Coloring Consciousness:

Exploring the Neural Correlates of Conscious Perception by Manipulating Awareness of Color

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Abstract

The neural correlates of consciousness (NCCs) continue to be debated as researchers disagree about what awareness truly is and how conscious perception takes place. This study aimed to index proposed NCC components in a three-phase inattentional blindness paradigm. We compare conditions in which subjects were unaware of task-irrelevant color (phase I) vs. aware of task-irrelevant color (phase II), and aware of task-irrelevant color (phase II) vs. aware of task-relevant color (phase III). In phase I, 58% of subjects did not report seeing color, but demonstrated trending event-related potentials (ERP) revealing a possible signature of non-conscious sensory processing of color. ERP data also revealed an attention effect measured by the N2pc in phase III, but not in phase II, even though subjects reported consciously perceiving the color stimuli in both phases. Contrary to our predictions, the VAN component did not significantly correlate with the onset of conscious perception, but we anticipate that with more data this hypothesis would be supported. Similar to the N2pc, the P3 component was found only in phase III, when the color stimuli were task-relevant, indicating that it is not a well-qualified contender for an NCC. These findings indicate that the brain may "see" things we are not paying attention to, nor are we aware of.

For Emma and Ethan, the strongest, silliest, most brilliant people I know.

And for my two steadfast supporters,
who inspired my curiosity and wonder.
You paved my path to psychology
with love and respect, Mom and Dad.

Chapter 1

Introduction

1.1 Approaching Consciousness

The depths of the ocean's floor and the reaches of outer space remain mysterious, still yet to be completely explored. The sheer distance that separates us from these places justifies, in part, our difficulty accessing the information they have to offer. Another remaining scientific frontier is the brain, which rests suspended in cerebrospinal fluid within each of our skulls. It is an organ so critical, so closely related to our selves and yet much of what the brain does and how it does it remains a mystery that scientific inquiry is still working through. In particular, one of the central mysteries lies in how the electrical firing of populations of neurons gives way to the conscious experience of humans. The inherently subjective nature of consciousness has led the scientific community to mostly avoid investigating it. Philosopher David Chalmers observes, "conscious experience is at once the most familiar thing in the world and the most mysterious," (Chalmers, 1996, p. 3). We each have consciousness, each have personal experiences that are our own, but the inner-workings of how these experiences are generated is foreign to us.

With such an elusive topic, definitions are hard to come by. However, the following definition from The International Dictionary of Psychology in 1989 captures the state of the topic at the time: "Consciousness: the having of perceptions, thoughts and feelings; awareness. The term is impossible to define except in terms that are unintelligible without a grasp of what consciousness means…Nothing worth reading has been written about it" (Sutherland, 1989). Since this definition was published, a great deal has been written about consciousness and much of it is worth reading. The present thesis is certainly about consciousness and it strives to be worth reading.

There are two primary ways we talk about consciousness. They can be distinguished by defining them as intransitive and transitive (Dehaene, 2014). Intransitive consciousness refers to a type of mental state. One way we conceive of these states is to refer to them as ‘levels’ of consciousness, for example, sleep, wakefulness, vegetative or comatose states, altered states such as hypnosis and drug-induced states, etc. In everyday life, most consider our normal waking state to be “conscious.” Transitive consciousness, on the other hand, refers to content. For example, I am conscious *of* the sound of geese outside my window. The distinction boils down to *being* conscious as opposed to being conscious *of* something (Dehaene, 2014). In this thesis, the focus will be on the transitive use of the term “consciousness,” the moment-by-moment content of our subjective awareness.

1.2 Philosophy of Mind

Consciousness defines the individual human experience. It provides our lives with texture. We might perceive the same things, but in different ways. This subjectivity can be considered an enriching quality and also an obstacle in sharing experience. If two people look at the Pacific Ocean, are they having the same visual experience? Does the color that you and I both call blue look the same to both of us? And if there is a difference between our perceptions, are we able to properly communicate that to each other? Philosophy of mind deals with problems such as these.

Consciousness is a crucial element that comprises the essence of the felt experience of life. This felt experience is composed of subjective content. For instance, riding a bicycle is an activity that consists of the same physical actions for most everyone who does it. But when someone asks me, “what is it like to ride a bike?” their question is not answered if I explained the process of putting on a helmet, holding handlebars and pedaling. They are asking what it f*eels* like. Philosophers of mind refer to this subjective content as qualia, the what-it’s-like of an experience. Philosopher Thomas Nagel describes qualia as the subjective character of experience (Nagel, 1974). Daniel Dennett summarizes the field’s definition by stating that qualia are “ineffable,” “intrinsic,” "private," and "directly or immediately apprehensible in consciousness" (Dennett, 1988). So what creates the experience of these private and intrinsic qualia?

René Descartes looked for the mind in the skull. He found that all the structures of the brain were duplicates—one in each hemisphere—except for the pineal body, which he determined was the location of the soul, the essence of each individual (Graziano, 2013). Although he was incorrect, he has been historically accredited with being the first to connect the brain with this felt experience of life. Many philosophers of mind stand opposed to any theory that uses brain activity to explain consciousness—a school of thought known as reductionism—because it takes this incredible, rich experience and boils it down to cells firing in the brain. For some philosophers, this is unacceptable, but others are open to the goal of explaining our subjective experience, our qualia with neural activity.

Many theories of consciousness have attempted to account for the phenomenon of consciousness by pointing to the brain and proclaiming that they have found the source of conscious experience (Graziano, 2013). This is essentially like someone "explaining" the magic trick of pulling a rabbit out of a hat by pointing to the hat and saying, "that is where the trick happens." We want to know *how* consciousness happens. Pointing to where is simply not enough to satisfy this inquiry (Graziano, 2013).

Philosopher David Chalmers has a tall order for a theory of consciousness. He states that a good one should, "give the conditions under which physical processes give rise to consciousness, and for those processes that give rise to consciousness, it should specify just what sort of experience is associated…, explain *how* it arises, so that the emergence of consciousness seems intelligible rather than magical" (Chalmers, p. 5, 1996). Though this is difficult to deliver, several recent theories have been proposed and this thesis will summarize their contributions, with a particular focus on explaining the neural basis of conscious visual content.

1.3 Attention, Awareness, and Conscious Perception

Terminology

This section will attempt to settle the confusion that often accompanies discussions of consciousness, awareness, and attention, as the three are conflated and occasionally treated as synonymous. The world around us is rich with information. Everywhere we look there is sensory input to perceive. Attention works by a process of selecting a subset of these competing sensory signals for more detailed perceptual and cognitive processing. When we visually examine a scene in front of us, there is an overload of content. The brain, though an extremely powerful computational system, has limited resources for processing this information. The whole scene cannot possibly be given equal processing energy. Due to biological constraints, a brain that fully processed every bit of visual information in a scene would likely not fit inside our skulls. The information in the visual field competes for attention. When one signal captures attention, others are suppressed; when one signal is deemed behaviorally relevant by the organism, it is enhanced while other signals are filtered out (Figure 1.3a).

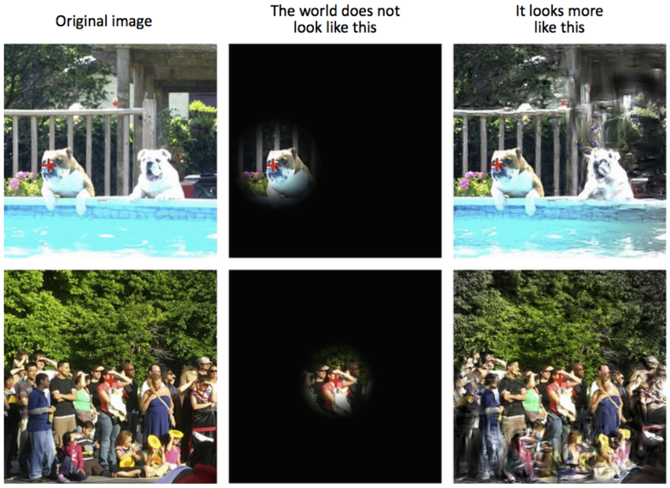


Figure 1.3a. Selective attention's role in visual processing of a complex scene
The red crosses indicate where one's eyes might be fixed in a given perceptual moment. The images in the left column are rich and contain full detail (this is how we think we see). When we are attending to a small portion of a complex visual scene, the rest of the world does not disappear as shown in the center column of images. The right column illustrates a model of how we likely do see the world. The aspect of the scene we attend to is rich with detail while the rest of the scene, though still present in our visual field—is not. Figure adapted from Cohen, Dennett, & Kanwisher (2016).

The definition of awareness—a term often used interchangeably with "consciousness"—is more controversial. A number of neuroscientists who study consciousness in the lab have operationally defined awareness as reportable subjective content. If I am aware of something, I should be able to describe it, describe *something* about it, or even just be able to articulate the fact that I saw something at all (Dehaene, 2014). Some believe that awareness is a necessary prerequisite for attention (Lamme, 2006), others believe that attention is necessary for awareness (Dehaene, 2014), and still others believe that awareness is not a process itself, but rather a piece of information that is generated when the process of attention is modeled by a separate second-order mechanism (Graziano, 2013). In this thesis, the terms, "conscious perception" and "perceptual awareness" are used interchangeably to mean the experience of seeing something and being able to report on its presence. In terms of the definition, I will be adopting Dehaene's (2006) concept of awareness.

Neuroanatomy

Over the course of this thesis, I will be discussing areas of the brain and before that begins, I would like to orient the reader to some of the relevant jargon. Figure 1.3b illustrates the human brain oriented as though the person whose head it is hypothetically inside is facing to the left. The blue area is referred to as the frontal lobe. This area is located behind the forehead and it extends about halfway to the back of the head, when the parietal lobe begins, illustrated as the yellow area in Figure 1.3b. Behind the parietal lobe and colored pink below, is the occipital lobe at the very back of the head. The occipital lobe is the location of the visual cortex and thus, where much of the current study's data was recorded from. The green area illustrated in Figure 1.3b is called the temporal lobe, so called because it is the area that extends from beneath the temples on either side back to the very back of the brain where it meets the occipital lobe. The frontal lobe is referred to as an anterior area because it is located forward on the head and the occipital, on the other hand, is the most posterior (or toward the back) area of the brain. These terms will be used to orient the reader to where electrical activity of the brain was recorded by electroencephalography (EEG).

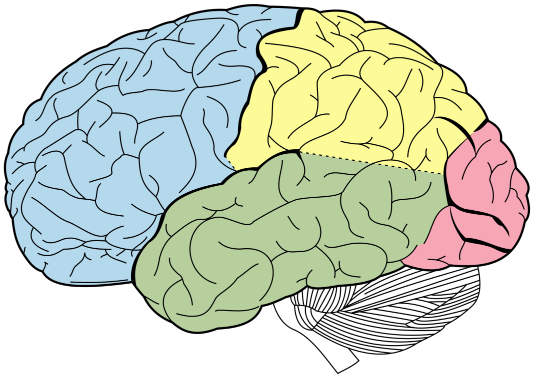


Figure 1.3b. The lobes of the brain

The blue area illustrates the frontal lobe, the yellow represents the parietal lobe, the red area shows the occipital lobe at the back of the head, and the green area is the temporal lobe, located on the very sides of the brain behind the temples and extending back behind the ears. Retrieved from https://en.wikipedia.org/wiki/File:Lobes_of_the_brain_NL.svg.

Dominant theories of consciousness

There are two main schools of thought that address the neural correlates of conscious perception, The Global Neuronal Workspace Theory (GNWT) currently supported most famously by Stanislas Dehaene (introduced originally by Bernard Baars, 1983), and the Recurrent Processing Theory (RPT), introduced by Victor Lamme (2006). Additionally, a more recent theory of consciousness and the brain called the Attention Schema Theory (AST) has been proposed by Michael Graziano (2013).

Global Neuronal Workspace Theory

The global workspace hypothesis was proposed by Baars in 1983 (Sergent & Dehaene, 2004), but its major contemporary proponent is Stanislas Dehaene. It is now formally referred to as the global neuronal workspace theory (GNWT). The GNWT argues that conscious perception happens by way of an ignition of activity that spreads across a widespread neuronal network relatively late in processing following stimulus onset, at ~400 ms. According to Sergent & Dehaene (2004), there is a set of "workspace neurons" that take in and maintain the consciously perceived information, making it available to many other neural processes. The brain is demonstrably modular and this makes it difficult for us to imagine how we could have access to so many attributes of a percept simultaneously (Sergent & Dehaene, 2004). The GNWT posits that after stimulus presentation, there is first 100 - 300 ms of feedforward and localized feedback (e.g. within the occipital lobe) before some of the perceptual content (whatever is selected by attention) enters the global workspace which is marked by wide-spread (particularly fronto-parietal) recurrent processing. Once the content is in the global neuronal workspace, it is accessible to processes such as feature selection (i.e. identifying and attending to a particular aspect of an object or percept). There is long distance synchrony between populations of neurons that makes up this global activity (Sergent & Dehaene, 2004).

The proposed workspace neurons are a microcosm of Dehaene's concept of conscious access. He posits that there is a limited amount of information that we report having perceived and that this information is a subset of a slightly larger body of information in the global neuronal workspace that can be utilized by different cognitive processes.

Dehaene holds the view that we see far less than we believe we do and that our brain processes more information unconsciously than we would expect (Dehaene & Naccache, 2000). He and philosopher Daniel Dennett (2007) agree that our understanding of what we perceive is an illusion, that our conscious experience is not nearly as rich as we would like to believe. If we are not able to report on what we see, then we must not really be experiencing it (Dehaene, 2014).

Recurrent Processing Theory

Lamme's (2006) theory takes visual hierarchy into careful consideration as a means of examining conscious perception. He equates conscious visual perception with "seeing" and this is noteworthy. Before beginning to discuss Lamme's theory, it is important to address this stress on the visual domain. At this point in time, studies of the neural correlates of consciousness have leaned heavily toward the visual sensory modality. This is the case for a reason, and it is the very reason Lamme stays so close to the discussion of visual processing: simply that we know more about visual perception than we do about other sensory modalities. Using vision is a way to limit the unknowns involved in the study. The general hope is that by focusing on one sensory modality, we can gradually discover a robust set of principles that will likely generalize (with a few modifications) to all other sensory modalities.

The visual system processes information through feedforward and feedback mechanisms. Initial activity travels through the layers of the visual system in a feedforward manner, from the retina through the thalamus to the visual cortex in the occipital lobe where it travels through areas that process different attributes of an object or scene (e.g. color, motion, shape, etc.). Once the feedforward sweep reaches the primary visual cortex and all levels above, feedback signals are sent from higher- to lower-level areas (e.g. from V4-to-V2, from V2-to-V1, from V1-to-thalamus, etc.), followed by subsequent volleys of delayed feedforward processing. Recurrent processing (RP) refers to feedforward and feedback loops that start at around 100 ms following stimulus presentation. RP can be localized (i.e. within a few adjacent visual cortical areas) or widespread (e.g. between frontal and parietal areas). Data have consistently shown that localized RP in the visual cortex works to integrate discrete bits of information into a unified percept (Lamme, 2010). In terms of conscious visual perception, Lamme takes a more phenomenal approach than Dehaene and has a more liberal view in terms of the amount of visual information we can consciously perceive at any given moment. This differs markedly from GNWT, which posits that we are only ever conscious of a few things at a time and that our subjective impression of a rich visual world is an illusion (created partially by our ability to rapidly shift our eyes and explore various aspects of the visual scene, and our memory and expectations based on prior experience). Lamme believes that we have rich conscious representations of what we see, but that they are not maintained in memory and are therefore often unavailable for report. The RPT finds that the brain activity correlated with conscious perception of a stimulus occurs on the earlier side, approximately 150 ms after stimulus presentation, as opposed to the late wave of activity posited by GNWT at >300-400 ms.

One critical difference between the GNWT and the RPT is that they may be coming from different views of what consciousness really is. Dehaene uses the term, “access” to refer to conscious perception. Lamme discusses seeing as the manifestation of “phenomenal” consciousness, at least that of visual conscious perception.

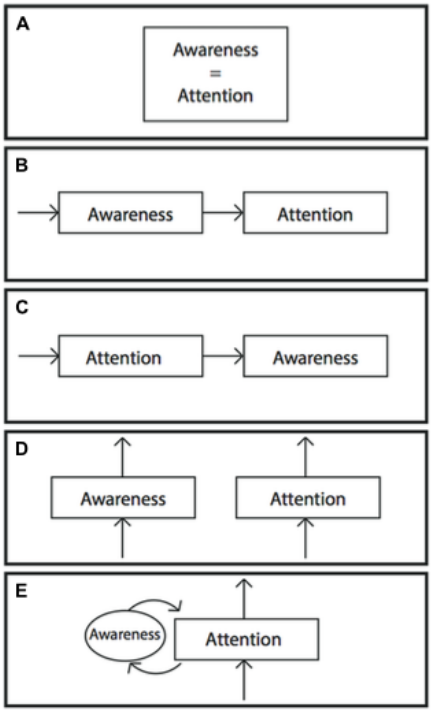


Figure 1.3c. Relevant models of the relationship between attention and awareness
Each panel illustrates a relevant hypothesis about the relationship between attention and awareness, such as A) that the two are the same process, as many have historically argued, B) that awareness comes before attention, as Lamme argues, C) that attention comes before awareness, as Dehaene argues, D) that the two processes occur independently of each other, as Tsuchiya & Koch (2015) argue, and E) awareness is a piece of information describing attention, which illustrates the positon of Attention Schema Theory, as argued by Graziano. Figure adapted from Graziano & Webb, 2015.

Attention Schema Theory

A theory called the Attention Schema Theory (AST), established by Michael Graziano (2011) offers a new perspective to the discussion. It is more of a social theory of consciousness, not addressing the neural correlates thereof in terms of ERP data, but its purpose and function in human beings.

In this theory, Graziano proposes a potential purpose for consciousness. As many philosophers and psychologists have noted, consciousness seems epiphenomenal because presumably, we could carry out all the actions we need to in order to survive without having an accompanying subjective experience. Graziano proposes that subjective awareness is advantageous because it allows us to observe and interpret the focus of attention of other organisms—whether they be of our species or another—and this same process of representing (modeling) the allocation of attention, once turned in towards our own mind, provides a useful means for predicting our own behavior. For example, if I am a hunter and I see that the deer I am pursuing is not looking at me, I can safely assume that it is not aware of my presence. In my own experience, when I am paying attention to something nearby, I typically look at it and acknowledge it at least for a moment. When the brain models this process of attention (similar to how the brain creates a simplified model or "schema" of our own bodies), additional information is generated and this information can be useful for other cognitive systems, for example, predicting behavior. Awareness can then give feedback to attention, directing it to the relevant stimulus. In Graziano's theory, awareness is a simplified perceptual model of attention, and this "attention schema" can be used to enhance my understanding of my own experience as well as to better understand and predict the behavior of other organisms. Importantly, awareness or the "attention schema" can then influence what we pay attention to.

One of René Magritte's most famous works, "The Treachery of Images" (Figure 1.3d) is an oil painting of a pipe and below the image is a caption that reads, "Ceci n'est pas une pipe," which translates to, "this is not a pipe." This statement calls attention to representation by acknowledging the fact that the painting depicts a pipe, but it is not a pipe itself. This is essentially the way Graziano sees awareness, as a representation of attention. Awareness is not attention itself, but it is a schema thereof. It is how the brain describes our current focus of attention and the attention of others. When we recall a person or a memory, that person is not inside our brain and the events of the memory are not recurring inside our heads. Rather, our brain contains rough sketches of these things, simplified versions to represent them efficiently (Graziano, 2013).

Figure 1.3d. Rene Magritte's "The Treachery of Images"
In Graziano's book on the Attention Schema Theory, he posits that awareness is a piece of information representing attention rather than a process in itself, just as this painting is a representation of a pipe, not a pipe itself. Retrieved from http://collections.lacma.org/node/239578.

1.4 Isolating Consciousness

The 3-NCC Problem

In the process of searching for an understanding of the neural basis of consciousness, some in the field have adopted the strategy of first looking for patterns of brain activity that consistently correlate with reported subjective experiences. These sought-after neural patterns are called the neural correlates of consciousness (NCCs). Christof Koch defines the NCCs as the "minimal set of neural events jointly sufficient for a specific conscious experience (given the appropriate enabling conditions)" (Aru et al., 2012).

The initial method employed by researchers interested in what was expected to be the (singular) NCC is called contrastive analysis. This technique consists of maintaining very similar—if not identical—physical stimuli while varying the conscious perception or (lack thereof) of these stimuli. By varying conscious perception while maintaining constant physical stimuli, the technique intended to find the NCC without the confounds of unconscious processes that go along with target perception that would be found in both aware and unaware conditions. While this is undoubtedly a logical way to limit confounds and isolate the processes we seek, it has yielded highly variable results (Aru et al., 2012). It has become clear after much work with contrastive analysis that this method does not target exclusively the instant of conscious perception, but also some very closely entangled processes (Aru et al., 2012). However, this does not mean it cannot still be employed to explore the NCCs.

NCCs were initially classified as a single set of processes with discrete correlates of conscious perception. However, after more in-depth investigation, it was found that there is additional activity related to conscious perception that must be accounted for. The first is composed of the *prerequisites* (NCC-pr) that include the activity associated with preparation for the presentation of a stimulus and expectation of what is to come (Aru et al., 2012). The second is composed of the *consequences* of conscious perception (NCC-co). This category includes components that reflect post-perceptual processing of a stimulus. For example, if a subject sees a face, he might identify the face, recognize the emotional expression of the face, store the image of the face in memory, etc. The disentanglement of these different, but tightly related processes involved in interacting with each other and the world that surrounds us is a concrete and attainable way for us to gain an intimate understanding of the neural activity that indexes the instant of perceptual awareness (which some have labelled the NCC–*proper*).

Inattentional blindness

Dehaene (2006) identifies two types of stimuli that do not rise to the level of consciousness. The first is subliminal, which are stimuli that cannot be perceived because of their physical properties (e.g. very dim, low contrast, very brief, or masked by other stimuli), even if attention is focused on detecting such stimuli. The second is preconscious, meaning that the physical properties of the stimuli (e.g. bright, high-contrast, long duration, unmasked) make it possible (and even easy) to perceive, but it is not consciously perceived due to the absence or distraction of attention. The current experiment focuses on the latter. A phenomenon that allows one to measure preconscious processing of physically salient stimuli due to attentional distraction is known as “inattentional blindness.”

In 1992, Mack and Rock discovered that by rendering subjects sufficiently distracted by a task that demands focus, an unexpected stimulus can go completely unnoticed. The results of Mack and Rock's studies led to the hypothesis that conscious perception cannot occur in the absence of attention (Mack & Rock, 1998; Cohen et al., 2012). In other words, attention is necessary for conscious perception.

The inattentional blindness phenomenon is elicited by giving subjects a difficult task and presenting an unexpected stimulus in addition to the stimuli relevant to the task. By rendering subjects sufficiently distracted by a task that demands focus, they can miss some very prominent stimuli. A famous iteration of this paradigm comes in the form of a video of people—half wearing white shirts, half in black shirts—moving around each other and passing a basketball between members of the same team. The video instructs subjects to count the number of times the ball is passed between the players wearing white shirts. Over the course of the task, as the subject focuses on the players moving around each other and passing the ball, a person in a black gorilla suit enters the frame, pounds her chest, and then exits the frame. None of the basketball players acknowledge the presence of the gorilla and the video ends with two questions. The first is the one subjects are expecting: how many times did the white team pass the ball? Then a second question appears on the screen: did you notice the gorilla? Approximately half the subjects who view this video do not notice the gorilla (Simons & Chabris, 1999).

Because it is necessary for inattentional blindness that subjects do not expect the critical stimulus, once they know it will be there, the effect disappears. This means that there is one critical trial per subject, which is a substantial limitation (Mack & Rock, 1998). The current study uses an extended inattentional blindness in order to gain sufficient brain data (to achieve adequate signal-to-noise ratios, many trials were averaged together). We use the phenomenon to examine the differences in neural activity that accompany the perception of the same salient stimuli with and without subjects' awareness of their having perceived them.

The Event-Related Potential Technique and Components of Interest

Each neuroimaging technique offers slightly different advantages. For example, functional magnetic resonance imaging (fMRI) offers information about activity by recording the blood oxygenation level in different regions of the brain, offering excellent spatial resolution. This is advantageous in the localization of brain function. Electroencephalography (EEG)—the technique employed in this thesis—records post-synaptic potentials (i.e. electrical activity) of populations of neurons from electrodes placed on the scalp. EEG data picks up signals from many different sources, including electrical potentials from muscle activity. However, by time-locking to a specific moment of cognitive activity, sensory experience, or motor action, one can find data in the form of electrical potentials related to these moments, or "events," hence the name, "event-related potential" (ERP). The ERPs are recordings of neural activity with superior temporal resolution (Luck, 2014).

This study will analyze four ERP "components" in pursuit of better categorization of the NCCs. In the following sub-sections, I will discuss the known properties of each ERP component and the importance of the component (as a marker of a specific sensory, perceptual, or cognitive process) in the current study. The four components of interest are the SEC, VAN, P3, and N2pc.

The Sensory Effect of Color

In 2003, Schoenfeld et al. discovered an ERP component they called the sensory effect of color (SEC) that indexes early sensory processing of color in human subjects. The component has been shown to be present whether the colored stimulus is attended or unattended by subjects (Schoenfeld et al., 2003). The neural signature of this processing is a positivity beginning at ~100 ms post stimulus-onset and peak of 200 – 250 ms.

While the SEC occurred in the color-attended and color-unattended conditions, difference wave analysis indicated that there was an attention effect on the component (Schoenfeld et al., 2003). This means that when the colored stimuli—in this case, moving dots—were attended by the subject, the amplitude of the wave was significantly higher. Schoenfeld et al. (2003) localized the SEC and the attention effect thereof to a color-selective area of the fusiform gyrus, which is located in the occipitotemporal lobe.

The SEC has not yet been extensively studied, and it has been found with only red stimuli thus far. Due to its presence in both attended and unattended conditions, I hypothesize that it will provide a baseline indication of color processing in all three phases of the current experiment, including during inattentional blindness.

The Visual Awareness Negativity

The visual awareness negativity (VAN) was given its self-evident name for its proposed correlation with perceptual awareness of visual stimuli. It has been reported as an increased negativity at ~200 ms at posterior electrode sites. Visual awareness has also been correlated with increased activity in frontoparietal areas, to which attention effects are often attributed (Koivisto & Revonsuo, 2010). Thus, disentangling awareness and attention continues to be a difficult task. Studies have suggested that the VAN varies independently of attention, but researchers remain uncertain of attention's effect on the VAN component. One study showed that manipulations of spatial attention (e.g. presentation of aware and unaware stimuli in the periphery while attention is focused on the center of the visual field) did not interfere with the VAN's index of awareness (Koivisto & Revonsuo, 2010). However, a serious limitation of this study was its lack of control for rapid shifts of attention from fixation to the periphery (e.g. horizontal eye movements). One thing that has been documented is that the VAN varies independently of stimulus relevance (Koivisto & Revonsuo, 2010). The current study's analysis of the VAN aims to examine the relationship it has with spatial attention and awareness and their interaction with each other.

The P3

The P3 is so-called because it is a late parietal positivity (P) with an onset of ~300 ms. The P3 has been studied extensively and different experimental manipulations have elucidated some interesting effects with regards to this component. For example, the target to target interval (time between target stimulus-presentation) is one factor that determines the amplitude of the P3 component. Longer intervals between targets elicit higher amplitude (Polich, 2012). It has also been demonstrated that the P3 has something to do with resource allocation because when subjects dedicate more effort to the task at hand, the amplitude increases (Luck, 2014).

The current study focuses on the P3's role in conscious perception. This component is the source of some controversy when it comes to the 3-NCC problem. Some researchers have hypothesized that it may be an NCC-proper, indexing the instant of conscious perception (Sergent & Dehaene, 2004). Other studies have presented results that indicate that the P3 does not correlate with conscious perception, but rather correlates with NCC-co or post-perceptual processes (Koivisto & Revonsuo, 2010). In an inattentional blindness study, the P3 was not present when subjects were unaware of the hidden stimuli, and was also not present when subjects became aware of the initially hidden stimuli while completing a task unrelated to said stimuli. The P3 was only present when subjects were aware of the stimuli *and* the stimuli were relevant to the task they were completing (Pitts et al., 2014a; Pitts et al., 2014b). The findings of Shafto & Pitts (2015) also support the theory that the P3 is a correlate of the consequences of conscious perception that take place once subjects are aware of a stimulus and it is relevant to the task at hand. This study's use of the P3 aims to contribute to this controversial debate.

The N2pc

The N2pc is an ERP component that has been associated with selective visual attention. It is so called because it is a negativity (N) in the waveform occurring roughly between 200 and 300 ms after stimulus-onset (2) and it is observed in the posterior-contralateral (pc) electrode channels (Luck, 2014, p. 88). In response to a visual stimulus on one side of the visual field, there is a greater negativity found in the electrodes contralateral to (on the opposite side of) the position of the stimulus. Therefore, if I am attending to a target in the left visual field, there is greater negativity in the right hemisphere of my brain and vice versa. The contralateral nature of this component is thought to correspond to the contralateral organization of the visual system (the right visual cortex processes information from the left visual field and vice versa).

The N2pc's correlation with selective attention is demonstrated by the fact that its amplitude is influenced by the presence of distractor stimuli. When stimuli are salient, but irrelevant to the subject's task, the N2pc is helpful in determining if a subject is attending to them. This component correlates with the focusing of attention in order to locate a target in the presence of distractors (Luck & Hillyard, 1994). This use of the N2pc applies well to the current study.

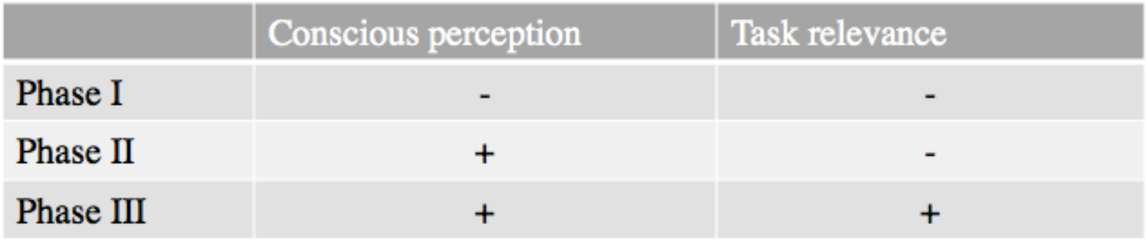
In this study, the N2pc will index whether a subject is attending to the colored squares positioned in the left or right of the changing grey background. Subjects fixated on a point in the center of the screen with colored stimuli appearing in their periphery. When we see this negativity in the left hemisphere, it will indicate that the subject was attending to a colored square in the right side of the grid and vice versa.

1.5 Current Study

Rationale

Color

Shafto and Pitts (2015) conducted a study on which the experimental design of this thesis is based. Their critical stimuli—those of which subjects were initially unaware—were simple line drawings of faces. The goal was to measure the N170, a well-documented ERP component observed upon the perception of a face. These face stimuli appeared in the center of the screen around the fixation point randomly. The N170 was a useful component for this type of study given its robust and reliable effects. One of the main questions asked in Shafto and Pitts' (2015) study was whether the N170, and thus face perception, occurred during inattentional blindness. In keeping with this method of choosing a component that would be clear and robust in ERP recordings, this thesis employs color stimuli and seeks to measure the SEC.



	Conscious perception	Task relevance
Phase I	-	-
Phase II	+	-
Phase III	+	+

Table 1.5a. Indexing conscious perception and task relevance of colored squares
This table describes the comparisons between aware vs. unaware trials and task-irrelevant vs. task-irrelevant color in the grid for the inattentionally blind (IB) group. A "+" indicates presence and a "-" indicates absence of the element listed above each column.

Research questions

Table 1.5 summarizes the overall design of this study. In phase I, subjects were naïve to the presence of color and completed an unrelated distractor task. Some noticed the color stimuli (the "noticer" group) and others did not (the inattentionally blind group). For the inattentionally blind (IB) group, conscious perception was absent and the color stimuli were task irrelevant (as in the top row of Table 1.5). In phase II, after being cued in to the possibility of color being present, the IB group then had conscious perception of the color while still completing the same unrelated task. For the noticer group, nothing changes from phase I to phase II; they remain aware of the color stimuli and continue completing the task to which color is irrelevant. Then, in phase III, subjects all consciously perceived the color stimuli and began completing a task to which the color stimuli were relevant (a color discrimination task).

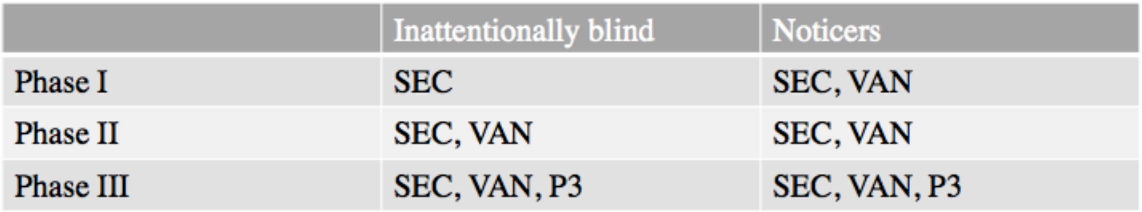
There are three basic questions that drive this thesis. Each question has a corresponding ERP component that was introduced above and relates to the presence (or absence) of conscious perception and task-relevance (or irrelevance) of the color stimuli. These research questions are as follows:

1. Does a subject's brain "see" color when the subject is not conscious of the color's presence in their visual field?

2. Is there a difference in neural activity that correlates with the occurrence of conscious color perception?
3. How does the need to immediately report on what color a subject consciously perceives affect the neural activity that follows this perception?

Predictions

Basic hypotheses



	Inattentionally blind	Noticers
Phase I	**SEC**	**SEC, VAN**
Phase II	**SEC, VAN**	**SEC, VAN**
Phase III	**SEC, VAN, P3**	**SEC, VAN, P3**

Table 1.5b. Basic hypotheses
This table represents the components we hypothesize will be present for each phase by group.

SEC

I predict that the SEC will be present in all phases for all subjects. Previous work with this component has demonstrated that it is found regardless of attention or task relevance. This work has shown that when color is presented to a subject, the SEC component can be found (Schoenfeld et al., 2003). However, to reiterate, in previous studies that have identified the SEC, the color presented was red and it was presented in the center of the screen. The present study differs from these past experiments in that the colors are less salient and are presented peripherally, in the top left and top right of the screen. If these predictions are confirmed, the SEC will be an indication that the subject perceived the colored squares, whether they report seeing them or not.

VAN

Because the VAN has been shown to correlate with visual awareness, we expect to find the VAN in phases II and III in the IB group and all phases in the noticer group (because they will report having awareness of the color stimuli during the first phase). The VAN is expected to correlate tightly with subjective reports of awareness—but not task-relevance of—color stimuli. Therefore, once the IB subjects are cued in to (or aware of) the potential presence of color stimuli in the grid, their neural activity will change accordingly with said awareness.

P3

Due to the recent findings that have demonstrated that the P3 may be better categorized as an NCC-co rather than an NCC-proper due to its tight correlation with task-relevance of time-locked stimuli (Pitts et al., 2014b; Shafto & Pitts, 2015), we also expect to find the P3 component exclusively in phase III of the experiment. If this is the case, then this finding will support the hypothesis that the P3 is present only when critical stimuli are task-relevant.

Attention-specific hypotheses

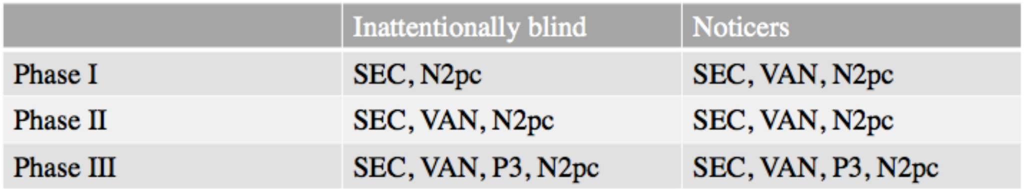
The following predictions are based upon the behavior of the N2pc in the resulting data and the relation of this component to others we will observe (Table 1.5b). The N2pc is correlated with visual attention to lateralized stimuli.

The first possibility is that the N2pc is present in all three phases, even in inattentionally blind subjects. Because the N2pc has been found to denote visual attention, we can take this result as evidence of one particular type of attention without subjective report of awareness (Luck, 2014). When subjects do not report having seen the colored squares, but the N2pc is present, this demonstrates that their brain paid attention to the color despite their lack of awareness. If we find that the N2pc is present in all three phases, then we can speculate that the VAN is not a related component to the N2pc nor are the two conflated.

The second potential outcome is that the N2pc is found in the second and third phases, but not the first in IB subjects. This would indicate that attention varies with awareness, supporting AST's claim that awareness describes attention (Graziano, 2013).

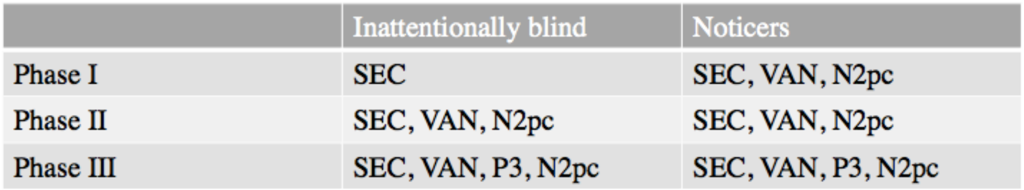
Finally, the third possible outcome is that the N2pc is found only in phase III, when the colored stimuli become task-relevant. This finding might force us to reevaluate the classification of the N2pc and what it indexes. In this case, the particular attentional process indexed by the N2pc and awareness are demonstrably separable (as in the first possible outcome).

C.



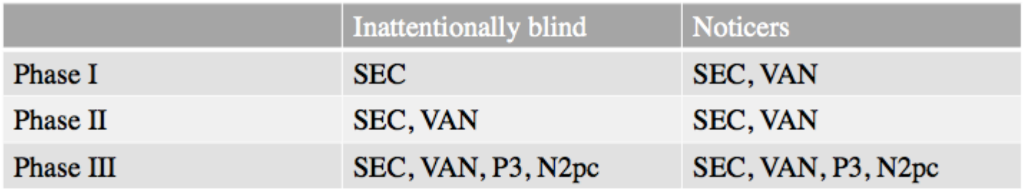
	Inattentionally blind	Noticers
Phase I	SEC, N2pc	SEC, VAN, N2pc
Phase II	SEC, VAN, N2pc	SEC, VAN, N2pc
Phase III	SEC, VAN, P3, N2pc	SEC, VAN, P3, N2pc

D.



	Inattentionally blind	Noticers
Phase I	SEC	SEC, VAN, N2pc
Phase II	SEC, VAN, N2pc	SEC, VAN, N2pc
Phase III	SEC, VAN, P3, N2pc	SEC, VAN, P3, N2pc

E.



	Inattentionally blind	Noticers
Phase I	SEC	SEC, VAN
Phase II	SEC, VAN	SEC, VAN
Phase III	SEC, VAN, P3, N2pc	SEC, VAN, P3, N2pc

Table 1.5c-e. A breakdown of the three possible outcomes with regard to the N2pc C) the N2pc is present in all three phases in both groups, D) it is present in phase I for noticers and only phases II and III in IB, and E) it is present only in phase III for both groups in which the color becomes relevant to the subjects' task.

Chapter 2

Methods

2.1 Participants

23 healthy, right-handed Reed College community members (11 female, mean age = 20.83, SD = 2.37) with normal or corrected-to-normal vision gave informed consent to participate in this study. Compensation for participation included five tickets for a Reed College psychology department-run lottery with a $50 prize. Three subjects were excluded from data analysis because they did not fit the criteria for either group. One subject was excluded due to a report of colorblindness to purple during the study. One subject was excluded from behavioral analysis due to a disproportionately poor performance on phase III's color discrimination task despite having no history of color blindness. This subject's ERP data were still analyzed. 19 subjects were analyzed after exclusion (9 female, mean age = 20.84, SD = 2.29, none colorblind). All procedures were approved by the Reed College Institutional Review Board.

2.2 Stimuli and Tasks

The computer screen was black with a white fixation point (0.16° visual angle) in the center of a 1,012.8 x 1,012.8 pixel grid. This grid (21.2°) was composed of 400 squares (0.82°) with black lines outlining the columns and rows (Figure 2.2a). Each square was pseudo-randomly assigned a shade of grey with luminance between RGB 50, 50, 50 and RGB 200, 200, 200, incremented in steps of 10 (16 possible luminance values; mean = 125, 125, 125). The grey assignment of each square was randomized, but this randomization was restricted such that no adjacent squares could be assigned the same shade. Three concentric white rings overlaid the grid, each of which had 4 equidistant white circles on them. The inner ring had small circles (0.82°), the middle ring had medium circles (1.23°), and the outer ring had large circles (1.64°). These circles revolved clockwise or counterclockwise (alternating at the beginning of each block) around the fixation point in the center of the grid on their respective rings, like planets in orbit (13.84 rotations per minute, 18.45 rotations per block). Stimuli were programmed and presented with Presentation software (Neurobehavioral Systems, San Francisco, CA) on a Dell SA2311W monitor with a frame rate of 60 Hz.

The initial task was for subjects to respond with a button press whenever they noticed one of the 12 white circles change size (briefly expanding to 140, 160, or 180% of its original size for 300 ms before shrinking back to normal; Figure 2.2b). The ratio of size change (140, 160, or 180%) was determined by subjects' performance on the task during a training phase. Subjects began the task at a very low level of difficulty and advanced to more and more subtle changes in size. While the subject completed this task, the grid in the background underwent two changes per second. First, a long-duration grid was presented for ~700 ms followed immediately by a short-duration grid for 300 ms. This short-duration grid will henceforth be referred to as a trial. Although the term "interstimulus interval" (ISI) typically refers to a blank screen between presentations of stimuli, we refer to the long-duration grid as the ISI. There is no stimulus offset in the traditional sense; the grid remains on the screen throughout each block. Target size-changes of the white circles occurred on 15% of trials and never during the ISI.

During the ISI and short-duration presentation, the shades of grey were reassigned pseudo-randomly to ensure that no adjacent squares had the same shade of grey. Figure 2.2d illustrates the sequence and timing of stimulus presentation.

In 50% of trials, one square took on one of two colors instead of a grey value. The colors presented were teal (RGB: 0,150, 150), henceforth referred to as the color stimulus (presented on 35% of trials), and lavender (RGB: 180, 150, 210), henceforth referred to as the infrequent color stimulus (presented on 15% of trials). The location of this colored square was randomized among 16 possible locations, eight in the upper-right of the grid and eight in the upper-left of the grid (6.95° from fixation). The task relevance of these colors varied depending on the phase, becoming relevant only in phase III.

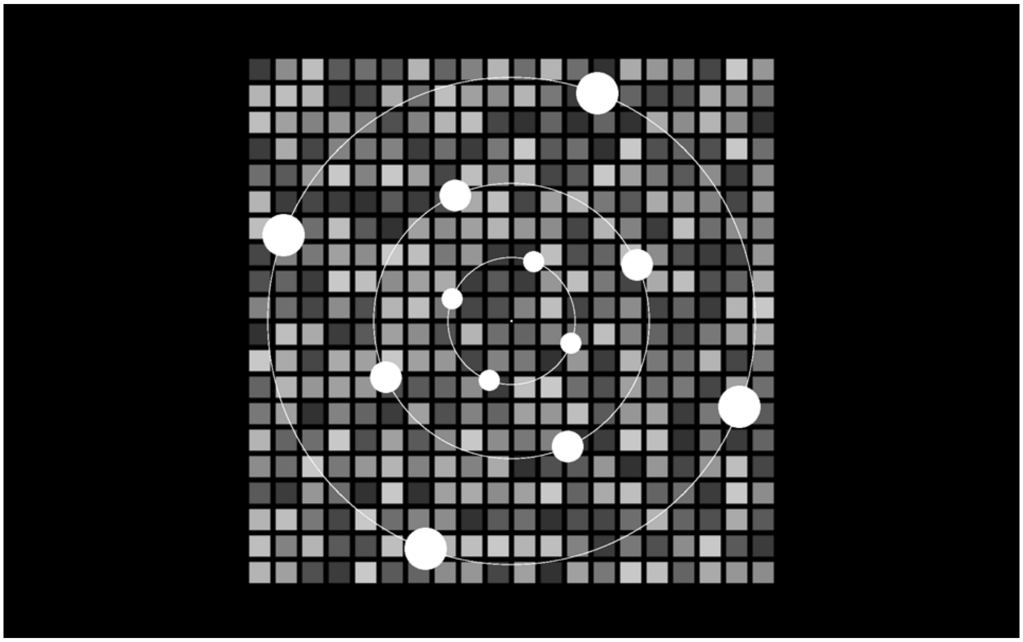


Figure 2.2a. An example of the random grey background (RG) stimuli

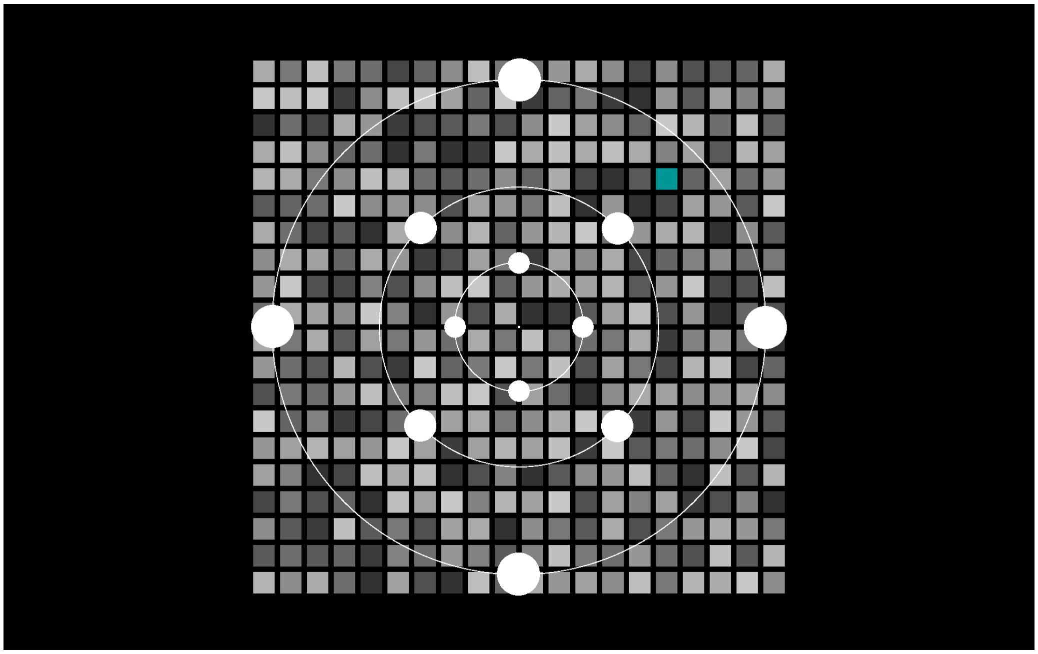


Figure 2.2b. An example of a trial with the color stimulus present.

The color stimulus is the teal square (RGB: 0,150, 150) in the upper-right of the grid.

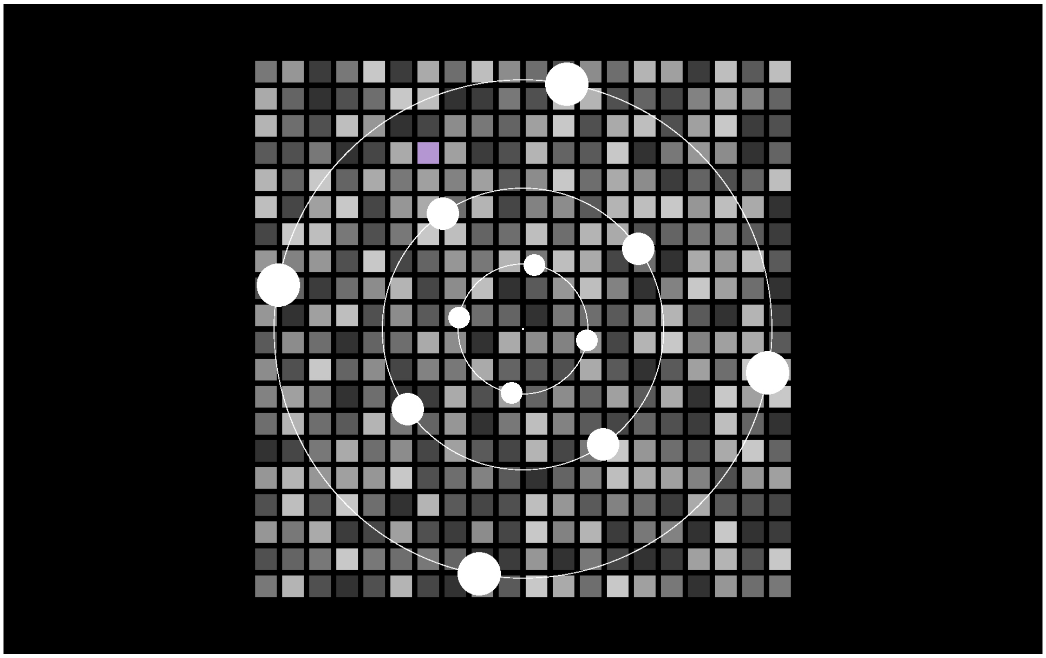


Figure 2.2c. An example of a trial with the infrequent color stimulus present.
The infrequent color stimulus is the lavender square (RGB: 180, 150, 210) in the upper-left of the grid.

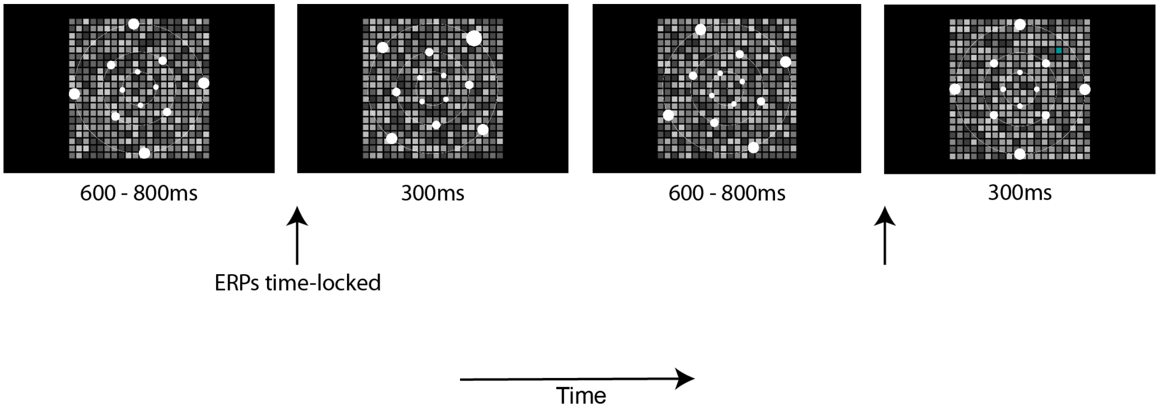


Figure 2.2d. Stimulus presentation sequence
The stimulus on the right shows an example of the color stimulus (teal square) appearing in the upper right of the grid. Vertical arrows indicate the time-locking of ERP data.

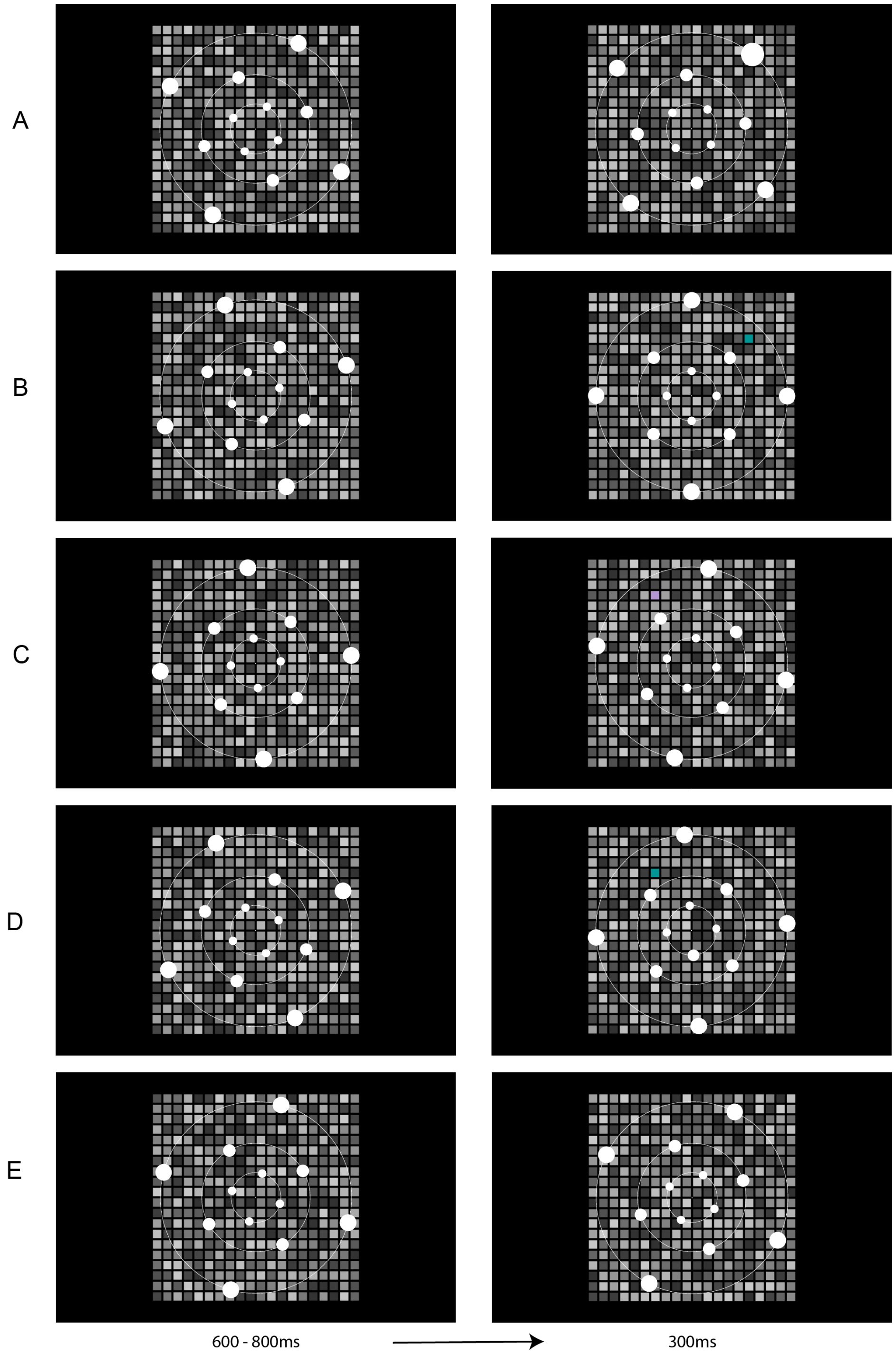


Figure 2.2e. Potential contents of the grid during 300-ms trials

The left column represents ISI random grey grids and the second column represents grids presented during 300-ms trials. Trials could include A) a circle size-change target, B) a color stimulus located to the left or right of fixation, C) an infrequent color stimulus located to the left or right of fixation, D) both a color (or infrequent color) stimulus *and* a size-change target, or E) no color stimuli or size-change targets.

2.3 EEG Apparatus

EEG was recorded with a custom 64-channel Herrsching DE-82211 EASYCAP from the ActiCap System. SUPER-VISC high-viscosity electrode gel was placed and spread on the scalp using syringes topped with blunt-tipped needles. Impedance was adjusted to be below 50 kΩ. EEG was recorded with FCz as a reference electrode and F4 was used as a ground electrode. Data was rereferenced to the average of the left and right mastoids. Electrode signals were amplified by BrainVision "Professional BrainAmp" amplifiers, with a 500Hz digitization rate. Responses were recorded with a Cedrus button-pad, Model RB-830.

2.4 Procedures

Subjects were seated in a sound-attenuated EEG chamber, with eyes ~70 cm from the screen. After being capped, subjects were reminded of their task and then began the training phase. The goal of the training period was to find a comfortable but challenging level of difficulty for the size-change detection task, with accuracy of approximately 60 - 80%. Subjects began training with a few rounds of large and obvious size-changes. The difficulty of this task was then gradually increased by making the size-changes more and more subtle (more difficult to detect) by decreasing the proportion by which they increased in size. On average, subjects completed 6 blocks of training (80 seconds per block) prior to phase I of the experiment. The color stimuli were not presented during any of the training blocks.

The main experiment consisted of three phases. Each phase was composed of 10 blocks, with each block lasting 80 seconds. Trials (meaning the presentation of a grid for 300 ms) occurred once per second with an ISI of ~600 – 800 ms. Therefore, each block contained 80 trials, 28 of which featured the color stimulus, 12 of which featured a size-change target, and 12 of which featured the infrequent color stimulus. The size changes and presence of color were not mutually exclusive in stimulus presentation. In fact, the first five trials of each block were programmed so that they would never feature a color (or infrequent color) stimulus nor a size-change. Subjects were given a short, selfmonitored break following each block and a longer break following each phase. The delay of color and size-change stimuli at the beginning of each block was due to the finding that after a break, especially one in which the subject chats with the experimenter, they are more likely to notice the critical stimuli being hidden (Shafto & Pitts, 2015).

After the first phase of the experiment, subjects were immediately issued a hard-copy of a questionnaire (Appendix A). This questionnaire began with a statement indicating that some participants were randomly assigned to groups that were presented stimuli other than the circles and the grey grid. The questionnaire then prompted the subject to report whether or not they noticed anything else on the screen. The next page of the questionnaire featured questions corresponding to images on the screen depicting example stimuli that were possibly presented. Subjects were prompted to view and evaluate whether or not they saw each one during the first phase of the experiment. One of these images included the grid with the (teal) color stimulus (Figure 2e), one included the infrequent (lavender) color stimulus (Figure 2c), and the remaining three were foils that depicted colors or patterns not actually presented during the experiment (Figure 2a, 2b & 2d). The questionnaire instructed subjects to rate their confidence in having seen each stimulus on a scale of one to five. A second question asked subjects to indicate when they first noticed each stimulus and to estimate how frequently they saw them. This questionnaire helped to determine whether the subject saw the color during the prior phase or not. Subjects were considered "noticers" if they mentioned the color stimulus on the initial open-ended questions *or* if they rated the color stimulus as a 4 or 5 after seeing the example (confident or very confident in having seen it). Subjects were considered "inattentionally blind" if they did not report seeing the color stimulus on the initial questions *and* if they rated the color stimulus as a 3 or less on the scale after having seen the example. Responses to the foil stimuli helped determine whether subjects' reports on the questionnaire were reliable (e.g., if they reported seeing things that were not physically there, their responses to the stimuli that were physically there could not be trusted).

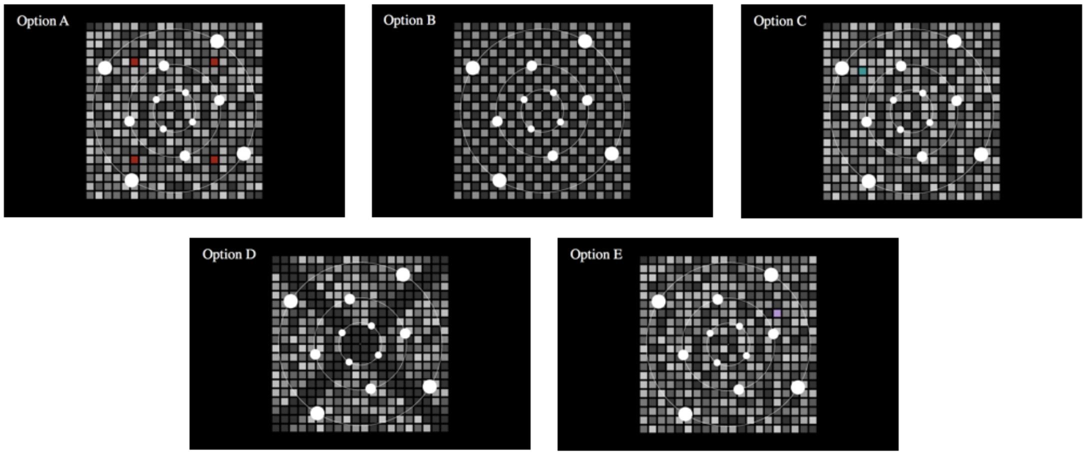


Figure 2.4a. Images presented for confidence ratings on the inter-trial questionnaire.

In Phase II, subjects completed the same task and were given no additional instructions. However, through the questionnaire, the previously naïve subjects were now cued in to the potential for something else to be presented on the screen (why else would the experimenter be asking these questions?), thus increasing watchfulness for the previously unexpected stimuli. After the second phase—which featured identical stimuli to phase I—subjects were issued the same questionnaire again.

Subjects were then given instructions for a new color discrimination task. They were instructed to forego the circle size-change task and instead to respond with a button-press only when they saw the infrequent lavender color in the background grid. Although no overt responses were required to the teal color stimulus, the task in phase III rendered this stimulus task-relevant since a discrimination between teal and lavender was now necessary. After completing the third phase of the experiment, subjects were debriefed and notified of the true research question.

2.5 Data Analysis

EEG data were processed and analyzed using BrainVision Analyzer software (Brain Products, Germany). Artifacts such as blinking, eye movements, and muscle activity were rejected semi-automatically (mean percentage of trials kept M = 85.47%, SD = 7.00). Raw EEG data for each subject were time-locked to the onset of short-duration grid trials and segmented by condition (e.g. phase 1 color-present, phase 1 random grey, etc.) (Figure 2.2d). Data were re-referenced to the average of the right and left mastoids. Epochs (or time-windows) and electrodes analyzed for each ERP component were determined based on published findings.

Chapter 3

Results

3.1 Questionnaire Results

The predetermined criteria to be considered a noticer—those who were aware of the color—were that subjects must either report noticing color on the first question or rate their confidence that they saw the color stimulus as either a four ("confident I saw it") or a five ("very confident I saw it") on the second, recognition-based question. This covers the case in which subjects saw the color, but do not remember seeing it without being reminded by the examples. One noticer subject did not report seeing the color on the first question, but qualified as a noticer through their responses to the confidence ratings on question two. The remaining noticers reported seeing color in response to the initial, free report question.

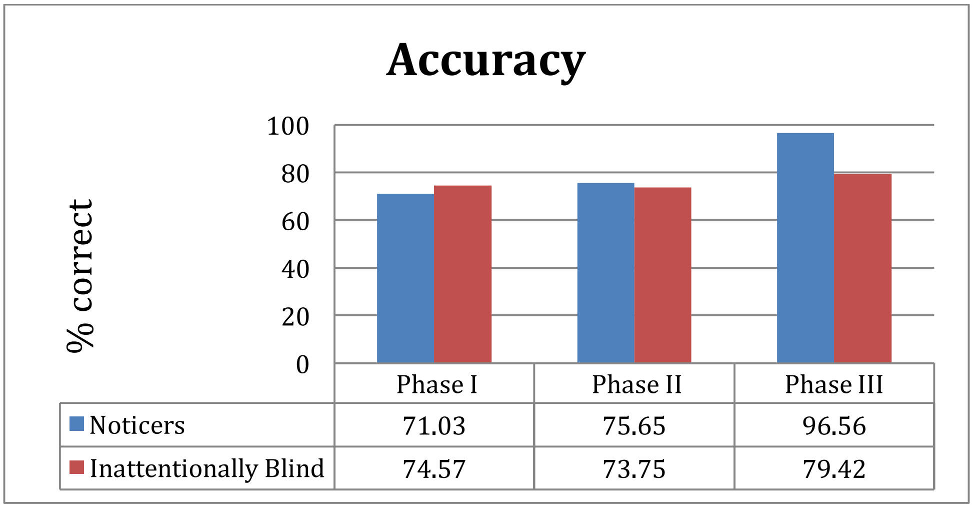
Whereas to be considered IB, subjects must not have reported seeing color in question one and rated their confidence as a three ("uncertain") or below (two: "confident I did not see it", one: "very confident I did not see it"). A typical response to the first question was, "I did not notice anything else." According to these criteria, of the 19 subjects analyzed after exclusion, 11 (58%) were classified as inattentionally blind (IB)

On the second questionnaire, IB subjects' confidence ratings consistently increased to a rating of four or five with the exception of two subjects who were excluded from data analysis due to their failing to report seeing color again in phase II.

3.2 Behavioral Results

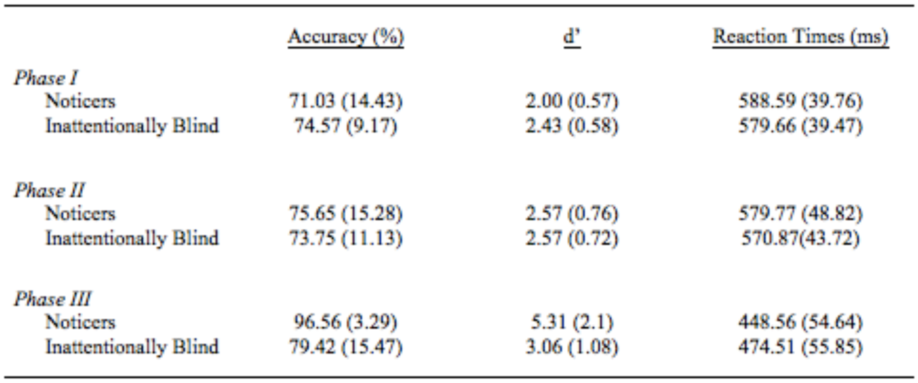
Accuracy

All subjects demonstrated accurate performance with high hit-rates on the size-change detection task in phases I and II and the color-discrimination task in phase III (IB phase I: M = 74.57%, SD = 9.17%; IB phase II: M = 73.75%, SD = 11.13%; IB phase III: M = 79.42%, SD = 15.47%; Noticer phase I: M = 71.03%, SD = 14.43%, Noticer phase II: M = 75.65%, SD = 15.28%; Noticer phase III: M = 96.56%, SD = 3.29%). A one-way ANOVA examining the effect of group on accuracy demonstrated that IB subjects and noticers did not differ significantly in their accuracy $F(1, 16) = 1.45, p = 0.25$ (Table 3.1). However, a one-way ANOVA examining the effect of phase revealed a significant effect of phase $F(2, 32) = 11.94, p = 0.0001$ (Figure 3.2a). A 3 x 2 mixed-model ANOVA comparing phase (phase I, phase II, and phase III) and group (IB and Noticer) revealed a significant interaction effect of group and phase, $F(2,32) = 5.01, p = 0.0128$.



	Phase I	Phase II	Phase III
🟦 Noticers	71.03	75.65	96.56
🟥 Inattentionally Blind	74.57	73.75	79.42

Figure 3.2a Mean hit rates of noticers and inattentionally blind subjects in each phase No significant difference in accuracy between groups, but there was a difference in phase and an interaction effect between phase and group.



	Accuracy (%)	d'	Reaction Times (ms)
Phase I			
Noticers	71.03 (14.43)	2.00 (0.57)	588.59 (39.76)
Inattentionally Blind	74.57 (9.17)	2.43 (0.58)	579.66 (39.47)
Phase II			
Noticers	75.65 (15.28)	2.57 (0.76)	579.77 (48.82)
Inattentionally Blind	73.75 (11.13)	2.57 (0.72)	570.87(43.72)
Phase III			
Noticers	96.56 (3.29)	5.31 (2.1)	448.56 (54.64)
Inattentionally Blind	79.42 (15.47)	3.06 (1.08)	474.51 (55.85)

Table 3.2. Descriptive statistics of behavioral data
Mean accuracy, d', and reaction times and standard deviations (in parentheses) reported for each group in each phase.

D prime

D prime (d') is a holistic descriptive statistic of behavioral performance that takes into account both accuracy and false alarm rate. Larger d' values indicate better performance (i.e. high accuracy and low false-alarm rate) and overall, subjects performed well (IB phase I: M = 2.43, SD = 0.58; IB phase II: M = 2.57, SD = 0.72; IB phase III: M = 3.06, SD = 1.08; Noticer phase I: M = 2.00, SD = 0.57, Noticer phase II: M = 2.57, SD = 0.76; Noticer phase III: M = 5.31, SD = 2.1) (Table 3.2).

IB and noticers did not differ significantly in their behavioral performance, as indicated by a one-way ANOVA analyzing the effect of group $F(1, 16) = 2.62$, $p = 0.1252$ (Table 3.2). A one-way ANOVA demonstrated that there was a significant effect of phase on d' within subjects $F(2, 32) = 25.02$, $p < 0.0001$ (Table 3.2). A 3 x 2 mixed-model ANOVA comparing d' by phase (phase I, phase II, phase III) and group (IB and noticer) revealed a significant interaction effect between phase and group $F(2, 32) = 11.71$, $p = 0.0002$.

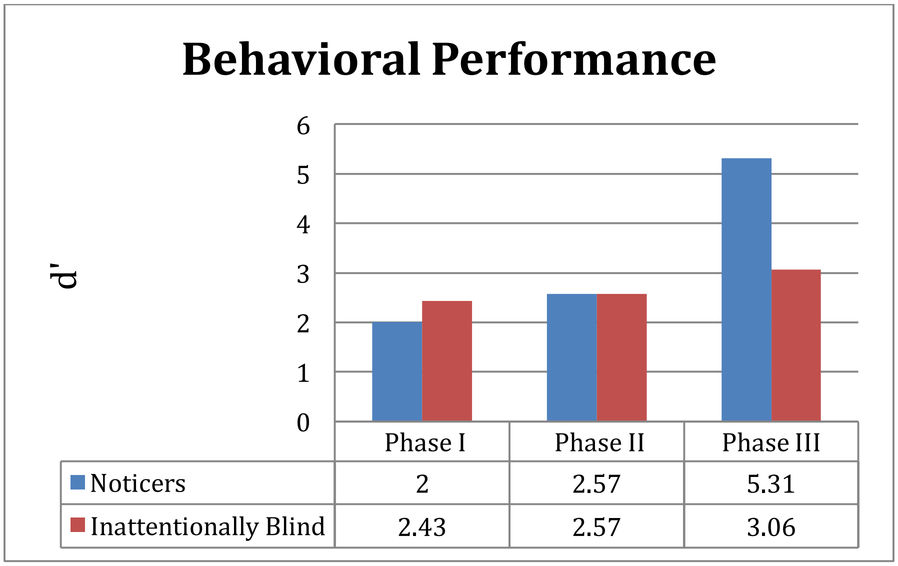


Figure 3.2b Mean d' values of noticers and inattentionally blind subjects in each phase We found no significant difference in accuracy between groups, but there was between phases.

Reaction Time

Reaction times were a normal range for all phases, but were faster in phase III for both groups (IB phase I: M = 579.66, SD = 39.47; IB phase II: M = 570.87, SD = 43.72; IB phase III: M = 474.51, SD = 55.85; Noticer phase I: M = 588.59, SD = 39.76, Noticer phase II: M = 579.77, SD = 48.82; Noticer phase III: M = 448.56, SD = 54.64) (Figure 3.2c).

One-way ANOVAs showed that reaction times differed significantly by phase ($F(2, 32) = 120.16,\ p < 0.0001$), but not by group ($F(1, 16) = 0.02,\ p = 0.8943$) (Table 3.1). Reaction times decreased as the subjects progressed through the phases of the experiment, but the IB and noticers had statistically similar reaction times throughout the experiment (Table 3.1). A 3 x 2 mixed-model ANOVA comparing reaction times by phase (phase I, phase II, phase III) and group (IB and noticer) demonstrated a trending interaction between phase and group $F(2, 32) = 2.60, p = 0.0896$.

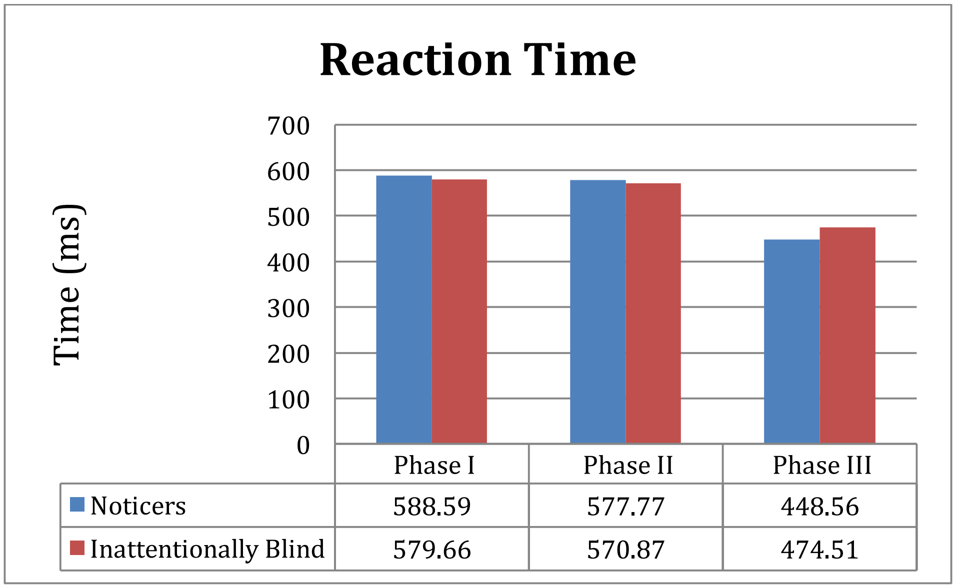


Figure 3.2c. Mean reaction times of noticers and inattentionally blind subjects in each phase

No significant difference in accuracy between groups, but there was a significant difference between phases.

3.3 ERP Data Analysis

For the SEC, VAN, and P3, we analyzed difference waves between the conditions of trials featuring only random arrangements of grey values in the background (RG, for “random grey”) and trials featuring the color stimulus (“color”) in the grid. Mean amplitudes listed refer to the amplitude of these difference waves, indicating whether the ERPs in response to grids with color present were significantly more negative or positive from those in response to grids with color absent. To analyze the N2pc, we subtracted ipsilateral activity from contralateral activity (for color presented to the left and right of fixation separately) and then averaged these values.

SEC Analysis

Analysis of SEC ERPs was conducted at electrode sites POz, O1, Oz, O2, and Iz (Figure 3.3a) at a time-window of 100 – 140 ms post stimulus-onset. We observed an early ERP difference for color compared to RG in the occipital electrodes in IB subjects phases I and III at ~100 ms and in noticers in all phases (voltage was more positive for color) (IB phase I: $t(10) = 1.55, p = 0.15$; IB phase III: $t(10) = 2.21, p = 0.0517$; Noticers phase I: $t(7) = 1.36, p = 0.22$; Noticers phase II: $t(7) = 1.1, p = 0.31$; Noticers phase III: $t(7) = 1.67, p = 0.1396$) (Table 3.3a). This effect is not demonstrated in phase II for IB subjects due to noise in the pre-stimulus interval (IB phase II: $t(10) = 0.5, p = 0.62$), but we expect that given its consistency in phases I and III and in all phases for noticers, it would be present if it were not for the noise blip at time 0.

Due to differences in location of the component, these findings do not directly reflect the SEC as it has been documented thus far, but they demonstrate the occurrence of non-conscious sensory processing of color. For the sake of simplicity, we will still refer to this finding as an SEC. This supports the hypothesis indicating that the brain perceived color in the absence of subjective report of awareness. Although this SEC was only marginally significant in phase III of the IB group and trending towards a significant difference in the other conditions, we believe that with more data, it would be significant in all phases for both groups. A within-subjects ANOVA indicated that for both groups, the difference waves for each phase were not significantly different from each other (IB: $F(2,10) = 1.07, p = 0.3612$; Noticers: $F(2,7) = 0.03, p = 0.8673$).

This positivity was also present at ~450 ms. We suspect that this is a response to the offset of the colored stimuli and onset of the ISI due to a luminance difference between the colored squares and the RG. It is also possible that the non-conscious sensory processing of color we observed is related to luminance rather than color. Given that the amplitude difference between the color trials and RB trials is present at offset in addition to ~120 ms post-onset, it may be a change-related difference. Regardless of what the difference indexes, this finding is evidence of non-conscious response to the difference between a random arrangement of grey values and the presence of a colored square. Whether this is related to luminance, the brain was picking up on a difference between the conditions and this is indication of non-conscious processing of color.

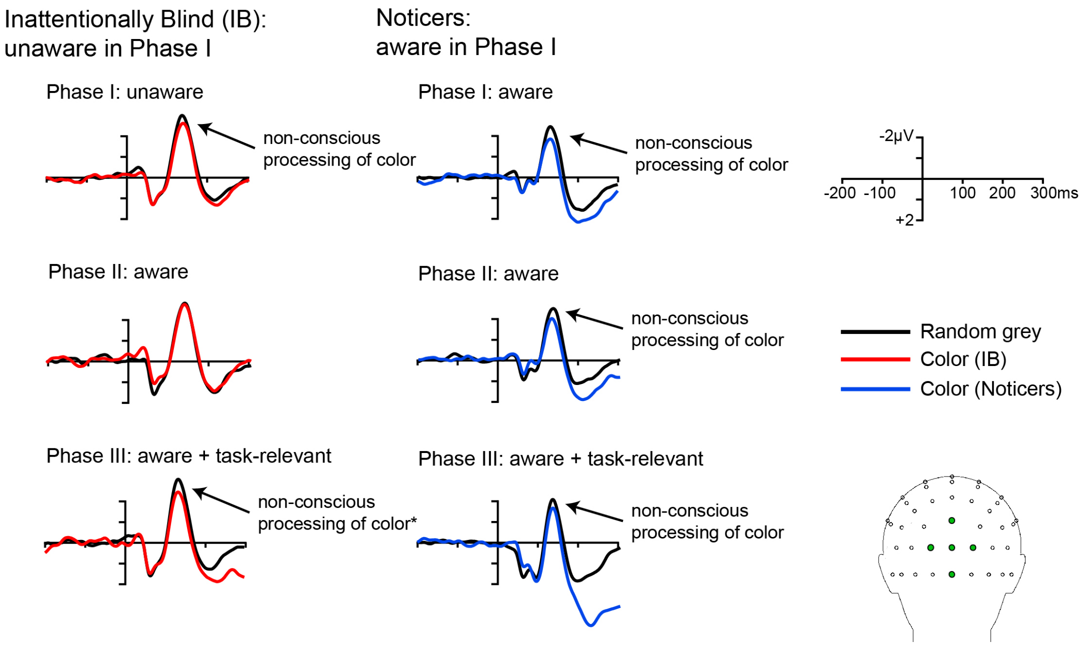


Figure 3.3a. ERPs of SEC in inattentionally blind subjects

Marginally significant presence of the component is indicated by an *. Arrows indicate the presence of a trend that we believe will be significant with more data.

	SEC	VAN	P3	N2pc
Phase I				
Noticers	0.37 (0.77)	-0.06 (0.75)	0.03 (0.74)	0.25 (0.42)
Inattentionally Blind	0.37 (0.78)	0.05 (0.78)	0.31 (0.84)	0.12 (0.34)
Phase II				
Noticers	0.35 (0.91)	-0.11 (0.9)	0.37 (0.94)	-0.06 (0.33)
Inattentionally Blind	0.09 (0.62)	-0.27 (0.89)	0.37 (0.75)	0.02 (0.17)
Phase III				
Noticers	0.42 (0.71)	-1.13 (0.93)	1.21 (0.89)	-0.44 (0.47)
Inattentionally Blind	0.45 (0.68)	-0.39 (0.95)	1.5 (1.26)	-0.53 (0.75)

Table 3.3a. Descriptive statistics of ERP data

Mean amplitude differences (μV) between random grey stimuli and color stimuli for each component and standard deviations (in parentheses) for each group in each phase.

VAN Analysis

VAN data was analyzed from 100 – 300 ms at electrode sites F1, Fz, F2, FC1, FCz, FC2. Figure 3.3b. illustrates ERP data from a single channel created by averaging the activity recorded by each of these electrodes.

Inattentionally Blind Group

A series of univariate single-sample t-tests demonstrated that the VAN was not significantly different from zero in any phase of the experiment (phase I: $t(10) = 0.23$, $p = 0.82$; phase II: $t(10) = -1.00$, $p = 0.3389$; phase III: $t(10) = -1.36$, $p = 0.2037$) (Table 3.3a). A within-subjects ANOVA demonstrated no effect of phase on the amplitude difference between trials that included color stimuli and RG trials, $F(2,10) = 0.62$, $p = 0.5473$. However, Figure 3.3b demonstrates a marked change in negativity for color between phase I and phase II, when subjective report of awareness changes.

Noticer Group

Single-sample t-tests revealed that for the noticer group, the VAN was not present in phases I or II, but was significant in phase III (phase I: $t(7) = -0.24$, $p = 0.8199$; phase II: $t(7) = -0.33$, $p = 0.7479$; phase III: $t(7) = -3.42$, $p = 0.0111$) (Table 3.3a). As demonstrated by a within-subjects ANOVA, phase had a nearly-significant effect on amplitude difference between color stimuli and RG $F(2,7) = 3.11$, $p = 0.0764$.

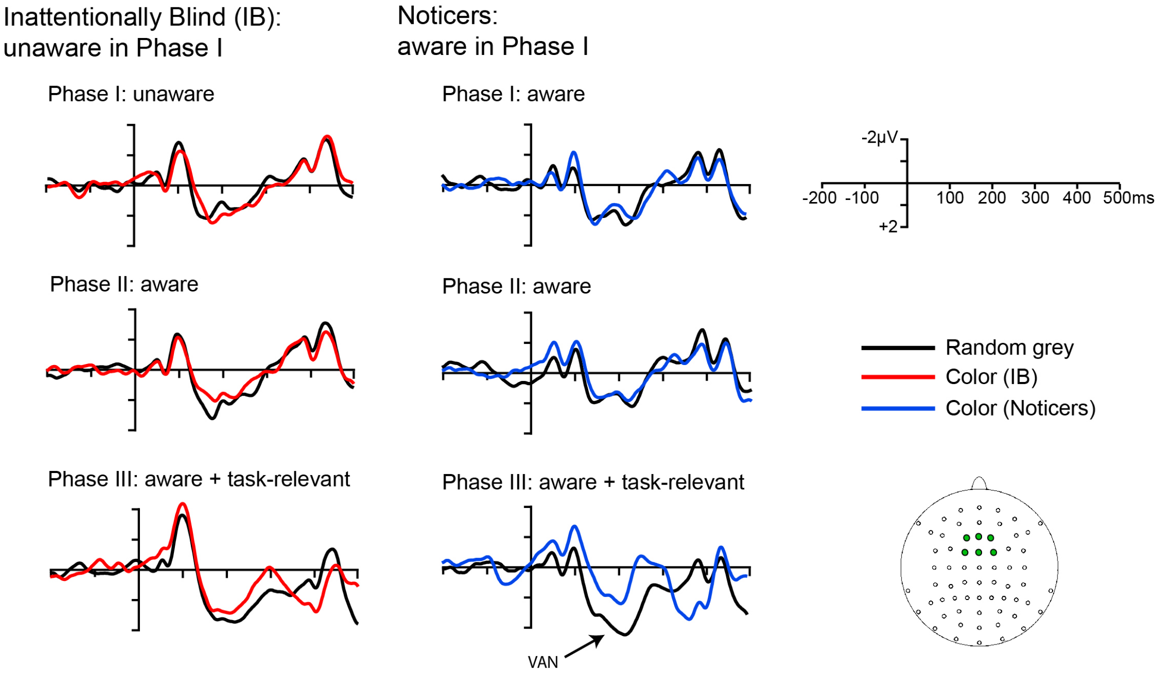


Figure 3.3b. ERPs of the VAN component in inattentionally blind and noticer subjects ERPs measured at electrode-sites F1, Fz, F2, FC1, FCz, and FC2. Significant effects were found only in phase III of the noticer group.

P3 Analysis

The P3 component was analyzed from 350 – 550 ms at electrode sites P1, Pz, P2, PO3, POz, and PO4. As expected, single sample univariate t-tests revealed that for both groups (noticers and IB), color stimuli did not elicit a P3 component in phase I or phase II (IB phase I: $t(10) = 1.25$, $p = .24$; IB phase II: $t(10) = 1.63$, $p = .13$; Noticers phase I: $t(7) = 0.11$, $p = 0.91$; Noticers phase II: $t(7) = 1.12$, $p = 0.3$) (Table 3.3a). However, the P3 showed a robust effect once the colored squares became task-relevant in phase III IB: $t(10) = 3.97, p = .0027$; Noticers: $t(7) = 3.85, p = 0.0063$). A within-subjects ANOVA demonstrated a significant effect of phase on the mean amplitude of difference waves in both groups (IB: $F(2,10) = 9.42, p = 0.0013$; Noticers: $F(2,7) = 4.04, p = 0.0413$).

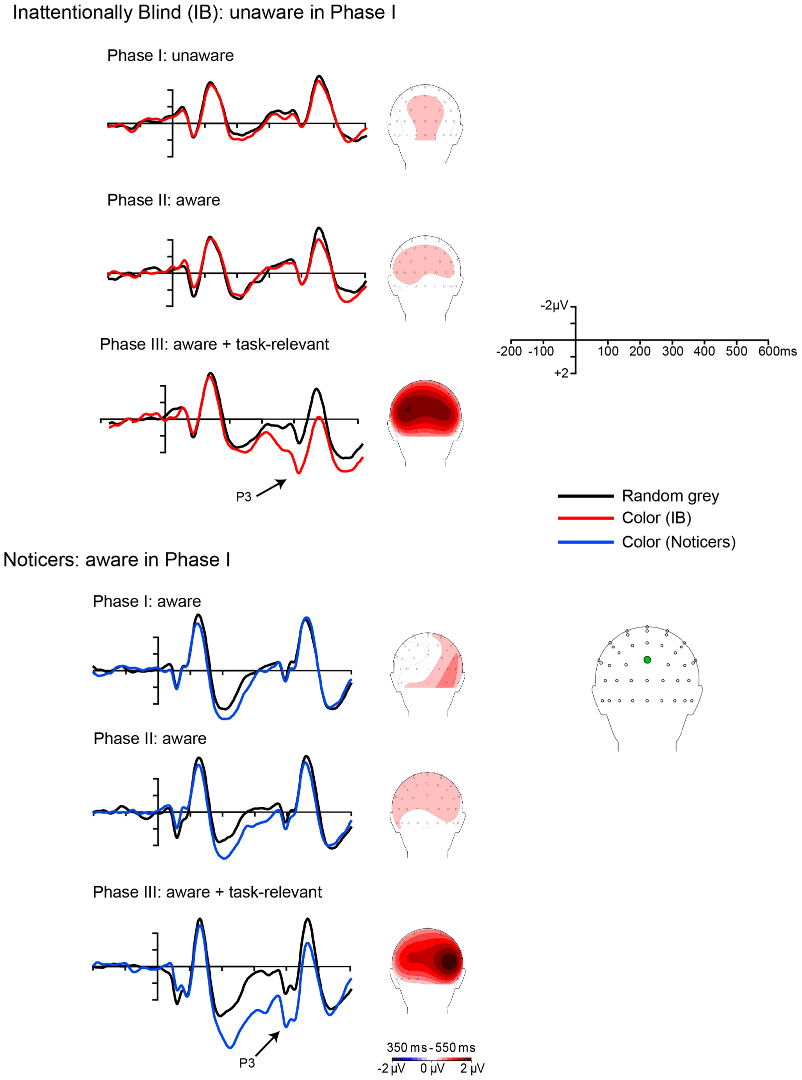


Figure 3.3c. ERPs of the P3 component in inattentionally blind and noticer subjects ERPs measured at electrode-site POz (posterior-occipital on midline) and difference maps.

N2pc Analysis

N2pc data was analyzed from the time-window of 200 – 300 ms at electrode sites PO3, PO4, PO7, PO8, PO9, PO10, P3, P4, P5, P6, P7, P8, P9, and P10 (Figure 3.3f).

Single sample t-tests demonstrated that the N2pc difference waves (contralateral activity - ipsilateral activity) showed a significant difference from zero only in phase III for both IB and noticers. Within-subjects ANOVAs demonstrated a significant effect of phase on the difference wave amplitude of the N2pc, indicating that the three phases differed significantly from each other (IB: $F(2, 10) = 5.39$, $p = 0.0134$; Noticers: $F(2, 7) = 10.43$, $p = 0.0017$) (Table 3.3a).

This means that the type of attention indexed by the N2pc appeared in the data only once the color became task-relevant. This makes sense given the previous finding that the N2pc demonstrates the enhancement and suppression model of attention (Luck, 2014; Jannati, Gaspar, & McDonald, 2013).

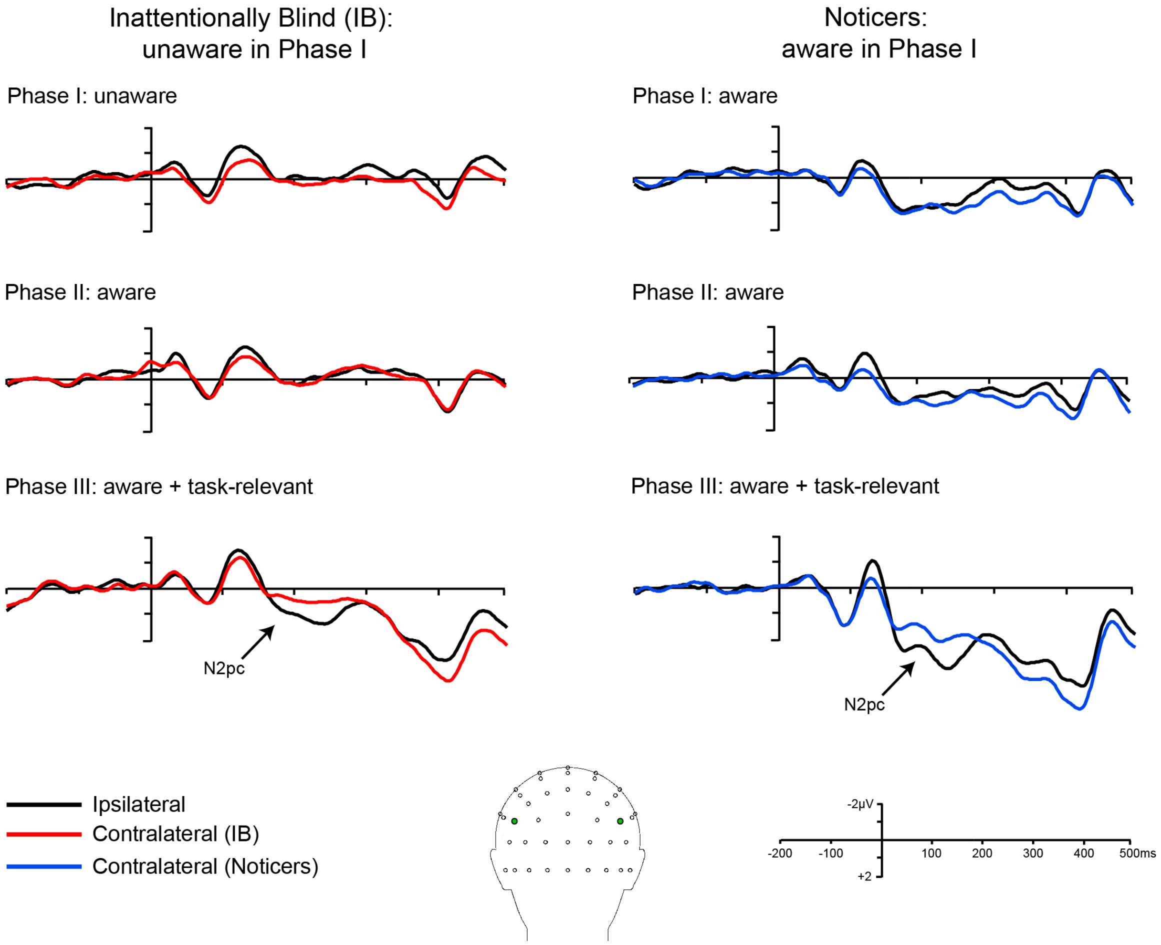


Figure 3.3d. ERPs of the N2pc in inattentionally blind and noticer subjects
ERPs plotted in this figure were recorded at electrode sites P5 and P6.

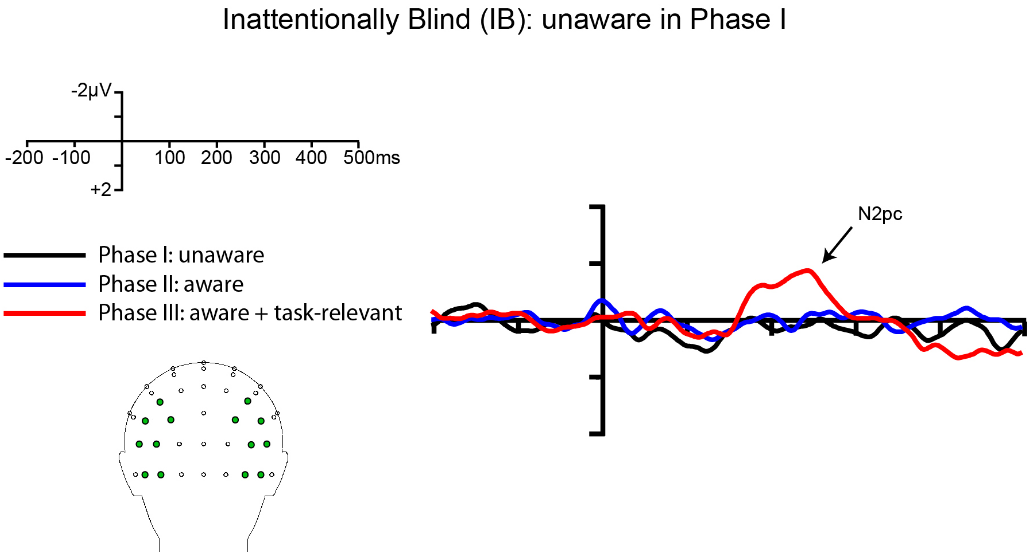


Figure 3.3e. Difference waves of N2pc in inattentionally blind subjects

Difference waves were calculated by subtracting contralateral – ipsilateral activity in response to color stimuli for each phase.

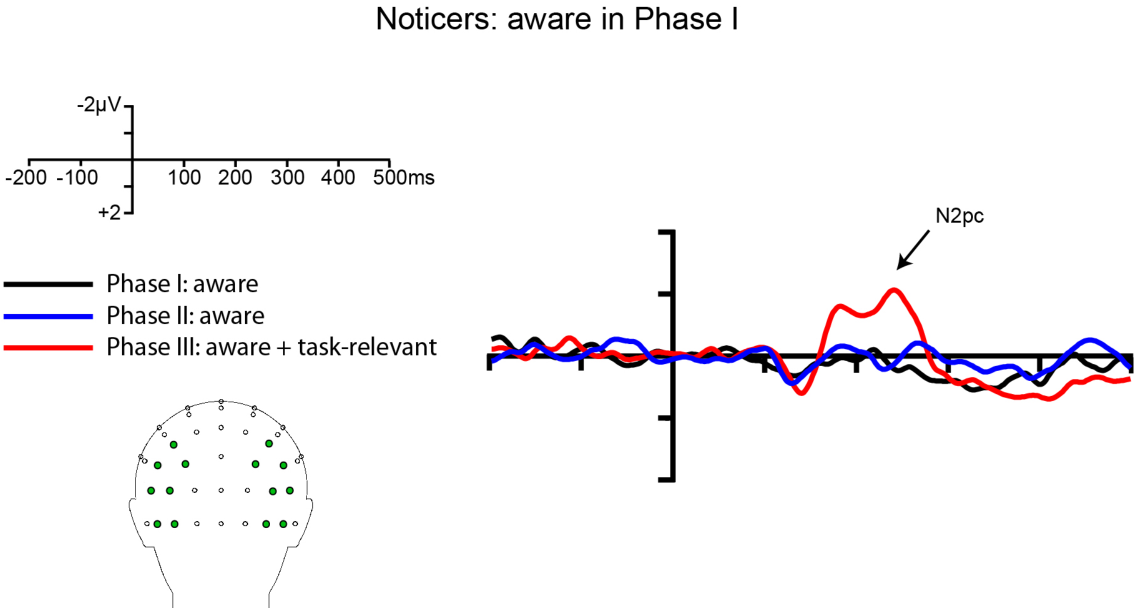
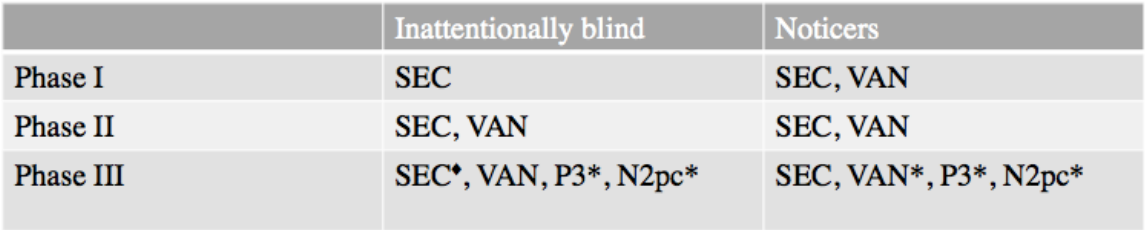


Figure 3.3f. Difference waves of N2pc in noticer subjects

Difference waves were calculated by subtracting contralateral – ipsilateral activity in response to color stimuli for each phase.



	Inattentionally blind	Noticers
Phase I	SEC	SEC, VAN
Phase II	SEC, VAN	SEC, VAN
Phase III	SEC◆, VAN, P3*, N2pc*	SEC, VAN*, P3*, N2pc*

Table 3.3b. Ultimate findings in terms of presence of components

Presence of components in a given phase was determined by finding amplitude differences between ERPs to color stimuli and RG stimuli that were significantly greater than zero. Significant findings are marked with a *, marginally significant findings are marked with a ◆, and others listed are expected with more data.

Chapter 4

Discussion

4.1 Summary of Results

We found that our own variation of the SEC, a non-conscious sensory processing of color was trending in all phases of the experiment and marginally significant in phase III for the IB group. This indicates that the brain does "see" color stimuli without the perceptual awareness of such stimuli. The VAN was found only in phase III for noticers, once the color stimuli were task relevant, which was inconsistent with past findings that it is independent of task-relevance (Koivisto & Revonsuo, 2010). We believe that with more data, the VAN might be found in all three phases in noticer subjects and that it could be found in phases II and III in IB subjects, but it is possible that it should be reevaluated in terms of what it indexes in the process of conscious perception. The P3 component demonstrated a robust presence in phase III for both groups and there was no significant P3 difference between ERPs to color stimuli and RG stimuli in phases I or II. This result confirms the hypothesis that the P3 is not an NCC proper, but rather reflects post-perceptual processing necessary for reporting or acting upon the conscious perception of the color stimuli. Finally, the N2pc was also found only in phase III in both groups of subjects. This indicates that the type of attention indexed by the N2pc may be more related to task-relevance of the critical stimuli than had been previously thought.

4.2 Connecting to Theories

The results of this thesis study do not clearly support one theory or another. They find a sort of middle ground, corroborating pieces of various theories while disagreeing with other pieces of these same theories. The observation of an early positivity related to the perception of color stimuli regardless of subjective report of awareness suggests that this component indexes pre-conscious color processing. It is possible that, as Lamme posits, subjects consciously perceived the color, but simply were not able to report on the experience or perhaps forgot the color was there before they were asked about what they saw. In this view, the SEC might be the NCC for awareness of color. However, consciously perceiving the color and not remembering to report it seems unlikely in the current paradigm in which 280 color stimuli were presented in each phase (presumably this large number of repetitions would increase the chance of subjects remembering having consciously seen the color when queried after-the-fact).

The conclusions we draw about the P3 indicate that conscious perception does not occur as late as Dehaene argues, that this controversial component fits neatly into the category of NCC-co due to its post-perceptual role in reporting on one's conscious experience. Interestingly, this study also implicates the N2pc as a task-relevant marker of attention rather than an NCC. It remains unclear whether the N2pc is generated before or after conscious perception of the target stimulus is first established.

4.3 Returning to the 3-NCC Problem

The finding that the N2pc was not present until phase III while we suspect that with more data, the VAN would be present in phases II and III for IB subjects offers a tempting conclusion that attention and awareness are separable in this paradigm. However, it would be an oversimplification to state that we observed awareness in the absence of attention in phase II of the current experiment. The N2pc indicates a specific type of visual attention and it remains unclear what exact process the VAN indexes. Although we anticipated that the N2pc would be a well-suited index of attention in this study, it is entirely possible (and very likely) that a different kind of attentional change occurred between phases I and II. When a subject is initially "inattentionally blind" in phase I (e.g. to the presence of color), and is then cued in to notice the previously unnoticed stimulus in phase II, this change in awareness is likely caused by a change in attention. Indeed, the entire method of cueing subjects by asking the questions and showing the examples, relies on the notion of subjects now "being on the lookout" for the stimulus they previously failed to notice. Thus, it is unclear whether the VAN reflects the change in attention (from not being-on-the-lookout to being-on-the-lookout) or the change in awareness (from not noticing the color to noticing the color). What we can conclude from the current study is that the N2pc does not reflect the attentional change that enables the transition from being inattentionally blind to noticing a stimulus. Instead, the N2pc reflected the transition from seeing a task-irrelevant to a task-relevant stimulus, i.e. seeing a stimulus and not having to do anything about it, versus seeing a stimulus and having to perform an active discrimination task on it in order to carry out the task at hand.

4.4 Limitations

The rejection of horizontal eye movement artifacts was a serious challenge in viewing the N2pc component. The N2pc is very easily confounded by any movement of the eyes. This is particularly difficult because the N2pc is particular to lateralized stimuli (Luck, 2014). This means that subjects were likely especially tempted to move their eyes from the center point to attend to the colored stimuli presented to the left and right of the fixation point. In future studies, this must be controlled for from the very beginning of the experiment. We observed a particularly high rate of eye movements, but discovered this after having run a few subjects.

As demonstrated in Figure 3.2a, 3.2b, and Table 3.2, noticer performance on the color discrimination task in phase III was drastically more accurate and demonstrated higher d’ values than IB subjects. This finding may be representative of some difference between the groups in their perception of color. However, it is also very likely that this simply demonstrates the effect of the practice that noticer group had. Noticers had been aware of the color stimuli for up to twice as many trials as the IB group, assuming they noticed the color right away (the amount of practice decreased depending on how late into the first phase the subject noticed the color). They may not have been using the color stimuli for the task they were completing, but they had been perceiving it consciously for longer than the IB group. The practice afforded to them by this extra experience of conscious perception could very well explain the significant difference in performance in phase III.

We designed the experiment such that the proportion of critical stimuli (those that require a response) in each task was identical (circle size changes on 15% of trials and infrequent color stimuli on 15% of trials). Ideally the difficulty of the color discrimination task in phase III would be equal to that of the size change task in phases I and II. However in designing this experiment, the selection of colors that could be hidden from participants was prioritized above the difficulty of the discrimination task.

4.5 Future Directions

This paradigm is effective in comparing some critical conditions (i.e. unaware vs. aware and task-irrelevant vs. task-relevant) in order to model difficult to measure subjective experiences. The use of color as the critical stimuli in this paradigm leads us to believe that the qualities of the colors used could be manipulated further. Given that 58% of subjects were IB (11/19), perhaps the hue and saturation could be increased in order to see how salient a color can be while still able to be hidden from approximately half of the subjects. With more time and more subjects, this could have been adjusted to push the boundaries of perception even more. In calibrating the colors for this thesis, the ability to hide them from subjects was prioritized above using more salient colors (e.g. red) in order to elicit a true SEC. This format of an inattentional blindness paradigm makes great use of the phenomenon without only having two conditions. By making the unaware stimuli task-relevant in phase III, productive comparisons can be made and this will continue to prove a useful manipulation in future studies of the NCC.

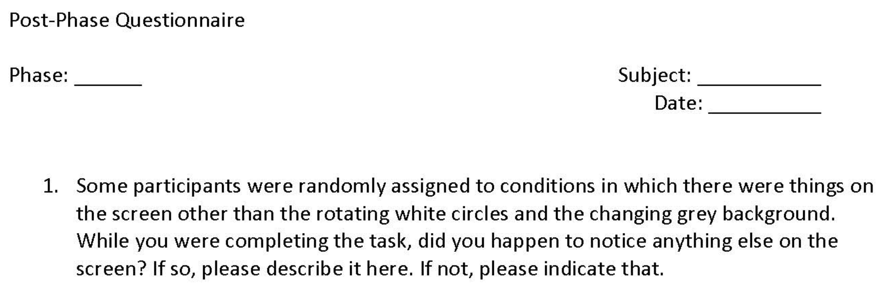
4.6 Conclusion

It is tempting to reduce complex and intricate cognitive processes down to an ERP component. The convenience of being able to say that the VAN was observed and therefore the subject had awareness is enticing, but the results of this study indicate that this correlation may well be an oversimplification itself. Reductionism is not the most effective way to address such a rich and complex thing as consciousness (Nagel, 1974) and that applies equally to attention and awareness.

The findings of the current thesis encourage us to take a closer look at the role of task-relevance in conscious perception. Task-relevance in this paradigm was a model of report on subjective experience. Although subjects weren’t asked to talk about the color stimulus every time they saw it, they were asked to press a button to indicate that they were aware of its presence in the grid. This experimental model does not perfectly map onto the experience of reporting on what one perceives, but the finding is worth exploring in future studies.

The mystery of consciousness is yet to be solved, but as with outer space, and the depths of Earth’s oceans, every little step forward counts. In the scientific community, discoveries do not occur completely and in an instant, like Dorothy leaving the black and white of Kansas and entering the vibrant land of Oz. As scientists, a twister will not take us there. We must discover the details of consciousness slowly, like black and white fading into color. Although questions will always remain, with patience we will get closer and closer to Oz.

Appendix A: Post-phase Questionnaire



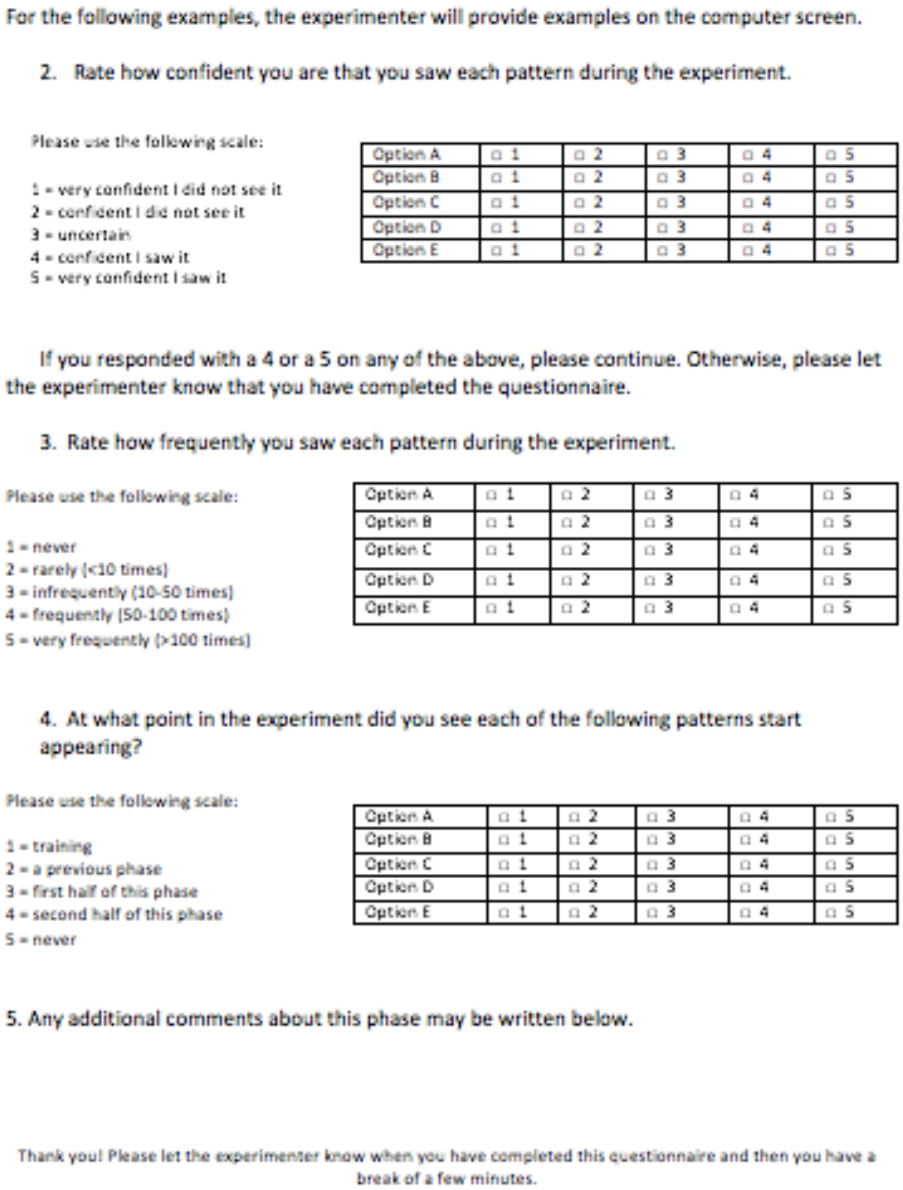
Post-Phase Questionnaire

Phase: ______

Subject: ___________

Date: __________

1. Some participants were randomly assigned to conditions in which there were things on the screen other than the rotating white circles and the changing grey background. While you were completing the task, did you happen to notice anything else on the screen? If so, please describe it here. If not, please indicate that.



For the following examples, the experimenter will provide examples on the computer screen.

2. Rate how confident you are that you saw each pattern during the experiment.

Please use the following scale:

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

Option A	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option B	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option C	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option D	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option E	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

If you responded with a 4 or a 5 on any of the above, please continue. Otherwise, please let the experimenter know that you have completed the questionnaire.

3. Rate how frequently you saw each pattern during the experiment.

Please use the following scale:

1 = never
2 = rarely (<10 times)
3 = infrequently (10-50 times)
4 = frequently (50-100 times)
5 = very frequently (>100 times)

Option A	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option B	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option C	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option D	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option E	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

4. At what point in the experiment did you see each of the following patterns start appearing?

Please use the following scale:

1 = training
2 = a previous phase
3 = first half of this phase
4 = second half of this phase
5 = never

Option A	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option B	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option C	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option D	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Option E	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

5. Any additional comments about this phase may be written below.

Thank you! Please let the experimenter know when you have completed this questionnaire and then you have a break of a few minutes.

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