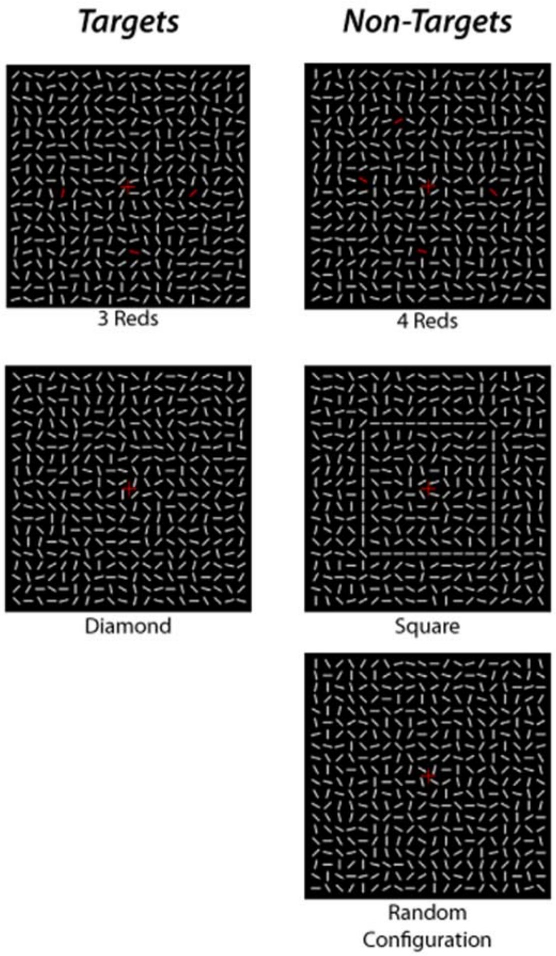


Figure 3.1 Sample stimuli

Either the ‘3 Reds’ or the ‘Diamond’ served as the target during a trial block; there was only one target at any time. The ‘4 Reds’, ‘Square’, and ‘Randoms’ were always non-targets, but the ‘4 Reds’ or ‘Square’ became task-relevant if the ‘3 Reds’ or ‘Diamond’, respectively, were the current target.

Since each of the five stimuli was shown for either 300ms or 16ms, there were ten combinations of stimulus-type and stimulus-duration. Each of these 10 different stimuli was presented equiprobably on 10% of the trials. On separate blocks of trials, subjects were instructed to respond to either the ‘3 Reds’ stimulus (color task) or the ‘Diamond’ stimulus (shape task). For analysis purposes, this combination of task (color or shape) and stimulus-type/stimulus-duration (10 different stimuli) resulted in 20 different types of trials, each occurring on 5% of all trials. Over the course of the experiment, each participant had 180 trials of each combination, 3600 trials total.

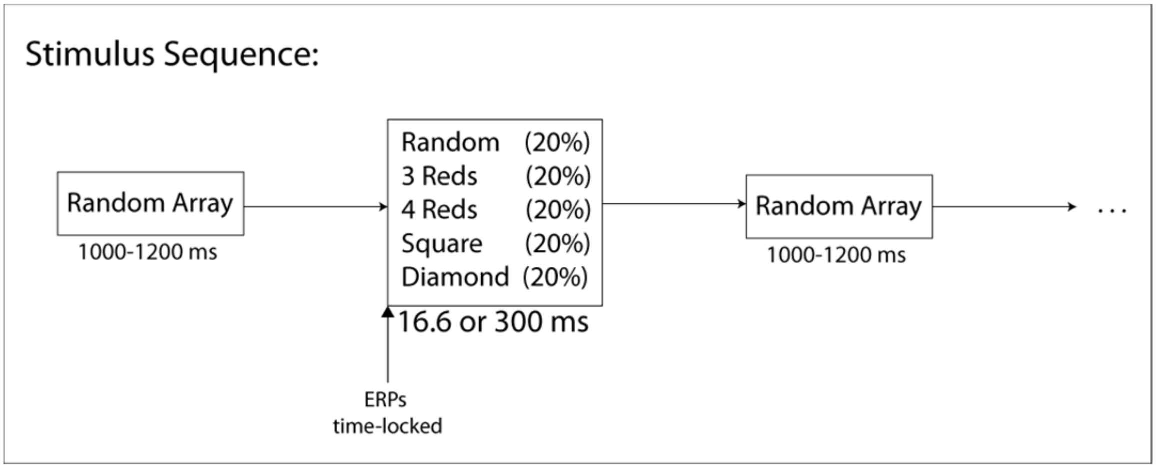


Figure 3.2 Stimulus presentation sequence
Line segment orientations alternated between random configurations and one of five stimulus types: a configuration containing 3 red lines, 4 red lines, a square pattern, a diamond pattern, or another random array.

3.3 Procedure

Participants engaged in one of two alternating discrimination tasks throughout the EEG recording. Participants were either instructed to respond whenever they perceived three red lines (3 Reds) or they were asked to respond whenever they saw a diamond pattern. Both tasks consisted of pushing a button with the right index finger whenever the target stimulus was consciously perceived (CEDRIS button pad, Model RB-830).

When ‘3 Reds’ was the target stimulus, both colored stimuli were considered task-relevant due to their similarity and the discrimination necessary to perform the task.

The shape stimuli were thus task-irrelevant at that time, as they did not have to be attended to in the same manner. Similarly, if the diamond pattern was the target, then both shape stimuli were task-relevant while the colored stimuli were task-irrelevant.

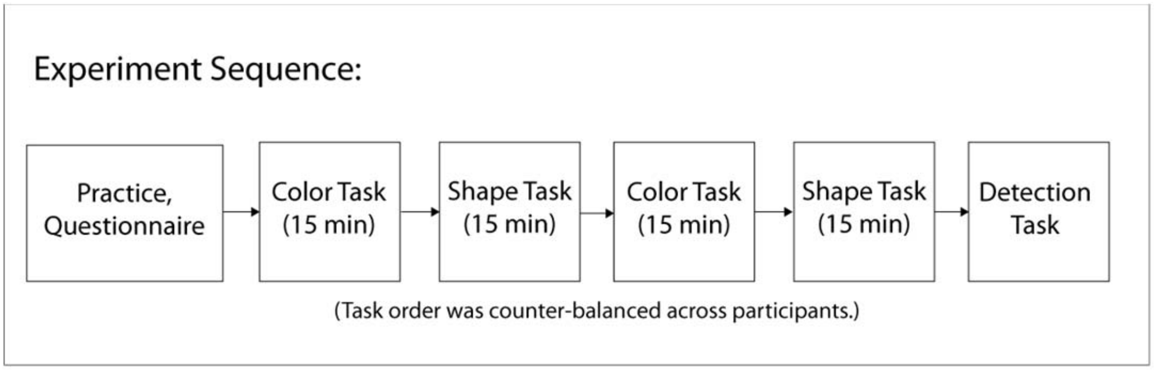


Figure 3.3 Experiment Sequence
After practice, subjects alternated between the color and shape tasks. Following EEG recording, participants completed a short detection task to confirm their unawareness of the short (16ms) stimuli.

To familiarize participants with the stimuli, still frames of each of the five stimuli were initially shown as examples. Then, prior to EEG recording, participants practiced both discrimination tasks for about 5 minutes each. Awareness of the 300ms task-irrelevant stimuli was confirmed by a questionnaire administered immediately after each practice session. (See Appendix A for copies of the questionnaires.)

Participants performed the same task for three sequential blocks of trials (approximately 15 minutes) before the task changed (e.g. color-then-shape or shape-then-color). This sequence was then repeated. Each subject therefore completed a total of 12 blocks: 6 of the shape task and 6 of the color task. Each block was composed of 300 individual trials which were further divided into five sub-blocks composed of 60 trials each. Short self-paced breaks were provided after each sub-block, and extended mandatory breaks were given between each block. The order of the tasks was counter-balanced across participants. See Figure 3.3 for a diagram of the experiment sequence.

The final task was a brief detection test similar to the behavioral experiment, except it only involved the SOAs of 16ms and 300ms. This task was included to verify unawareness of the stimuli presented for the shorter (16ms) duration. Participants were instructed to respond whenever they perceived the square pattern or the four red lines. It was explained that the 3 Reds and diamond stimuli were now omitted, so rather than requiring discrimination, this task was simply about detection. Participants were encouraged to adopt a somewhat liberal response criterion, responding even if they just caught a glimpse of color or shape. Upon completion, participants were allowed to wash their hair, (profusely) thanked, and dismissed from the laboratory.

3.4 EEG Methods

Brain electrical activity was noninvasively recorded from the scalp using customized electrode caps with 96 electrode placements (EASYCAP GmbH, Herrsching, Germany). Electrode locations were modified from the standard system for equidistant recording. See Appendix B for a full map of channel locations overlaid on the standard system. Electrode impedances were kept below 5 kΩ. Electrode signals were amplified by three modular amplifiers (Brain Vision LLC, Morrisville, NC) and digitized at a rate of 500 Hz.

Eye movements were monitored by vertical and horizontal EOG recordings. A central electrode near CPz served as the reference for all scalp channels and vertical EOG. Left and right horizontal EOG channels were re-referenced offline as a bipolar pair. Each recording session usually lasted for 4-4.5 hours, including setup, cap/electrode preparation, practice, main experiment sessions, detection task, and clean-up.

ERPs were time-locked to the line segment orientation changes, baseline corrected from -100 to 0 msec, and low-pass filtered at 25 Hz. Trials were discarded if they contained artifacts such as eye blinks, eye movement, or other muscle movements. ERPs (for all channels except the HEOG) were re-referenced to the average of the left and right mastoid channels before analysis.

3.5 Comparisons of Interest

Comparisons of interest were between ERPs elicited by non-target color and shape stimuli when color or shape was task-relevant or task-irrelevant and when subjects were aware (300ms) or unaware (16ms) of the stimuli. Non-target stimuli were considered for two reasons: this allows one to avoid confounding brain activity reflecting motor preparation and response execution, and the target color stimulus was asymmetrical, which could lead to unbalanced retinal input and confound analysis of occipital processing. In order to isolate the effects of condition from the effects of the physical properties of the stimuli, difference waves were used in analysis. Difference waves were derived by subtracting the average ERPs elicited by a condition's corresponding random array from the average ERPs elicited by the condition itself (for example, the mean ERP from a 300ms 4red during the color task minus the mean ERP from a 300ms random array during the color task).

In considering the neural correlates of perceptual awareness, a total of ten components were selected for statistical analyses (5 for color and 5 for shape). Time windows and electrode locations for component measurement were selected on the basis of the peak amplitudes and scalp distribution of the main experimental effects (difference waves of the four permutations of awareness and task-relevancy).

Chapter 4: Results

Single-sample t-tests were performed on the difference waves corresponding to non-target stimuli (Squares and 4 Reds) across the four possible conditions (unaware/aware x task-relevant/irrelevant). To correct for familywise error rate, mean amplitude (μV) differences were assessed using a significance threshold of $p < 0.0125$ (0.05 / 4 conditions). Figures of the ERPs, difference waves, and scalp topography corresponding to these stimuli occupy the following pages. A map of electrode locations may be found in Appendix B. Figures of the difference waves for target stimuli are shown in Appendix C.

	CIN	**VAN**	**SN**	**LOP**	**P3b**
Awr & Rel	-0.8554*	-2.6868*	-1.8566*	1.9433*	7.2566*
Awr & Irrel	-1.1820*	-1.0610*	-0.4748	0.6706	1.5021*
Unawr & Rel	-0.1583	-0.2051	-0.1403	-0.1548	-0.0315
Unawr & Irrel	-0.1337	-0.2229	-0.2075	-0.1632	0.1797

Table 4.1 Mean amplitudes elicited by non-target shape stimuli
Mean amplitudes (μV) elicited by square stimuli were analyzed during the time windows of the ERP components of interest. Significant amplitudes are marked by an asterisk. To correct for familywise error rate, a significance threshold of $p < 0.0125$ was used.

	CIN	**VAN**	**SN**	**LOP**	**P3b**
Awr & Rel	2.1342*	-3.4205*	-4.4804*	2.9205*	8.4916*
Awr & Irrel	0.7782	-3.0475*	-2.3123*	-0.1727	1.3551*
Unawr & Rel	-0.0047	-0.1537	-0.4306	0.6293*	1.3572*
Unawr & Irrel	0.1332	-0.0030	0.0617	-0.1096	0.0319

Table 4.2 Mean amplitudes elicited by non-target color stimuli
Mean amplitudes (µV) elicited by 4reds stimuli were analyzed during the time windows of the ERP components of interest. Significant amplitudes are marked by an asterisk. To correct for familywise error rate, a significance threshold of $p < 0.0125$ was used.

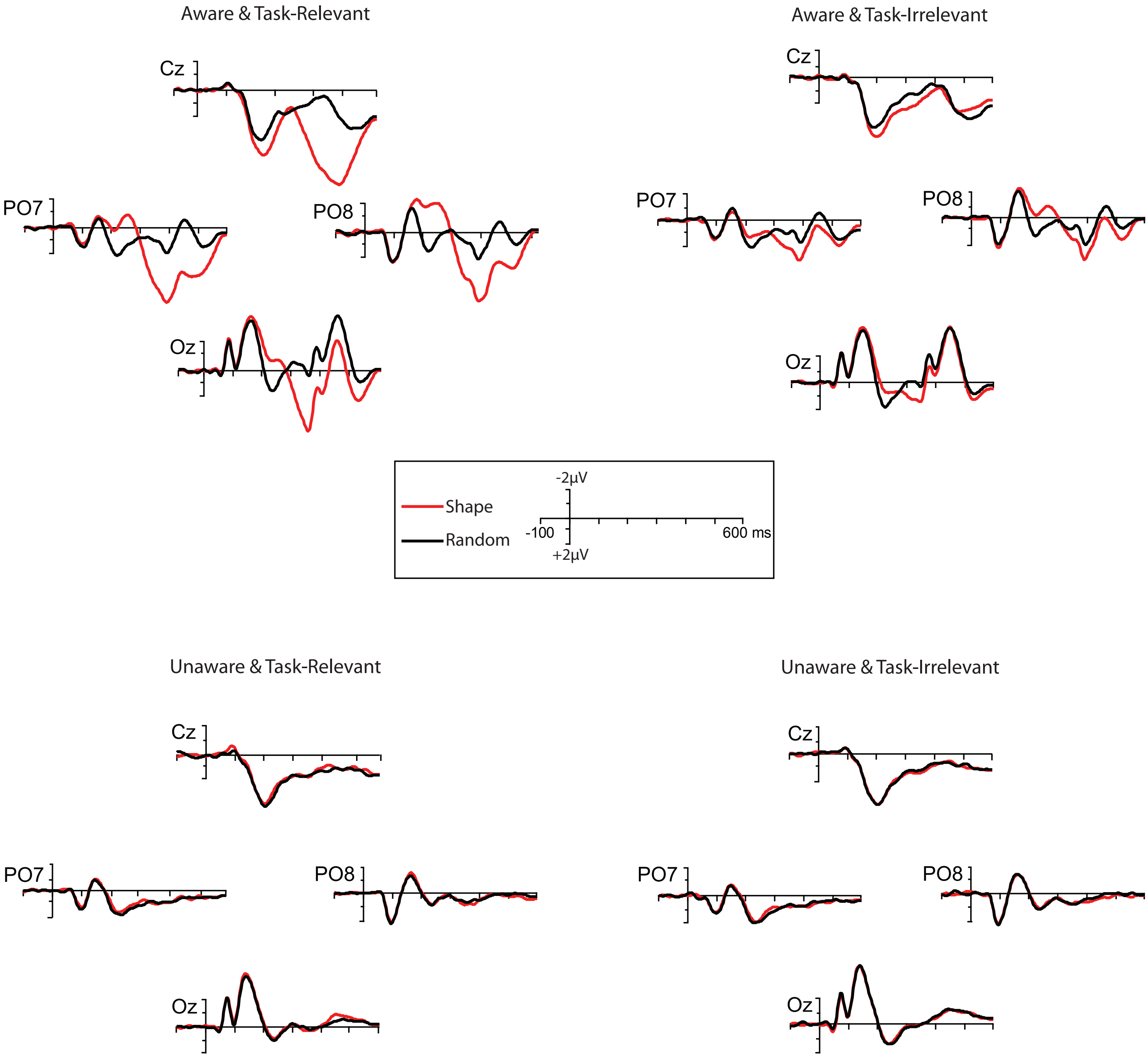


Figure 4.1 ERPs elicited by non-target shape stimuli

The average ERPs elicited by non-target shape stimuli are shown above. The average ERPs elicited by the square stimulus in a given condition are shown in red. The average ERPs elicited by the corresponding random array of the same condition are shown in black (for example, the mean ERP from a 300ms square during the shape task appears in red, while corresponding mean ERP from a 300ms random array during the shape task appears in black).

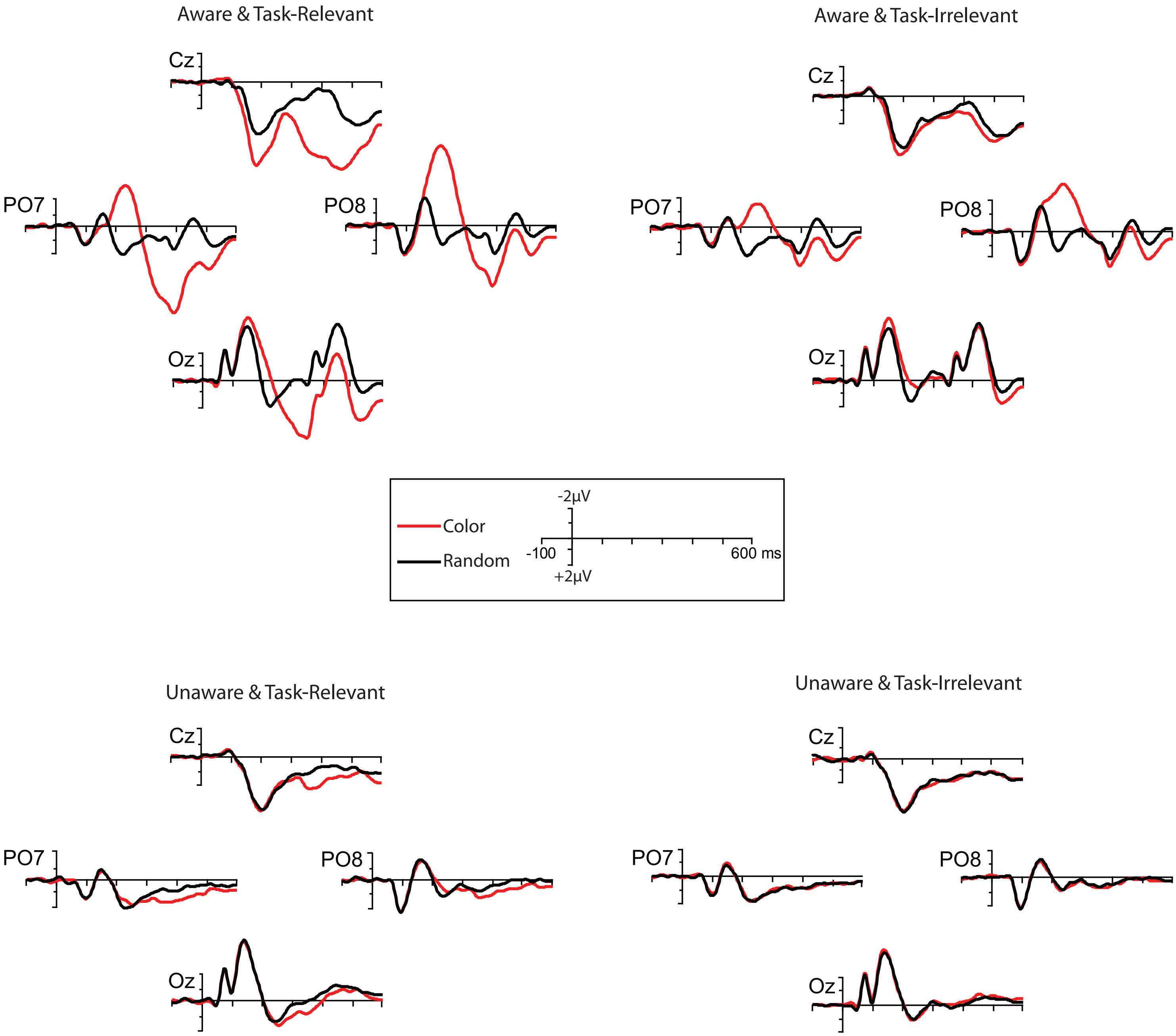


Figure 4.2 ERPs elicited by non-target color stimuli

The average ERPs elicited by non-target color stimuli are shown above. The average ERPs elicited by the 4reds stimulus in a given condition are shown in red. The average ERPs elicited by the corresponding random array of the same condition are shown in black (for example, the mean ERP from a 300ms 4reds during the color task appears in red, while corresponding mean ERP from a 300ms random array during the color task appears in black).

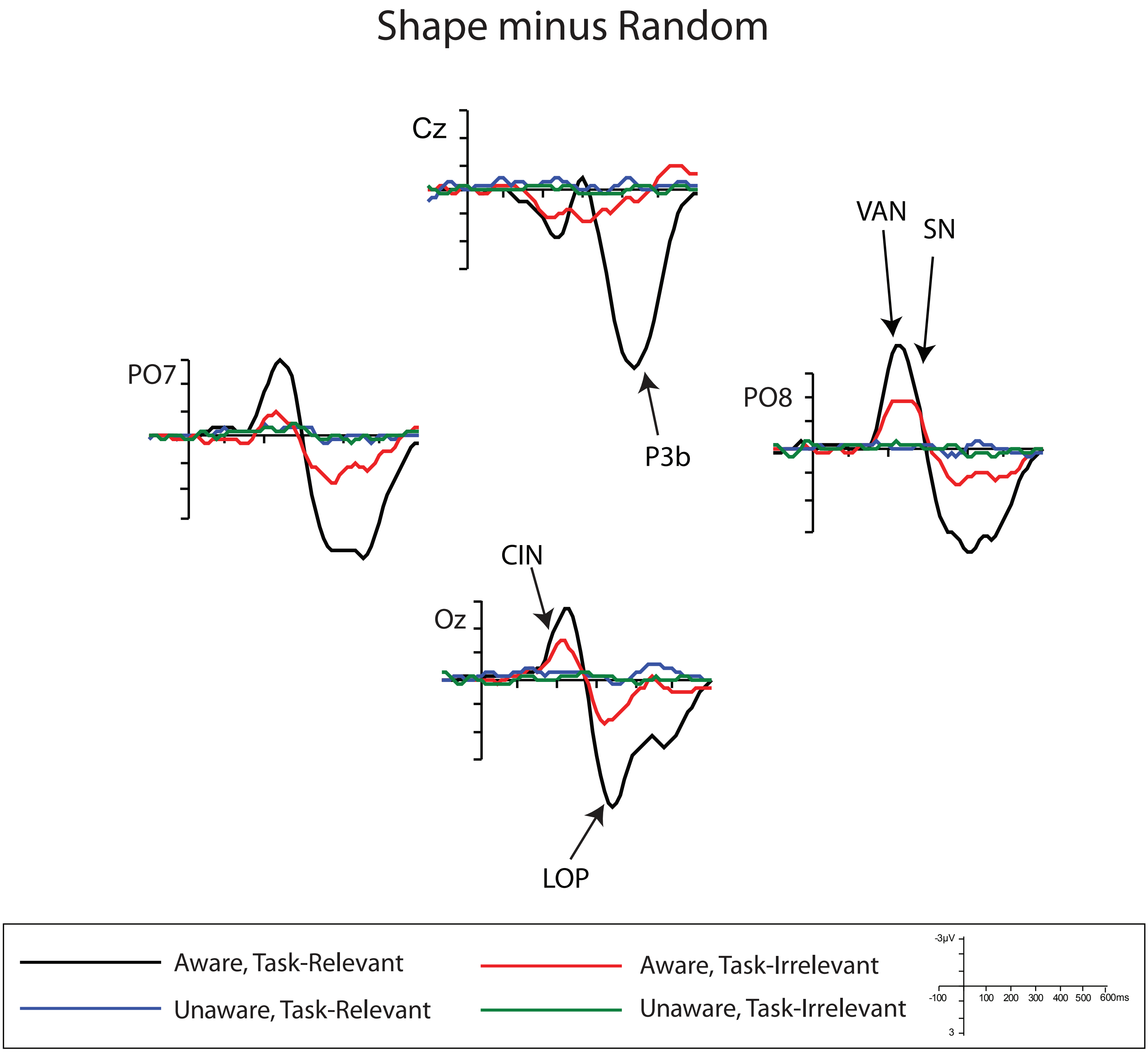


Figure 4.3 Difference waves elicited by non-target shape stimuli

The average difference waves for the square stimulus in a given condition are shown above. Difference waves were derived by subtracting the average ERPs elicited by a condition's corresponding random array from the average ERPs elicited by the condition itself (for example, the mean ERP from a 300ms square during the color task minus the mean ERP from a 300ms random array during the shape task).

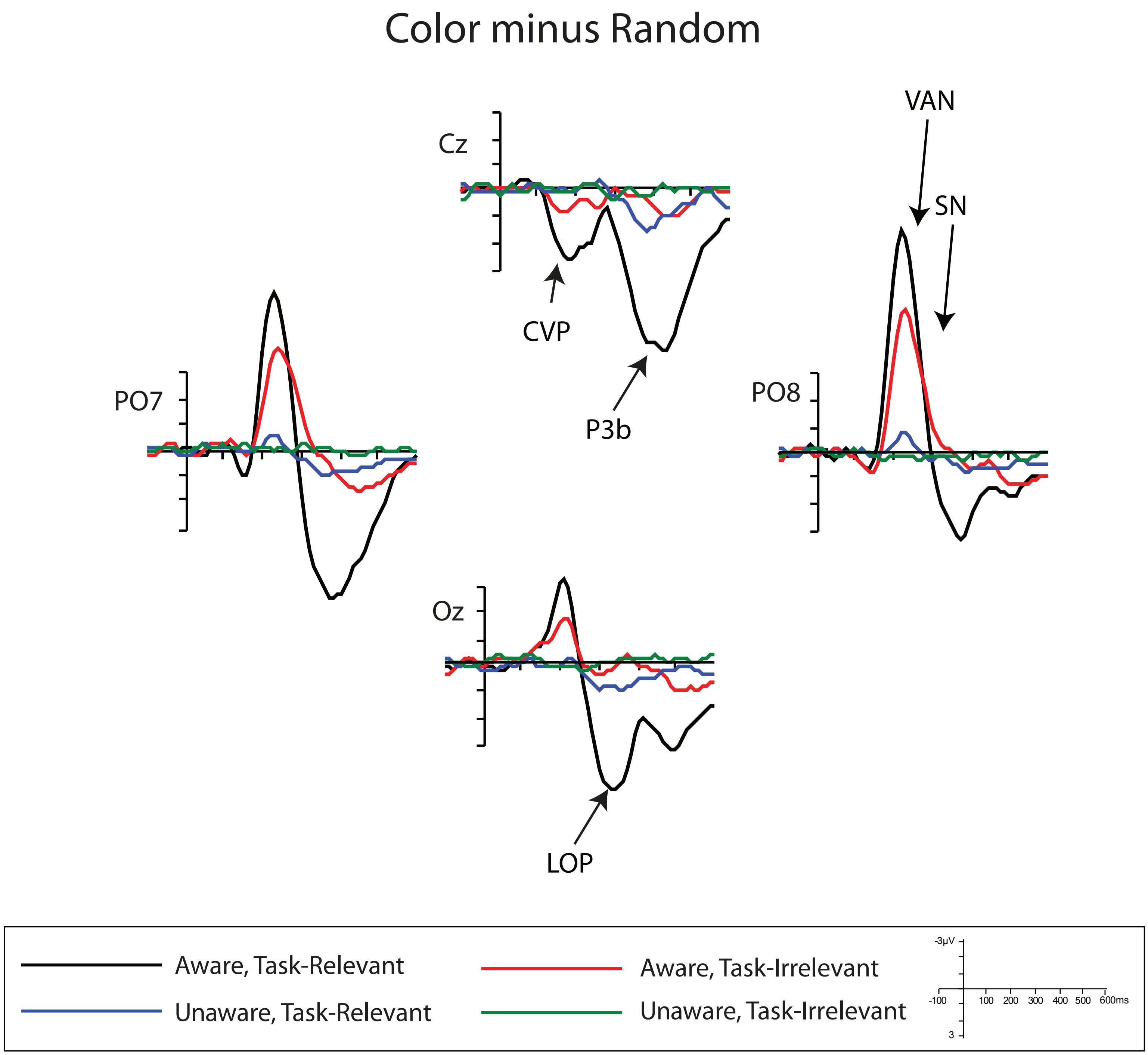


Figure 4.4 Difference waves elicited by non-target color stimuli

The average difference waves for the 4reds stimuli in a given condition are shown above. Difference waves were derived by subtracting the average ERPs elicited by a condition's corresponding random array from the average ERPs elicited by the condition itself (for example, the mean ERP from a 300ms 4reds during the color task minus the mean ERP from a 300ms random array during the color task).

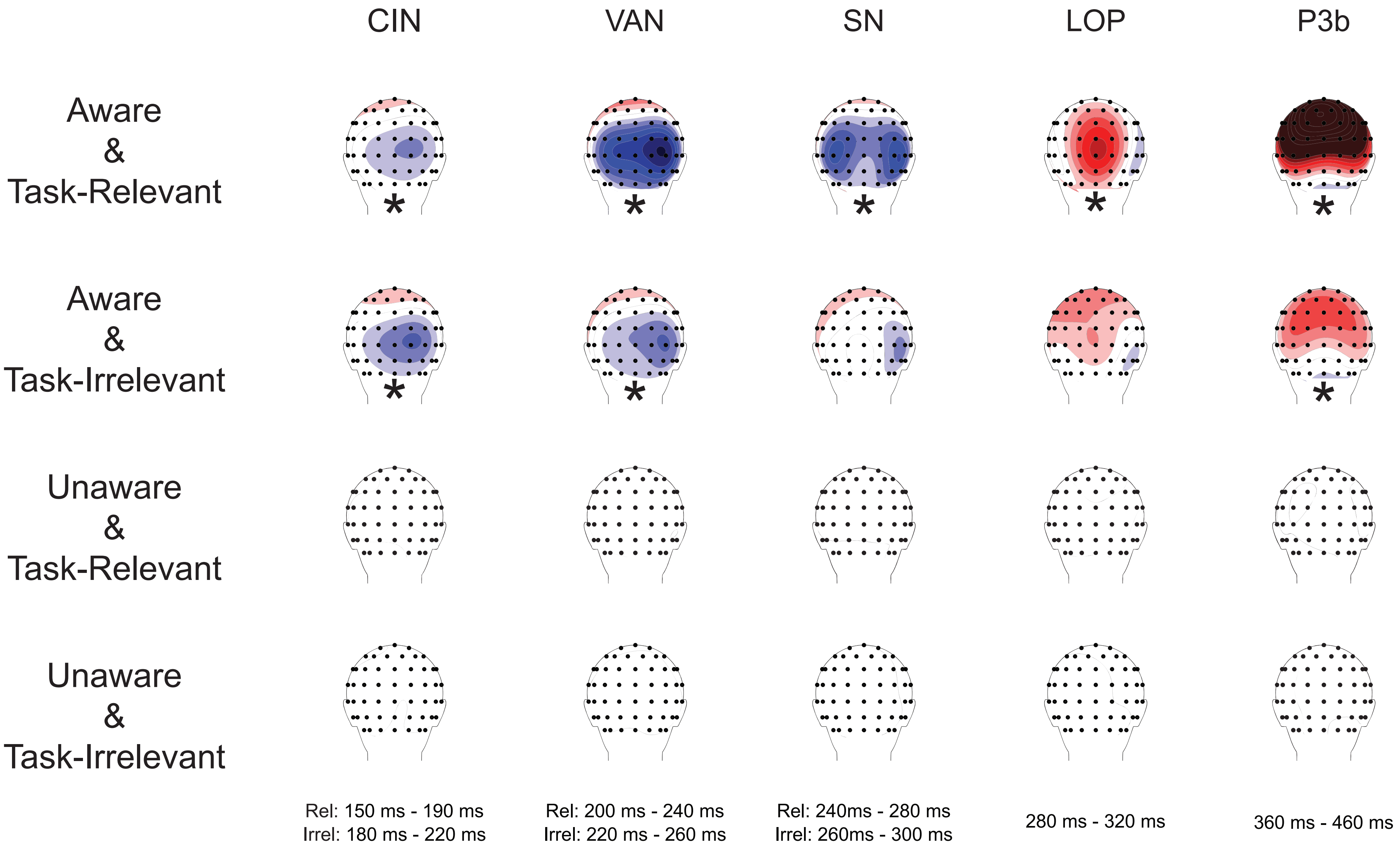


Figure 4.5 Scalp distribution of amplitude differences for shape stimuli
Scalp distributions of the amplitude (µV) differences for the square stimuli are shown above. Presence of an ERP component in a given conditon is marked by an asterisk. To correct for familywise error rate, a significance threshold of $p < 0.0125$ was used.

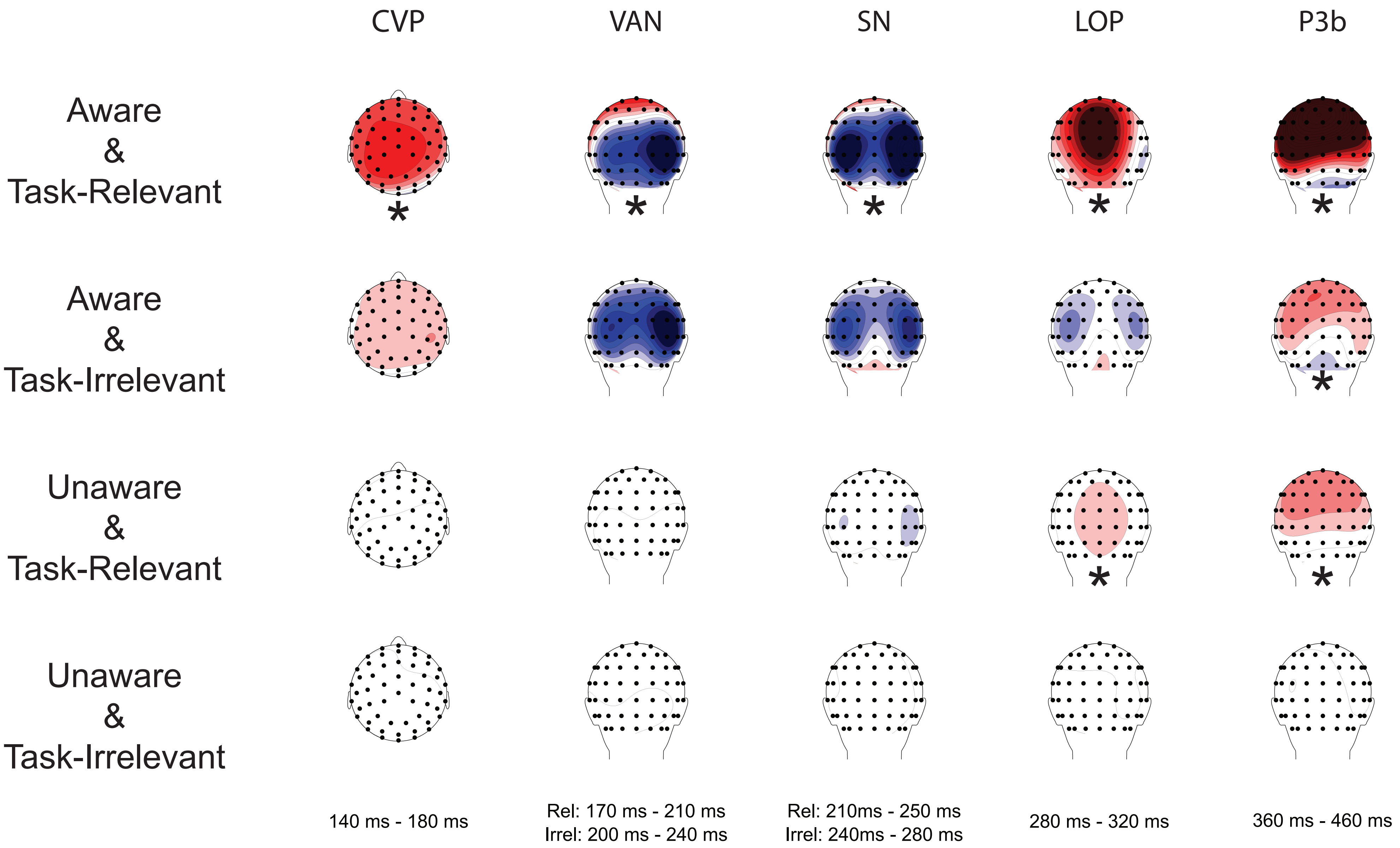


Figure 4.6 Scalp distribution of amplitude differences for color stimuli
Scalp distributions of the amplitude (μV) differences for the 4reds stimuli are shown above. Presence of an ERP component in a given condition is marked by an asterisk. To correct for familywise error rate, a significance threshold of $p < 0.0125$ was used.

4.1 Behavioral Results for the EEG Study

Behavioral results from the EEG study during the discrimination and detection tasks are shown in Tables 4.3 and 4.4 respectively. All integers reflect arithmetic means across participants. Accuracy is reflected by the average percentage of target hits. Sensitivity is reflected by d', a statistic commonly used in psychophysics to measure detection accuracy regardless of response bias by incorporating both hit rate and false alarm rate. A higher d' indicates that the signal can be more readily detected. Finally, reaction times are shown as the milliseconds post presentation at which a response was made.

Only nine 16ms targets were ever 'hit' across all participants over all blocks and both tasks. It seems likely that those responses corresponded to false alarms and were only incidentally recorded as hits. For this reason, reaction time was derived by the mean latency of responses to only the 300ms stimuli.

A standard correction was applied in the derivation of d'. Absolute scores (0s and 1s) were substituted with 1/(2N) and 1-1/(2N), respectively, where N represents the maximum number of false alarms or the total number of targets depending on the value being transformed.

		Hits (%)	**FAs (%)**	**d'**	**RT (ms)**
Diamonds	*300ms*	0.9342	0.0010	4.5998	567.87
	16ms	0.0000		0.8045	
3 Reds	*300ms*	0.9826	0.0058	4.7116	541.47
	16ms	0.0006		0.5074	

Table 4.3 Discrimination task performance during EEG recording

Target discrimination was significantly better during the color task (M = 0.9826) than during the shape task (M = 0.9342) for the 300ms stimuli, t (18) = 4.67, $p < 0.05$. Responses to the 16ms stimuli did not statistically differ. Notably, none of the masked diamonds were detected, and only two of the masked 3 Reds were 'hit'. As mentioned above, it's likely that these were responded to only incidentally and were not actually consciously perceived. Response times were significantly shorter for the 3 Reds (*M* = 541.47) than for the diamonds (*M* = 567.87), *t* (18) = 4.74, $p < 0.05$.

		Hits (%)	FAs (%)	d'	RT (ms)
Squares	*300ms*	0.9882	0.0024	4.3851	480.47
	16ms	0.0066		0.2870	
4 Reds	*300ms*	0.9969		4.4621	441.80
	16ms	0.0053		0.2761	

Table 4.4 Detection task performance post-recording

Detection of the 300ms 4 Reds (*M* = .9969) was significantly greater than detection of the 300ms Squares (*M* = 0.9882), *t* (18) = 2.54, $p < 0.05$. However, there were very few misses or false alarms for either of the 300ms stimuli. Detection performance did not significantly differ between the 16ms stimuli, and only four 16ms Squares and three 16ms 4 Reds were 'hit' in the detection tasks. Responses to the 4 Reds (*M* = 441.80) were significantly faster than to the Squares (*M* = 480.47), *t* (18) = 7.21, $p < 0.05$. Both latencies are considerably shorter than those in the discrimination task, reflecting the comparative ease of the detection task.

4.2 ERP Results for Shape Stimuli

4.2.1 Contour Integration Negativity

The Contour Integration Negativity (CIN) was assessed using nine occipital electrodes located along the midline (44, 45, 46, 62, 63, 64, 77, 78, 79). Average amplitudes between 150 and 190 msec for the task-relevant Squares and between 180 and 220 msec for the task-irrelevant Squares were used in analyses.

The CIN was found in the *aware & task-relevant* (*M* = -0.8554, *SD* = 1.0168, *t* (17) = -3.5693, *p* = 0.0024) and *aware & task-irrelevant* conditions (*M* = -1.1820, *SD* = 1.7544, *t* (17) = -2.8585, *p* = 0.0109). The *unaware & task-relevant* (*M* = -0.1583, *SD* =

0.5048, *t* (17) = -1.3308, *ns*) and *unaware & task-irrelevant* conditions (*M* = -0.1337, *SD* = 0.5876, *t* (17) = -0.9653, *ns*) did not contain the CIN.

4.2.2 Visual Awareness Negativity

The Visual Awareness Negativity (VAN) was assessed in two lateralized regions recorded by six electrodes each (Left: 46, 47, 64, 65, 79, 80; Right: 43, 44, 61, 62, 76, 77). Average amplitudes between 200 and 240 msec for the task-relevant Squares and between 220 and 260 msec for the task-irrelevant Squares were used in analyses.

The VAN was found in the *aware & task-relevant* (*M* = -2.6868, *SD* = 2.6321, *t* (17) = -4.3307, *p* = 0.0005) and *aware & task-irrelevant* (*M* = -1.0610, *SD* = 1.3425, *t* (17) = -3.3529, *p* = 0.0038) conditions. The *unaware & task-relevant* (*M* = -0.2051, *SD* = 0.8031, *t* (17) = -1.0836, *ns*) and *unaware & task-irrelevant* conditions (*M* = -0.2229, *SD* = 0.6271, *t* (17) = -1.5084, *ns*) did not contain the VAN.

4.2.3 Selection Negativity

The Selection Negativity (SN) was assessed in two lateralized regions recorded by six electrodes each (Left: 47, 48, 65, 66, 80, 81; Right: 42, 43, 60, 61, 75, 76). Average amplitudes between 240 and 280 msec for the task-relevant Squares and between 260 and 300 msec for the task-irrelevant Squares were used in analyses.

The SN was found in the *aware & task-relevant* condition (*M* = -1.8566, *SD* = 1.9131, *t* (17) = -4.1174, *p* = 0.0007). The *aware & task-irrelevant* (*M* = -0.4748, *SD* = 0.8078, *t* (17) = -2.4937, *ns*), *unaware & task-relevant* (*M* = -0.1403, *SD* = 0.5752, *t* (17) = -1.0350, *ns*), and *unaware & task-irrelevant* conditions (*M* = -0.2075, *SD* = 0.3948, *t* (17) = -2.2294, *ns*) did not contain the SN.

4.2.4 Late Occipital Positivity

A late occipital positivity (LOP) was assessed using the average amplitudes between 280 and 320 msec collapsed across nine occipital sites located along the midline (electrodes 44, 45, 46, 62, 63, 64, 77, 78, 79).

A LOP was found in the *aware & task-relevant* condition (*M* = 1.9433, *SD* = 2.4421, *t* (17) = 3.3761, *p* = 0.0036). The *aware & task-irrelevant* (*M* = 0.6706, *SD* = 1.1787, *t* (17) = 2.4137, *ns*), *unaware & task-relevant* (*M* = -0.1548, *SD* = 1.0142, *t* (17) = -0.6477, *ns*), and *unaware & task-irrelevant* conditions (*M* = -0.1632, *SD* = 0.7126, *t* (17) = -0.9717, *ns*) did not contain a LOP.

4.2.5 P3b

The P3b was assessed using the average amplitudes between 360 and 460 msec collapsed across nine medial parietal sites (electrodes 12, 13, 14, 15, 26, 27, 28, 29, 30).

The P3b was found in the *aware & task-relevant* (*M* = 7.2566, *SD* = 4.9611, *t* (17) = 19.0855, *p* < 0.0001) and *aware & task-irrelevant* conditions (*M* = 1.5021, *SD* = 2.0510, *t* (17) = 3.1071, *p* = 0.0064). The *unaware & task-relevant* (*M* = -0.0315, *SD* = 0.8654, *t* (17) = -0.1544, *ns*) and *unaware & task-irrelevant* conditions (*M* = 0.1797, *SD* = 0.9004, *t* (17) = 0.8470, *ns*) did not contain the P3b.

4.3 ERP Results for Color Stimuli

4.3.1 Color Vertex Positivity

An early positivity at the vertex of the scalp (CVP) was assessed using ten centrally located electrodes by analyzing each channel’s average amplitudes between 140 and 180 msec. Electrodes of interest were at the crown of the head: 1, 2, 3, 4, 5, 6, 10, 11, 16, and 17.

A CVP was found in the *aware & task-relevant* condition (*M* = 2.1342, *SD* = 2.1637, *t* (17) = 4.1848, *p* = 0.0006) and marginally significant in the *aware & task-irrelevant* conditions (*M* = 0.7782, *SD* = 1.2865, *t* (17) = 2.5663, *p* = 0.0200). The *unaware & task-relevant* (*M* = -0.0047, *SD* = 1.2019, *t* (17) = -0.0167, *ns)* and *unaware & task-irrelevant* conditions (*M* = 0.1332, *SD* = 1.1106, *t* (17) = 0.5088, *ns*) did not contain a CVP.

4.3.2 Visual Awareness Negativity

The Visual Awareness Negativity (VAN) was assessed in two lateralized regions recorded by six electrodes each (Left: 46, 47, 64, 65, 79, 80; Right: 43, 44, 61, 62, 76, 77). Average amplitudes between 170 and 210 msec for the task-relevant ‘4 Reds’ and between 200 and 240 msec for the task-irrelevant ‘4 Reds’ were used for analysis.

The VAN was found in the *aware & task-relevant* (M = -3.4205, SD = 3.6155, t (17) = -4.0138, p = 0.0009) and *aware & task-irrelevant* conditions (M = -3.0475, SD = 2.3670, t(17) = -5.4627, p < 0.0001). The VAN was not found in the *unaware & task-relevant* (M = -0.1537, SD = 0.7460, t (17) = -0.8743, *ns*) or *unaware & task-irrelevant* conditions (M = -0.0030, SD = 0.8325, t (17) = -0.0151, *ns*).

4.3.3 Selection Negativity

The Selection Negativity (SN) was assessed in two lateralized regions recorded by six electrodes each (Left: 47, 48, 65, 66, 80, 81; Right: 42, 43, 60, 61, 75, 76). Average amplitudes between 210 and 250 msec for the task-relevant ‘4 Reds’ and between 240 and 280 msec for the task-irrelevant ‘4 Reds’ were used for analysis.

The SN was found in the *aware & task-relevant* (M = -4.4804, SD = 2.7725, t (17) = -6.8561, p < 0.0001) and *aware & task-irrelevant* conditions (M = -2.3123, SD = 1.6195, t (17) = -6.0579, p < 0.0001). The SN was marginally significant in the *unaware & task-relevant* condition (M = -0.4306, SD = 0.7068, t (17) = -2.5847, p = 0.0193) but absent in the *unaware & task-irrelevant* condition (M = 0.0617, SD = 0.5731, t (17) = 0.4564, *ns*).

4.3.4 Late Occipital Positivity

A late occipital positivity (LOP) was assessed using the average amplitudes between 280 and 320 msec collapsed across nine occipital sites located along the midline (electrodes 44, 45, 46, 62, 63, 64, 77, 78, 79).

A LOP was found in the *aware & task-relevant* (M = 2.9205, SD = 2.8365, t (17) = 4.3683, p = 0.0004) and *unaware & task-relevant* conditions (M = 0.6293, SD =

0.9453, *t* (17) = 2.8244, *p* = 0.0117). The *aware & task-irrelevant* (*M* = -0.1727, *SD* = 1.4183, *t* (17) = -0.5167, *ns*) and *unaware & task-irrelevant* conditions (*M* = -0.1096, *SD* = 0.7129, *t* (17) = -0.6525, *ns*) did not contain a LOP.

4.3.5 P3b

The P3b was assessed using the average amplitudes between 360 and 460 msec collapsed across nine medial parietal sites (electrodes 12, 13, 14, 15, 26, 27, 28, 29, 30).

The P3b was found in the *aware & task-relevant* (*M* = 8.4916, *SD* = 5.3564, *t* (17) = 6.7259, *p* < 0.0001), *aware & task-irrelevant* (*M* = 1.3551, *SD* = 1.4046, *t* (17) = 4.0932, *p* = 0.0008), and *unaware & task-relevant* conditions (*M* = 1.3572, *SD* = 1.4100, *t* (17) = 4.0838, *p* = 0.0008). The *unaware & task-irrelevant* condition did not contain the P3b (*M* = 0.0319, *SD* = 1.0963, *t* (17) = 0.1235, *ns*).

Chapter 5: Conclusion

5.1 Main Findings

This study investigated whether proposed neural correlates of visual awareness could instead reflect task-oriented attention. Electrophysiological findings suggest that a negative peak at posterior recording sites occurring around 200 ms post-stimulus onset may be a marker of purely phenomenal visual experience. Other proposed correlates were found to be modulated by task-relevance, suggesting that these components instead reflect post-perceptual task-related processes.

Another inquiry made in this study was whether task-oriented attention modulates the processing of masked stimuli rendered "invisible." Statistical analysis did reveal a significant effect of task-relevance in non-conscious processing but effects were present only in color stimuli. Interpretation of this finding can be found below.

5.2 General Discussion

Components reflecting early sensory processing (CIN for shape stimuli and CVP for color) were the first ERP components assessed. These components were found in both *aware & task-relevant* conditions, the *shape-aware & task-irrelevant* condition, and marginally significant in the *color-aware & task-irrelevant* condition. However, these components were absent in all unaware conditions. Previous research has found the CIN in inattentionally-blind conditions, suggesting that these components reflect pre-perceptual sensory processing rather than conscious awareness (Pitts et al., 2012). It seems likely that these components reflect neural prerequisites to visual awareness. The absence of these components in the unaware conditions of the present study could be an effect of the extremely brief presentation interval (16 ms) prior to mask onset. In other words, the masking may have been so severe that this correlate to preconscious processing was blocked. This possibility could be further investigated by extending the masking SOA to a latency just below visibility threshold or by presenting much longer duration stimuli while diverting attention to render the stimuli perceptually invisible. In such situations, the CIN and CVP components would be elicited even during unaware conditions if they indeed reflect pre-conscious processing.

The VAN was only present in the aware conditions and unaffected by task-relevance; therefore it is a prime candidate for the core NCC. However, it is important to note the possibility that the VAN could instead be a signature of object-based attentional selection that is necessary for visual awareness while the true neural correlates of conscious perception remain at large. It is possible that the VAN is another pre-requisite for conscious perception and that an ERP correlate of core NCC does not exist. (The core NCC might only be measurable at a finer scale such as single-unit recording, for example.)

The SN was present in the both *aware & task-relevant* conditions, but it was absent in the *aware & task-irrelevant* condition for shapes. It was present in the *color-aware & task-irrelevant* condition but was also marginally significant in the *color-unaware & task-relevant* condition. Taken together, these results suggest that the SN is more closely linked with task-oriented attention than conscious awareness per se.

The LOP was only found in conditions with task-relevant stimuli (*shape-aware & task-relevant, color-aware & task-relevant*, and *color-unaware & task-relevant*). This suggests that the LOP is a signature of task-oriented attention instead of phenomenal experience.

The P3b was found in all aware conditions as well as the *color-unaware & task-irrelevant condition*. The P3b was absent in the shape aware & task-irrelevant condition. Again, this suggests that the P3b linked to task-related processes rather than visual awareness.

In conclusion, this study found strong evidence suggesting that the VAN is the only remaining candidate for an ERP correlate of phenomenal consciousness. The CIN and CVP are likely preconscious pre-requisites to consciousness. The SN, LOP, and P3b reflect task-related activity associated with conscious access, post-perceptual processing, and task-oriented attention rather than pure visual awareness, and should thus be considered NCC consequences rather than core NCC. The minimal set of necessary and sufficient neural events for visual experience may be considerably more limited than previously proposed. The early timing and spatial confinement of the VAN threatens the Global Neuronal Workspace Theory (GNWT), at least as the primary NCC for phenomenal consciousness. The GNWT may instead correspond to the neural correlates of access-consciousness necessary for post-perceptual processing.

Appendix A: Post-Training Questionnaires

Questionnaire - Color

Please rate how confident you are that you saw each pattern.

1 = very confident I did not see it
2 = confident I did not see it
3 = uncertain
4 = confident I saw it
5 = very confident I saw it

3 Red Lines	1	2	3	4	5
4 Red Lines	1	2	3	4	5

Please estimate how often you saw each pattern.

1 = never
2 = rarely / less than five times
3 = infrequently / 5-15 times
4 = frequently / 15-30 times
5 = very frequently / more than 30 times

3 Red Lines	1	2	3	4	5
4 Red Lines	1	2	3	4	5

Questionnaire - Shape

Please rate how confident you are that you saw each pattern.

1 = very confident I did not see it
2 = confident I did not see it
3 = uncertain
4 = confident I saw it
5 = very confident I saw it

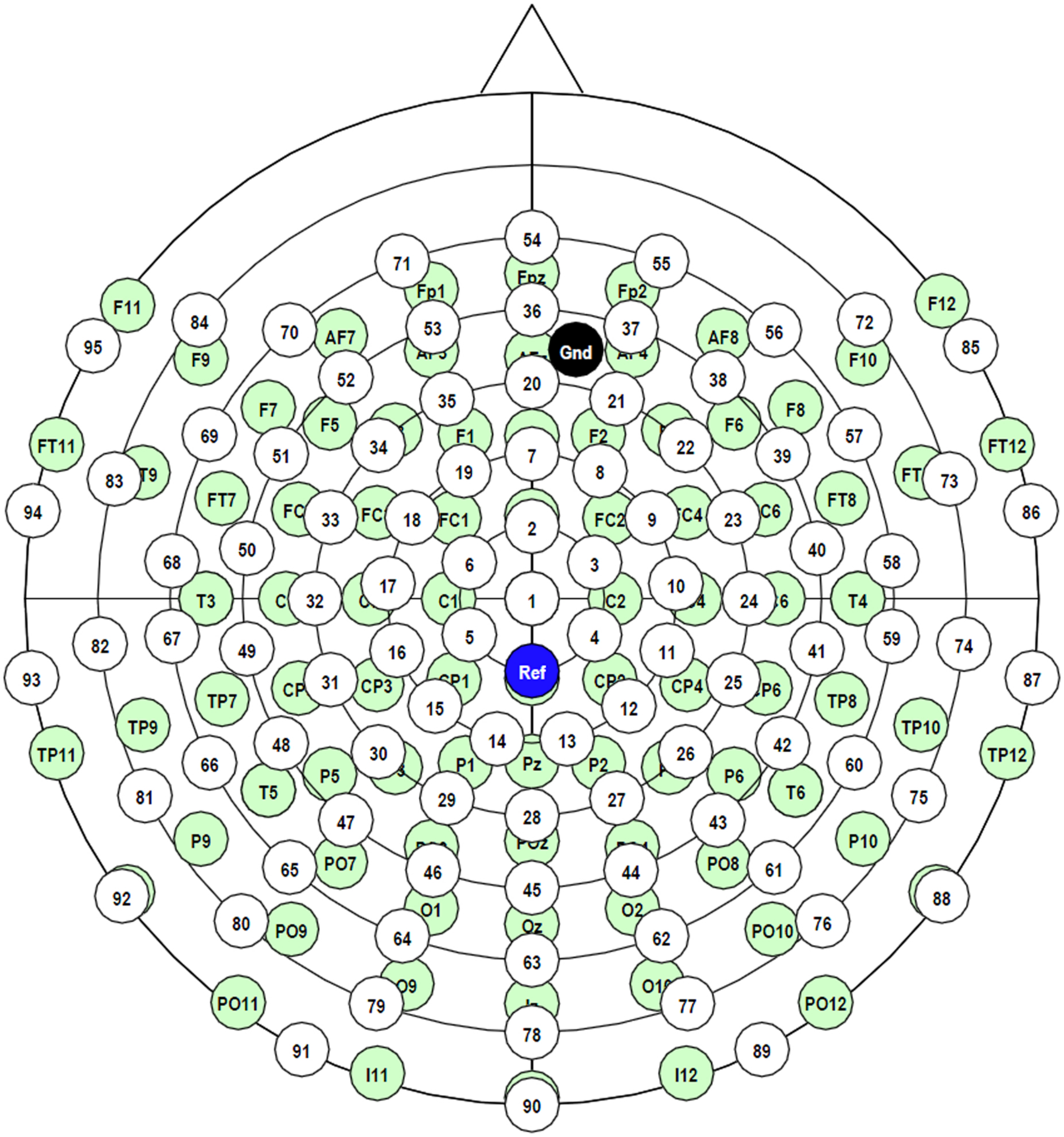
Diamond	1	2	3	4	5
Square	1	2	3	4	5

Please estimate how often you saw each pattern.

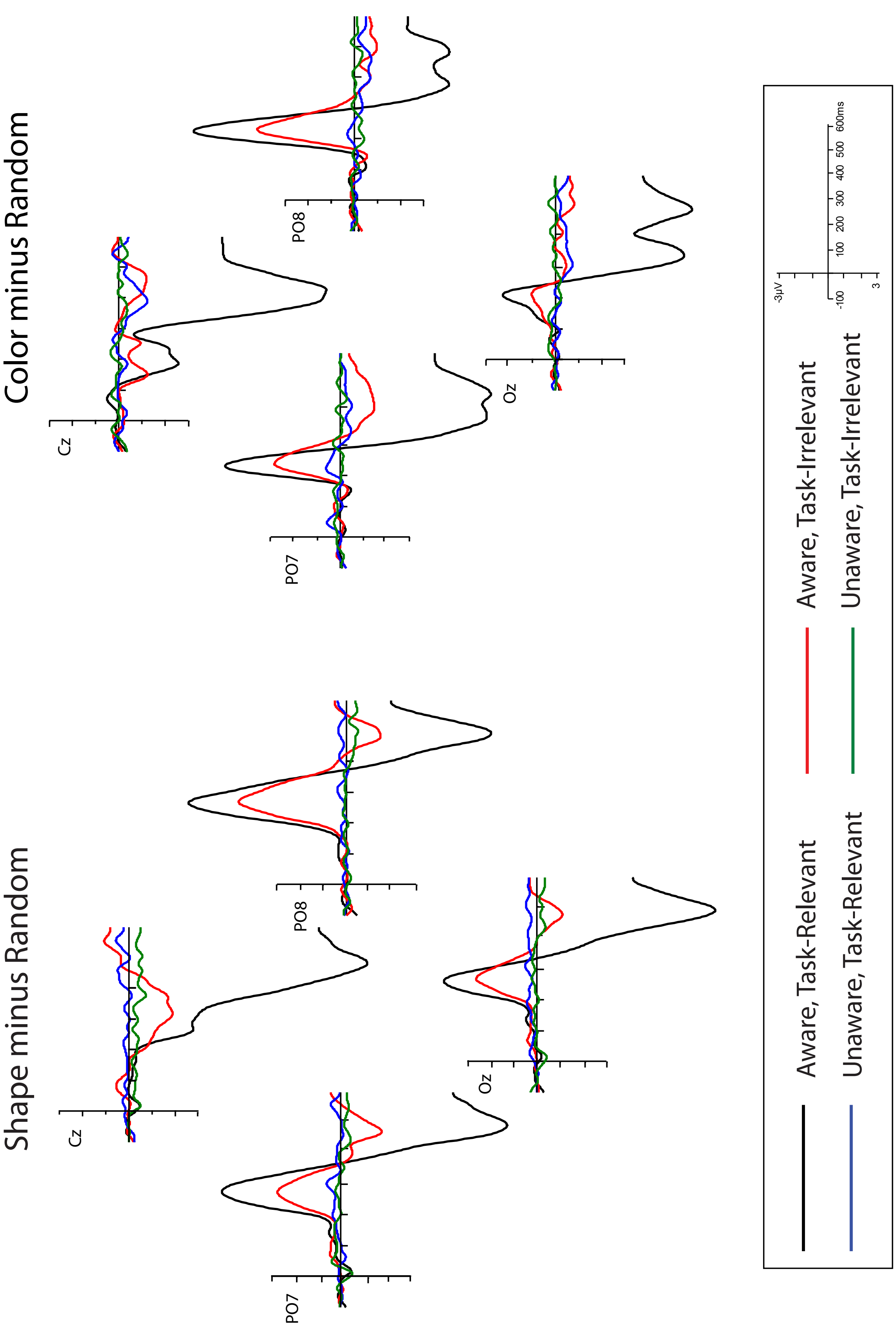
1 = never
2 = rarely / less than five times
3 = infrequently / 5-15 times
4 = frequently / 15-30 times
5 = very frequently / more than 30 times

Diamond	1	2	3	4	5
Square	1	2	3	4	5

Appendix B: Electrode Locations



Appendix C: Target Difference Waves



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