Neural signatures of conscious face perception: The N170 is absent during inattentional blindness

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Abstract

The inattention paradigm was adapted for recording event-related potentials (ERPs) in order to examine the neural correlates of conscious face perception. In the first phase of the experiment, subjects engaged in a difficult tracking task overlaid on changing configurations of line segments. Unbeknownst to the subjects, during half of the trials these line segments formed a face for 300ms while the other half of the trials contained only random arrangements. An awareness assessment revealed that nearly half of all subjects did not see the faces and remained inattentionally blind throughout more than 300 presentations of the face during this first phase. In the second phase, participants engaged in the same tracking task, but due to the intervening awareness assessment, all participants reported seeing the faces during this phase. In a third phase, the stimuli remained the same, but the participants were instructed to forego the tracking task and to perform an explicit face discrimination task. Comparisons between ERPs time-locked to face and non-face stimuli revealed that the face-specific N170 was completely absent during inattentional blindness. The N170 was clearly evident in subjects who happened to notice the faces in phase I, as well as in the inattentionally blind subjects once they noticed the faces in phase II. Additionally, when the faces became task-relevant in phase III, the amplitude of the N170 was significantly enhanced. These results suggest that the N170 is necessary for the conscious perception of faces.

For Mom and Dad

Chapter 1

Introduction

> In 1989 the philosopher Colin McGinn asked the following question: "How can technicolor phenomenology arise from soggy gray matter?". Since then, many authors in the field of consciousness research have quoted this question over and over, like a slogan... It seems that almost none of them discovered the subtle trap inherent in this question. The brain is not gray. The brain is colorless.
>
> — *Thomas Metzinger* [32]

In recent decades, large strides in brain imaging technologies have enabled great advances in our understanding of mind and brain, yet many of our most fundamental questions about the nature of consciousness remain unanswered. For example, it is not yet known how the brain produces consciousness, or what it is that separates the conscious activity of our brains from processes which precede and follow immediate awareness. A simpler take on this broad, but deeply significant question is to approach it from the angle of perception. Rather than to ask how consciousness is produced generally, one can look at the brain activity in response to a particular stimulus and explore which of these underlying processes are subconscious versus those that are consciously experienced.

In this chapter, I will give an overview of several philosophical and empirical perspectives on the neural correlates of consciousness. I will follow this with a discussion of inattentional blindness, and its use as a tool to explore perceptual processes. Finally, I will review the face perception literature, in particular the face-sensitive potentials that can be recorded at the scalp, and discuss what is currently known about subconscious and conscious face perception.

1.1 The Neural Correlates of Consciousness

Philosophical questions about the nature and causal properties of consciousness have existed for centuries. For René Descartes, the mind was a presence without substance, independent of the physical form. Over the years, there have been many different ideas on the subject, and Descartes' notion of substance dualism has long since been rejected by the scientific community. It is widely accepted that mental events are intimately related—if not identical with—physical events occurring in neural tissue. The nature of this relationship, however, has yet to be understood.

The frustration on this front was characterized by David Chalmers, who named the so-called hard problem of consciousness: how do subjective experiences, i.e. qualia, come to be? His claim was not simply that this question remained unanswered, but further that the question is inaccessible to the current scientific strategies used to study consciousness. Merely addressing information processing mechanisms, as has often been the concern of cognitive psychology, is inadequate to determine why we experience them as we do [6]. In contrast, other scholars such as Daniel Dennett have proposed that the question of qualia is ill-formed: the mechanisms that support our cognitive capacities amount to the phenomenal experience of being, and thus elucidating the architecture and functioning of our cognitive, memory, and perceptual systems will fully describe our conscious experience [8].

In order to make progress on this seemingly intractable problem, Christof Koch and many others have advocated focusing our empirical efforts on the somewhat more manageable problem [9, 49]: What are the precise mechanisms underlying awareness of visual stimuli, or neural correlates of consciousness (NCCs)? Even this question has prompted a wide variety of responses. Some of the frameworks useful for addressing this question are outlined here, along with some theories of what the neural correlates actually are.

1.1.1 Attention, Awareness, and Consciousness

The concepts of attention, awareness, and consciousness have colloquial associations, however, more rigorous definitions must be laid out for their empirical study. To be aware of a stimulus is to experience it consciously. The word conscious can also be used to distinguish between various mental states (e.g. sleeping and waking), however, that distinction is largely irrelevant within the scope of this thesis. For this reason, perceptual awareness and consciousness are used interchangeably in this paper. Attention refers to a different, yet fundamentally intertwined phenomenon although the exact relationship between consciousness and attention is currently unclear [49, 30].

Attention can often be broken into top-down and bottom-up, with top-down corresponding to the the directed actions of deliberate processing (e.g. voluntarily focusing on a textbook reading), while bottom-up attention refers to attentional capture by salient features and objects (e.g. when you hear a loud crash, and find your focus involuntary drawn to the source of the noise) [30]. Some types of attention can occur in the absence of awareness (e.g. for sufficiently degraded stimuli), but despite recent attempts to fully dissociate the two, evidence suggests that either top-down or bottom-up attention must be engaged for perceptual awareness to occur [7].

Whereas attention can exist in degrees, consciousness seems to be an all-or-nothing phenomenon, both in terms of subjective description, and in paradigms used to assess awareness [45]. Evidence suggests that a ”threshold” for awareness exists, and while early activity may be primarily mediated by the physical properties of the stimulus, later activity is determined by whether or not a stimulus reaches consciousness [45].

1.1.2 Frameworks for Examining the NCCs

Several theoretical frameworks have been proposed for effectively approaching the empirical study of neural correlates of visual awareness. One such framework, called the global workspace theory was originally proposed by Bernard Baars [3, 2]. He proposes that many processes are carried out subconsciously, and subjective experience occurs when the “spotlight” (corresponding to selective attention) is turned on a particular process.

Dehaene et al. [10] present a taxonomy of types of processing wherein sufficient sensory stimulation and access to attentional resources are needed in order for information to reach consciousness. Physically degraded stimuli are said to be *subliminal*, in the presence or absence of top-down attention. A stimulus would be considered *preconscious* when the stimulation is sufficient on a sensory level, but the information never gets processed and amplified by the top-down attentional circuitry. It is only with both sufficient stimulation, and attentional amplification that stimuli can be processed *consciously*. According to some theories, this latter situation depends on critically distributed processing, involving widespread synchronous activity. This would constitute the NCCs [10]. Victor Lamme's proposal roughly supports this global workspace framework, further proposing that the neural underpinnings of this spotlight would consist of reentrant processing, involving feedback from higher levels of the visual system to lower levels [29].

A different perspective, however, suggests that this later fronto-parietal activity may not correspond directly to consciousness [1]. Aru et al. [1] instead suggest a framework to dissociate the NCCs from other activity that often coincides with a conscious experience. There are several categories of processes that need to be dissociated. There are prerequisites of conscious processing (NCC-pr; e.g., low-level sensory processing), and there are consequences of conscious perception (NCC-co; e.g., storage in memory). The NCC-prs will always occur when there is awareness, but can occur in the absence of conscious processing as well. The NCC-cos will only occur when perception has occurred, but the immediate conscious experience does not require this activity.

This taxonomy distinguishes the NCC proper as the minimal set of processes necessary for a specific conscious experience, allowing one to discriminate between processes that always coincide with consciousness from those that are only associated with consciousness, but do not reflect the immediate conscious experience itself. For instance, the P1, a positive-going ERP waveform, is one of the earliest components that has been correlated with conscious perception, however, this activity seems to correspond instead to modulations of attention, and the correlations in activity with consciousness would then be due to the greater likelihood of processing a well-attended stimulus, an NCC-pr [42]. The P3, reflecting the widespread fronto-parietal activation that some believe reflects consciousness would fall into the category of NCC-co, sufficient but not necessary to infer conscious activity. The visual awareness negativity (VAN), occurring at around 200ms in the ventral visual processing stream, emerges as a likely candidate for the NCCs-proper by this taxonomy [42, 27].

1.1.3 Paradigms and methodologies

Several methods exist for accessing information about activity in the human brain. While animal studies can rely on recording the activity of individual or populations of neurons, human research must utilize noninvasive methods. One such method, electroencephalography (EEG) involves passive recording of electrical potentials at the scalp. These recordings are then time-locked to a particular event (e.g. stimulus presentation), and averaged over numerous trials in order to explore the modulations of neural activity that correspond specifically to that event. The waveforms produced by this procedure are known as event-related potentials (ERPs). ERPs provide very precise timing information, but the location of the corresponding neural generators can be ambiguous. This timing information can be very useful in establishing a sequence of events in something like conscious perception.

In order to appropriately dissociate the activity associated with conscious perception from prerequisites and consequences of conscious perception, research on the neural correlates of conscious perception often relies on paradigms that allow the stimulus and the task to remain constant, while altering perception. Ideally, this assures that any differences in brain activity are not due to the task or the environment, but purely reflective of the different experience. Some strategies used to reach this goal include using rapid serial visual presentation (RSVP) [45], bistable stimuli [18], backward masking [43] and binocular rivalry [48]. Inattentional blindness is an ideal paradigm for making this comparison because it requires no degradation of the stimulus or change in task between the aware and unaware conditions. It has been used effectively in order to examine conscious perception of shapes [41].

1.2 Inattentional Blindness

While the phrase "inattentional blindness" was not used until the 1990s [31], the first experiments exploring how unexpected events can go unnoticed when attention is occupied elsewhere occurred in the 1970s [36]. Ulric Neisser had participants watch videos of people passing a basketball. Superimposed on this scene, a woman carrying an umbrella appeared, readily visible to anyone not engaged in the tracking task, but amazingly not seen by many of those attending to the basketball. This experiment revealed that our perceptual world is not what it seems. Our experience of the world does not seem to lack detail, despite the fact that much of what strikes our retina never reaches our consciousness at all.

One of the most powerful demonstrations of the possibility for sustained inattentional blindness for dynamic events was a variation on Neisser's original paradigm. In this well-known study, participants count the number of basketball passes that occur between a team wearing matching shirts. During this tracking task, a person in a gorilla suit walks across the display, pausing briefly in the middle to pound her chest before continuing off of the screen. Noticing the gorilla would seem to be a trivial task, and yet, less than half of the participants noticed the gorilla [46].

By the taxonomy that Dehaene et al. [10] present, inattentional blindness is achieved for stimuli that are preconscious, i.e., they are sufficiently salient, but they do not engage widespread activity. Although inattentional blindness has been documented for a wide variety of stimuli, it is notoriously difficult to produce inattentional blindness to highly meaningful stimuli, faces in particular [31].

Objects that differ from the attended objects, and resemble ignored objects are more susceptible to inattentional blindness [34]. In the case of the gorilla study, this means that one is more likely to perceive the gorilla when one is tracking a team wearing black shirts than when one is tracking the white-shirt team.

1.2.1 Limitations

By the very nature of inattentional blindness, once a participant is aware of the presence of a critical stimulus in an inattentional blindness experiment, they are no longer blind to it. This means that the experimental sequence in an inattentional blindness study cannot be counterbalanced. A participant cannot move from the aware condition to the unaware condition—the transition is unidirectional.

In addition, this constraint makes using EEG in an inattentional blindness paradigm quite difficult. It can take hundreds of trials to get reliable ERP waveforms. Such designs require stimuli that are both salient enough to produce clear neural signals and unambiguous perception when attended, but invisible in the absence of attention. Particularly salient stimuli, such as faces or one's own name, are likely to capture attention, making inattentional blindness paradigms even harder to execute.

1.3 Visual Processing of Faces

Faces are some of the most relevant stimuli in our day-to-day lives. It is hypothesized that facial perception is, for this reason, unique [25]. This is supported by behavioral evidence that we process faces more quickly than other stimuli, and that face perception is particularly susceptible to interference from inversion. While turning an object upside-down is usually detrimental to encoding, faces are disproportionately affected [53]. Additionally, face processing differs in the time-course of development—the ability to learn new faces improves until the early 30s, while similar capacities (e.g. learning of inverted faces) stop developing years earlier [15].

In fMRI paradigms, several areas have been identified as particularly sensitive to the presence of faces. Most notable among face-sensitive areas are the fusiform face area (FFA) in the ventral visual stream [24, 25], the occipital face area (OFA), hypothesized to reflect earlier representations of parts of faces [40], and the superior temporal sulcus (STS) which seems to show sensitivity to dynamic social and emotional cues in face processing [21]. Damage to any of these regions can produce specific deficits in face processing. A handful of studies have reported face-specific FFA activity for unperceived faces, [28, 35, 33], although the activity is generally greatly reduced when compared with consciously perceived faces. Recently, Rodríguez et al. [43] used a backward-masking paradigm and found that unperceived faces did not elicit activity in any face-selective regions. This difference may be because their paradigm used a strong criterion for lack of awareness, rather than relying on a forced-choice, reducing the chance that stimuli resulting in fleeting awareness would be grouped with the genuinely unperceived stimuli.

1.3.1 Electrophysiology of face perception

The vertex positive potential (VPP), a frontal positivity at a latency of 150-200ms, was the first recognized electrophysiological component demonstrating face-sensitivity [20]. Later, the N170, a negative-going waveform over lateral-occipital locations, became the focus of much of the ERP research on face perception [4]. It is currently accepted that the VPP represents the same activity as the N170, seen from the opposite dipole [23].

N170

The N170 is the earliest electrophysiological component that shows consistent face-sensitivity. It consists of an increased negativity for face-stimuli than for other objects or patterns, seen most strongly over the posterior scalp at about 170ms post-stimulus, and is generally greater in amplitude over the right hemisphere. It is seen for inverted as well as upright faces, although inverted faces lead to a somewhat counterintuitive enhancement of this activity, as well as a delay in latency [12].

The N170 is not (or at least, not strongly) affected by repetition [44]. In fact, even one's own face will elicit a similar ERP to that of a stranger [47, 39]. This finding appears to rule out a role in the recognition of individual identity. Its activity is generally considered to reflect the categorical discrimination of faces [13].

While the N170 is present for selectively attended as well as ignored faces, it shows greater amplitude when faces are presented in spatially attended locations [17, 19]. It has been demonstrated that the N170 is also enhanced by task-related attention [11, 17, 37], although this has also been disputed [5].

Despite the large body of research of the N170, there is as of yet no consensus on the neural generator of this component. Different methodologies have found evidence for its localization it in the OFA, the FFA, and even the STS [44]. Given the difficulty in localization, it is likely that this component may reflect activity generated in multiple brain areas [14, 44].

Also contentious is whether the N170 occurs in the absence of visual awareness. A binocular rivalry paradigm [22] demonstrated that unperceived faces presented to the non-dominant eye elicit differences in activity in the 140-200ms range compared to scrambled, unperceived faces, although this difference was markedly less pronounced than for perceived faces. Another study found that fearful expression enhanced the N170—even when faces were task-irrelevant and subliminally presented [38]. In patients with hemispatial neglect, face-specific N170 component was intact even in unperceived faces presented to the neglected hemisphere [51].

Conversely, a recent study using both fMRI and ERPs in a backward-masking paradigm found that the N170 along with all subsequent face-specific activity, was abolished for unperceived faces [43]. Neither face-selective regions, nor ERP components were modulated by the presence of faces in the complete absence of awareness. Another recent masking study [16] found a similar absence of face-specific processing for unperceived stimuli, but also found that their masking technique interfered with early, feedforward visual processing. The immediate interruptions to visual stimuli that make masking possible may prevent early sensory processing and as well as subsequent conscious processing. If this is the case, the finding that the N170 is absent during backward masking could be due to disruption of NCC-pr as opposed to NCCs per se.

1.4 Research Question

The design for this study is based on research using an inattentional blindness paradigm in order to explore the conscious processing of shapes [41]. In this study, Pitts et al. [41] were able to effectively create conditions of inattentional blindness to a square pattern for hundreds of presentations using an attentionally demanding task. This paradigm was adapted in order to examine the processing of faces. The task was modified to take place in the same spatial area as the unattended stimuli, rather than the area surrounding them, thus providing tighter control of spatial attention. This new task also involved continuous motion (instead of shifts that occurred synchronously with changes in the critical patterns), so that the distractor stimuli did not contribute to ERPs.

This experiment explores the neural correlates of conscious perception, specifically of faces, using electrophysiological measures. The necessary comparisons were made by creating conditions of inattentional blindness toward the critical stimulus. By directing attention to a task of moderate difficulty which takes place in the same location in space as a subtly visible, but ignored face stimulus, we examine the activity associated with exposure to the contours present in a face in the absence of face perception.

Chapter 2

Methods

2.1 Participants

The 33 participants were between the ages of 18 and 26, right-handed, and were enrolled at Reed College (60.6% female, mean age = 20, $SD = 1.6$ years). Participants had normal or corrected to normal vision, as determined by a brief eye exam conducted before their participation. Participants were screened to ensure that they had no history of brain injury or neurological condition which might interfere with electrophysiological activity.

Participants were compensated with Psychology Lottery Tickets (1 ticket per half-hour of participation). At the end of the academic year, one winner was selected from the pool of entrants to receive $150.00. All procedures were approved by the Reed College Human Subjects Research Committee.

2.2 Stimuli

The face stimulus used throughout this experiment is loosely based on an average female face designed for and used in Zhao et al. [54] (see Figure 2.1). The 36-segment line rendering of this face was generated manually in Inkscape 0.48.2, using the bezier curve tool. In order to control for the low-level perceptual features (contours and contrasts), face and nonface stimuli each contained exactly seven copies of each line segment—only the arrangement and orientation of line segments changed between different background patterns. Line segments in face stimuli were distributed such that no line segments covered the small areas around each of the eyes, nose, and mouth. Line segments in the randomized stimuli were

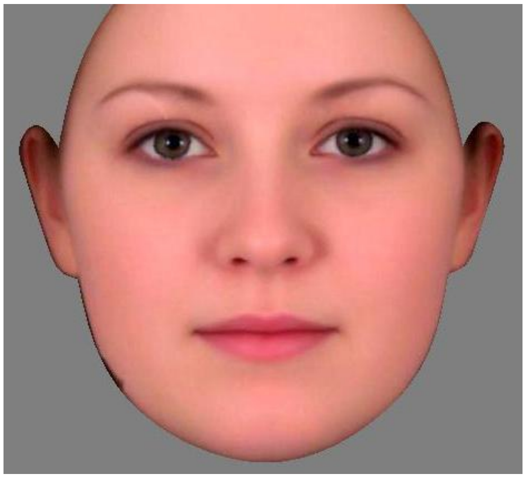


Figure 2.1: Average face from Zhao et al. [54]
Average female face from Zhao et al. [54], used in stimulus design. Freely available for research purposes.

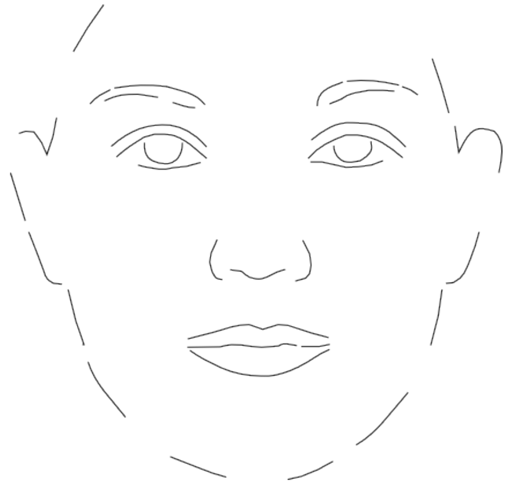


Figure 2.2: Face stimulus
The line-drawing derived from the average face, towards which half of participants were inattentionally blind.

distributed so that the number of line segments appearing in the area of each feature matched the number of line segments composing that feature, and no additional line segments overlapped with this area. Line segments in the faces that were missing pieces were arranged such that each line from the feature appeared in a random location/orientation within the region where that feature would appear, with no additional segments. The creation of these randomized background patterns was achieved using Processing 2.0b3.

The green disks, relevant for the first experimental task, and present throughout the experiment were (0,125,0) on an R,G,B scale. The target event consisted of a single disk brightening to (0,140,0).

Stimuli were presented using Presentation (Neurobehavioral Systems, San Fransisco CA).

A demo of the task and stimuli used throughout the experiment is available online at "http://youtu.be/aWsfO2FNlp0".

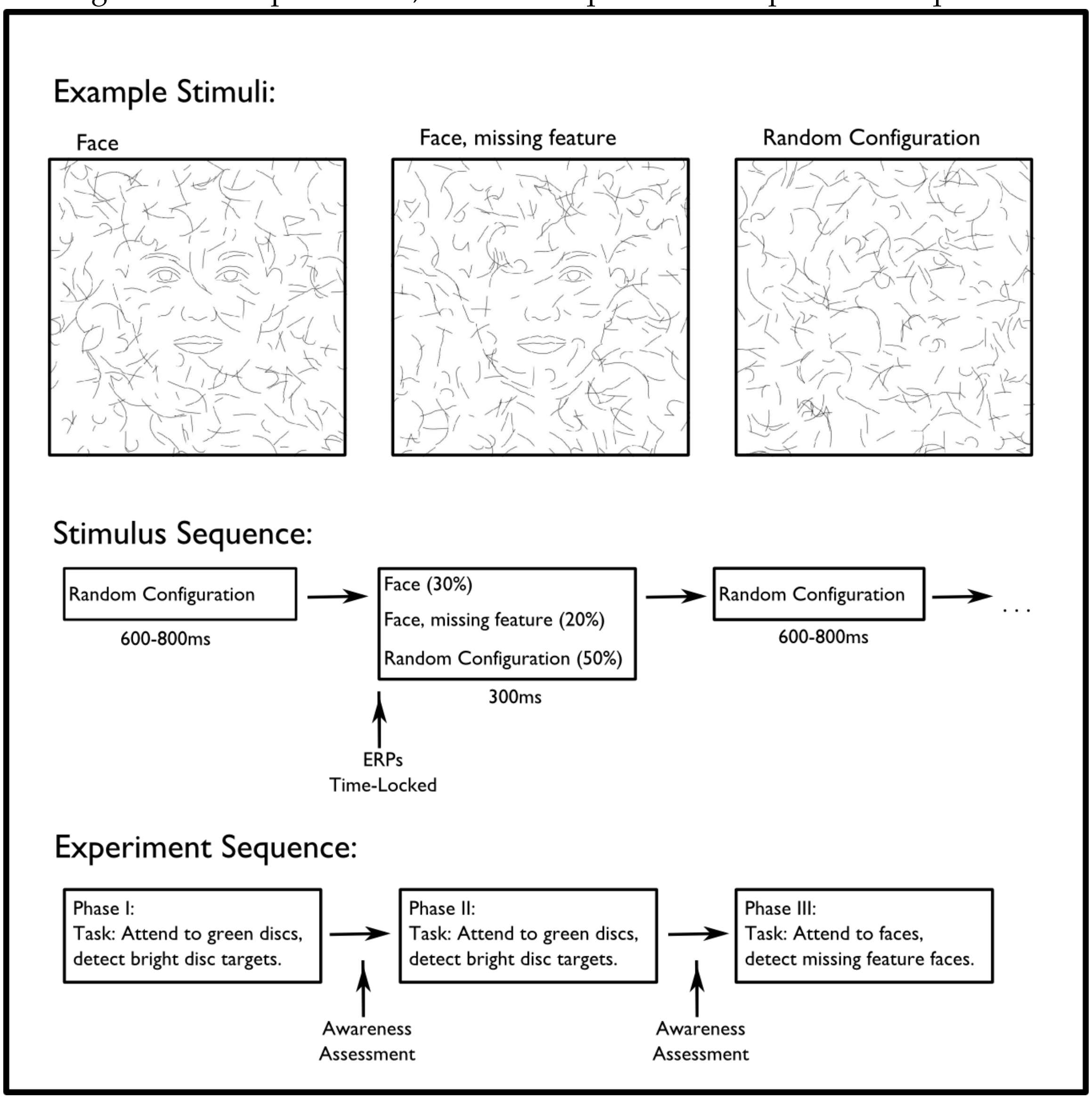
2.3 Apparatus and Setup

EEG was recorded using a custom 96 channel Herrsching DE-8211 "Easycap". Locations in this cap were modified from the standard system for equidistance. For a full map of channel locations, compared against the standard locations, see appendix C. Participants sat at approximately 75cm from the 1920 x 1200 pixel display screen, a Planar SA2311w23”-LCD monitor. Electrode signals were amplified by BrainVision “Professional BrainAmp” amplifiers, with a 500Hz digitization rate.

Responses were recorded with a Cedris button pad, Model RB-830.

EEG was recorded with Cz as a reference, then re-referenced to the average of all channels. While an averaged mastoid reference is recommended for most ERP analysis, given the topography of the N170, an average reference is preferred for face perception studies [23].

Figure 2.3: Sample stimuli, stimulus sequence and experiment sequence.



2.4 Procedures

2.4.1 EEG Recording and Capping

Participants were fitted with a 96-channel electrode cap. Eye blink artifacts were detected with additional VEOG electrode attached to the face below the left eye. Impedance levels were kept below $5k\Omega$. This was achieved with the use of a saline-based gel and some gentle scraping with the wooden end of a Q-tip, in order to abrade away a thin layer of skin cells.

Immediately after the experiment was finished, usually within 3 hours of their arrival, caps were removed and participants were able to wash their hair in the lab sink if they chose.

2.4.2 Tasks

The initial experimental task consisted of watching three green continuously spinning concentric circles. Each of the circles had four green discs lying on it, and periodically a single disc changed shade for 300ms (see figure 2.4). Participants watched for this change, and pressed a button upon noticing the change. While the participants focused on this task in the foreground, the background patterns composed of numerous irregular black line segments changed frequently. Participants were informed that these patterns were present to increase task difficulty. In the background, either a critical (i.e. face-present; 30% of trials), a critical missing (i.e. a face missing a single feature; 20% of trials), or a noncritical (i.e. a randomized pattern of face segments; 50% of trials), stimulus would be presented for 300ms, followed by an interstimulus interval (ISI) of between 600 and 800ms. During the ISI, a new noncritical background appeared. The tracking task was still present during the ISI, but targets only appeared during the critical 300ms (see figure 2.3).

Participants were given a chance to practice this task before EEG recording began. During this practice phase, no critical stimuli appeared. Participants practiced for one-minute intervals on increasingly difficult versions of the task. Difficulty was manipulated by altering the change in luminance of the target discs: a greater change was considered easier to perceive. The purpose of this practice was twofold: first, this gave participants a chance to learn to ignore the background patterns, and second, the difficulty of the task warranted practice. Once participants had been acclimated to this task, they began the first phase of the study.

The first phase lasted approximately 12 minutes (720 trials), with short breaks

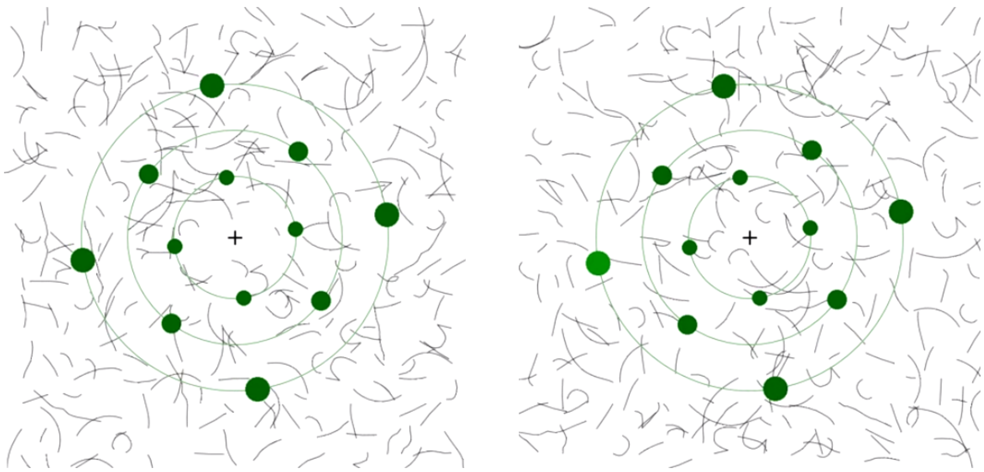


Figure 2.4: Example target event from phases I and II
The task in phases I and II consisted of responding to the luminance change of a single disk, as pictured above. As the rings continuously rotated, a single disc (the leftmost one, in this example) would periodically brighten for a 300ms duration.

every 60 trials (approximately every minute), and a longer break halfway through the phase. During this phase, critical stimuli were presented on 216 trials, critical missing stimuli were presented on 144 trials, and noncritical stimuli were presented on 360 trials. At the end of the first phase, participants completed a questionnaire (see Appendix A). The questionnaire assessed their awareness of the faces.

The first questions were open-ended, asking about the patterns that participants may have seen in the background. The next page asked participants to estimate the likelihood that and frequency with which various specific patterns appeared in the background. Examples of a background pattern from of each of five different categories (violin, face, lightbulb, flower, car) was presented on the monitor. Of these, only the face had ever actually appeared; however, these additional examples were included to dissociate participants who had genuinely seen the face from those who would tend to answer in positive to an experimenter's questions. Answers from this questionnaire were used to establish which participants were unaware in the first phase ($n = 14$)[1] from those who were aware in the first phase

[1]One of the subjects in the unaware category became aware of the faces 10 minutes into the first phase, and was able to report the presence of faces at the time of the first questionnaire. While the other four subjects who became aware of the faces halfway through the first phase were excluded, this participant constituted a special case. On the last trial in the 10th minute, the participant laughed out loud. The experimenter took note of the exact time that this event occurred. At the time of the questionnaire, the participant explicitly stated that the laughter coincided with the discovery of the faces in the background stimuli. Sufficient artifact-free trials were collected before this point

($n = 15$). The remaining four participants indicated that they had become aware of the faces after the break in the middle of the first phase, and they were excluded from the main analyses (see appendix B). In addition, this questionnaire and the attached example images served to cue any participants who were previously unaware to the existence of the face stimulus. In the second phase of the experiment, participants repeated the same task, then repeated the questionnaire. As expected, all participants reported noticing the faces the second time around.

The third phase of the experiment was exactly like the first two, except for the participant instructions. Subjects were instructed to attend to the lines in the background and to press a button when they saw a critical missing stimulus, and to ignore the previously attended spinning discs. The two tasks that they performed on the stimuli were designed to be similar in difficulty level.

2.5 Data Analysis

EEG data were processed using BrainVision Analyzer software (Brain Products, Germany). Artifacts (e.g. blinks and eye movements) were rejected semi-automatically. Participants who, after rejection of artifact trials and trials with button presses, were left with fewer than 100 trials in any one condition were excluded from the analyses ($n = 3$).

We examined the mean amplitudes for the observed ERP components. Main comparisons were within subjects between conditions in which they were unaware (phase I), and aware (phase II), as well as within the first phase between subjects who were aware, and those who where unaware.

Mean amplitudes between 150ms-190ms were examined for the N170, at lateral occipital electrode sites.

For phases 1 and 2, a subsequent negative difference, the Nd2 was measured at a window of 270-310ms. In keeping with previous results, this difference appeared earlier for attended stimuli [41], and the window chosen for the third phase was 230-270ms.

The selection negativity (SN) was measured over a slightly different set of lateral occipital electrodes from the prior negativities, at a window of 380-420ms. The P3 was measured at a time window of 350-450 milliseconds over a cluster of central-posterior electrodes.

An unexpected reduction in P1 amplitude for face-stimuli was seen consistently

in time to justify inclusion in the unaware group, using only data from the first 10 minutes.

enough to warrant further examination. Comparisons were carried out on a 50-90ms window for a cluster of 15 occipital electrodes.

All data were analyzed using R.15.1, using the package EZ for statistics. ANOVAs used Greenhouse-Geiser corrections for sphericity.

Chapter 3

Results

3.1 Behavioral results

Separate 2×2 ANOVAs examined the effects of phase (I, II) and group (aware, unaware) on reaction time, dprime, and accuracy on the first task (see Table 3.1). Reaction times for the first task decreased slightly between the first and second phases, $F(1,24) = 4.50, p = 0.044$, but there was no effect of group, $F(1,24) = 0.097, p = 0.75$ (see figure 3.1). There were no main effects of group ($F(1,24) = 1.366$, ns) or phase ($F(1,24) = 0.342$, ns) on accuracy, although there was an interaction effect ($F(1,24) = 10.67$, $p = 0.003$). Paired t-tests revealed that this interaction consisted of a drop in accuracy in the second phase for previously unaware participants after they noticed the faces, $t(11) = 2.52, p = 0.02$, and a drop in accuracy relative to the aware subjects, $t(17.8) = 2.271 p = 0.036$. However, dprime, a measure of sensitivity, did not change (see figure 3.2). dprime did not show main effects of group $F(1,24) = 0.048, p = 0.827$, phase $F(1,24) = 1.094, p = 0.305$, or a group by phase interaction effect $F(1,24) = 2.48, p = 0.128$. Thus, discrimination performance on the distracter task did not change across phases, even when subjects who were unaware of the faces in phase I, noticed these extra patterns in phase II.

3.1.1 Questionnaire Responses

Establishing membership to the aware and unaware groups was straightforward based on questionnaire data. After the first phase, in response to the open-ended questions, 20 of the 33 total participants spontaneously described faces. Of these, only 15 reported having noticed the faces in the first half of the first phase. Of the

Table 3.1: Task Performance

	Accuracy (%)	d′	Reaction Times (msec)
Phase 1			
unaware	75 (12)	3.10 (.66)	563 (37)
aware	74 (9)	2.93 (0.84)	579 (59)
Phase 2			
unaware	67 (12)	2.99 (0.50)	556 (43)
aware	76 (7)	3.10 (.0.60)	561 (57)
Phase 3			
unaware	59 (20)	1.99 (0.76)	668 (60)
aware	76 (13)	2.45 (0.46)	635 (60)

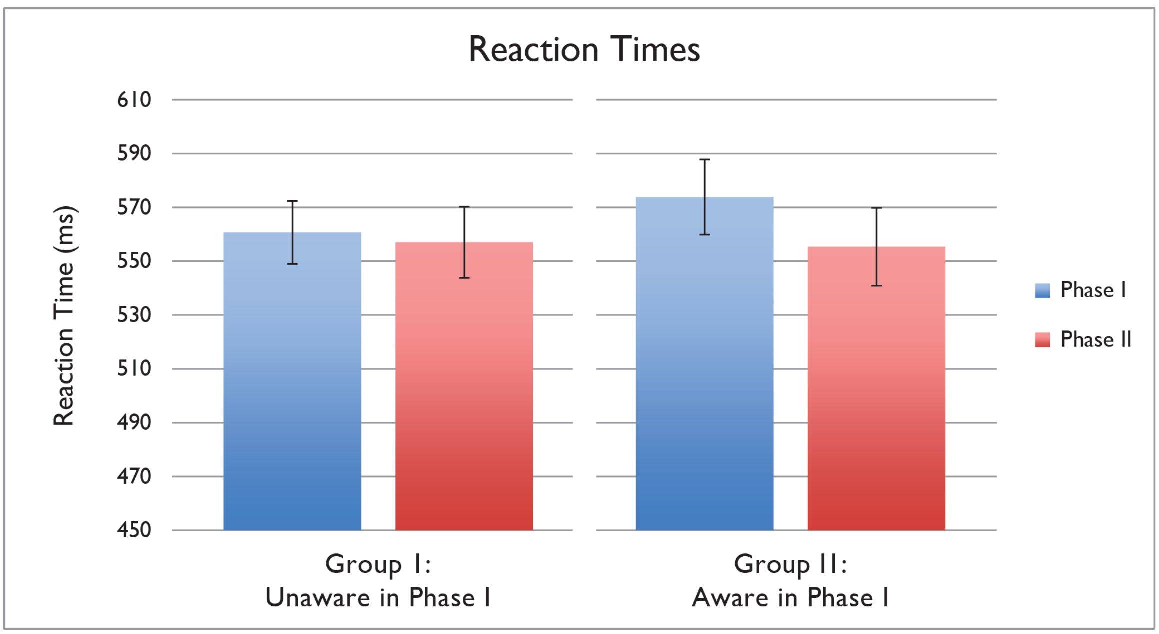


Figure 3.1: Reaction times
Reaction times for the tracking task. No significant differences were found between groups ($F(1, 24) = 0.097, p = 0.75$). Reaction times were faster in phase II (mean = 556.1623, sd = 49.46), than in phase I, (mean = 567.7906, sd = 46.76840), $F(1, 24) = 4.50, p = 0.044$

five who noticed more than halfway through the phase, four were excluded because they had inadequate trials to be analyzed as either aware or unaware in this

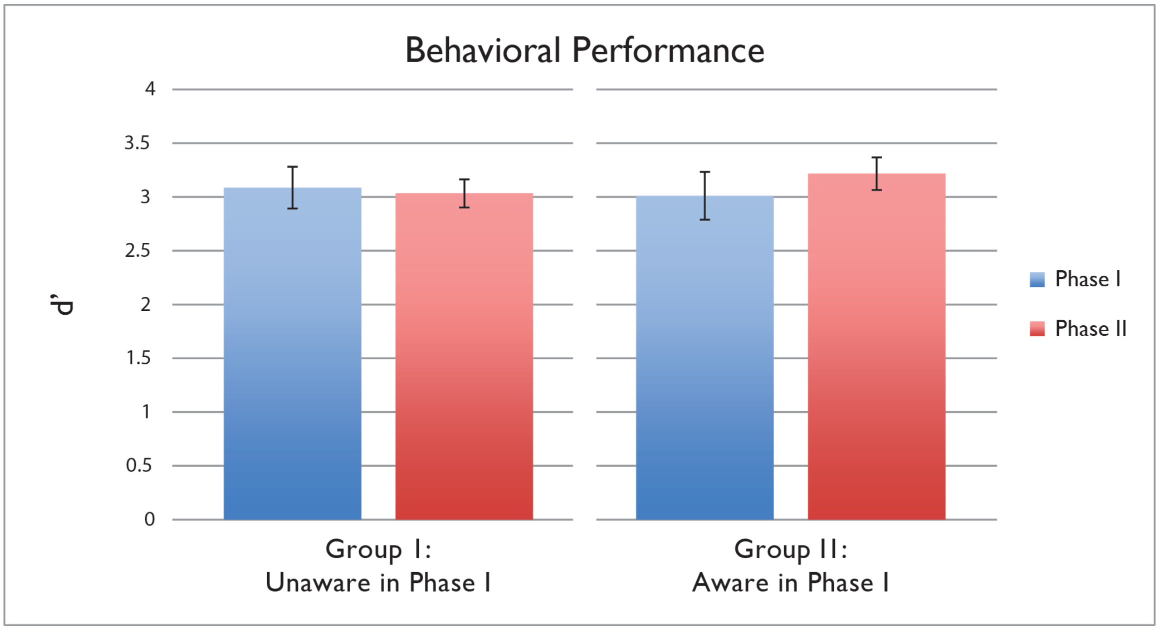


Figure 3.2: d' Scores
d' for the tracking task. d' is a measure of task performance that takes into account both accuracy and false alarm rates. No significant differences were found between groups, $F(1,24) = 0.048, p = 0.827$, or across phases, $F(1,24) = 1.094, p = 0.305$.

phase, while one noticed after exactly 171 presentations of the face[1], and this subset of his data was analyzed with the other unaware participants (the other trials were discarded). Of the 15 aware subjects, none described seeing faces missing pieces in response to the open-ended question. Some unaware participants did mention seeing patterns in the background, but the patterns described were unrelated to faces, such as "random changing with a uniform pulse, that of a heartbeat," or "I vaguely remember seeing lines come together and thinking of birds." One common sentiment expressed by unaware participants was, "I was putting all my attention (that I was able), on the dots so I have no idea." After the second phase, all participants described the faces, with 3 of the previously unaware and 4 of the aware participants mentioning the missing facial features. All participants in both phases who were aware of faces reported the highest possible confidence level in having seen the faces, while none of the unaware subjects reported a confidence level higher than "uncertain". When asked about frequency, all but one aware subject reported frequent or very frequent face presentation (the remaining subject reported that faces were "infrequent", or a 3 on a 1-5 scale). Taken together, these patterns made

[1]See footnote, page 15.

the division between unaware and aware subjects entirely unambiguous.

3.2 Analysis of ERP data

ERPs were time-locked to the appearance of face or scrambled background. Trials that included an event that served as a target in any phase (a brightened disc or a face-stimulus missing a feature) were excluded in all phases, along with all trials that contained a response, correct or erroneous. ERP waveforms from representative electrodes for a time period 100ms before stimulus presentation until 600ms after, separated by phase and by stimulus, can be found for the group of initially unaware participants (Figure 3.3), and aware participants (Figure 3.4). Difference waves (face − scrambled pattern) for a right, lateral-occipital electrode cluster can be found for unaware participants (see Figure 3.5), and for aware participants (see Figure 3.6).

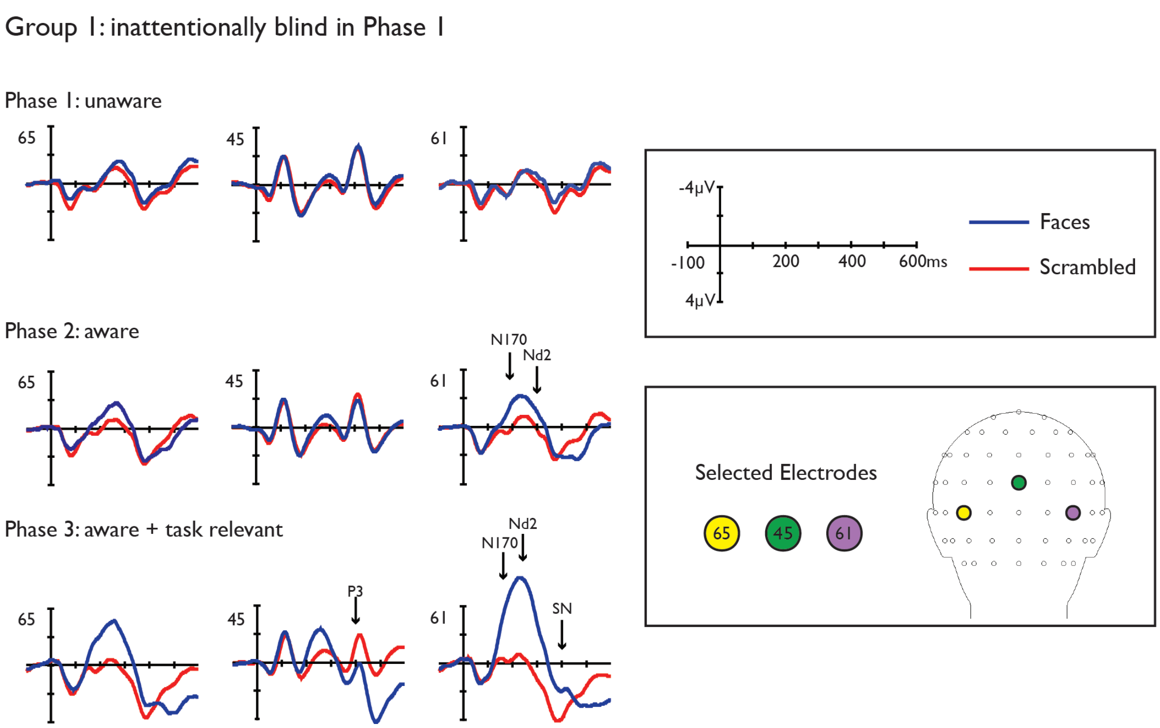


Figure 3.3: ERPs for group 1, unaware
ERP waveforms time-locked to the presentation of face and nonface stimuli for subjects who were inattentionally blind to faces for the entire duration of the first phase ($n = 12$). Significant differences denoted with an arrow.

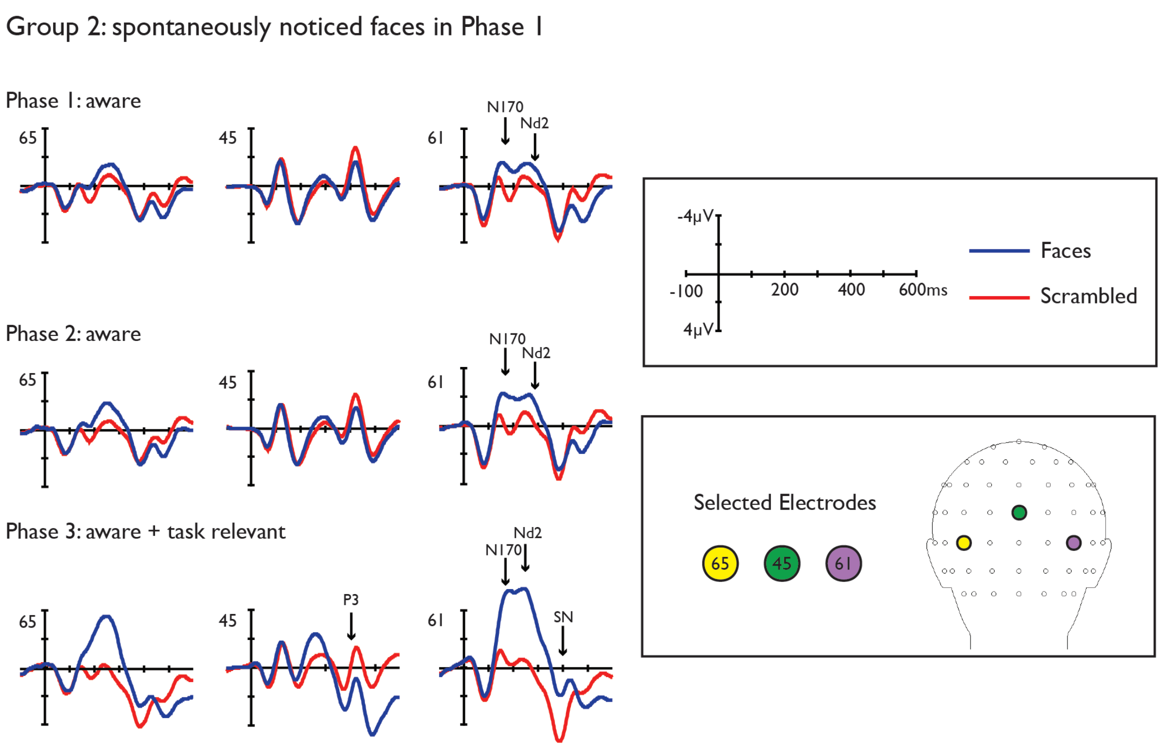


Figure 3.4: ERPs for group 2, aware
ERP waveforms time-locked to the presentation of face and nonface stimuli for subjects who spontaneously noticed faces during the first phase $(n = 14)$. Significant differences denoted with an arrow.

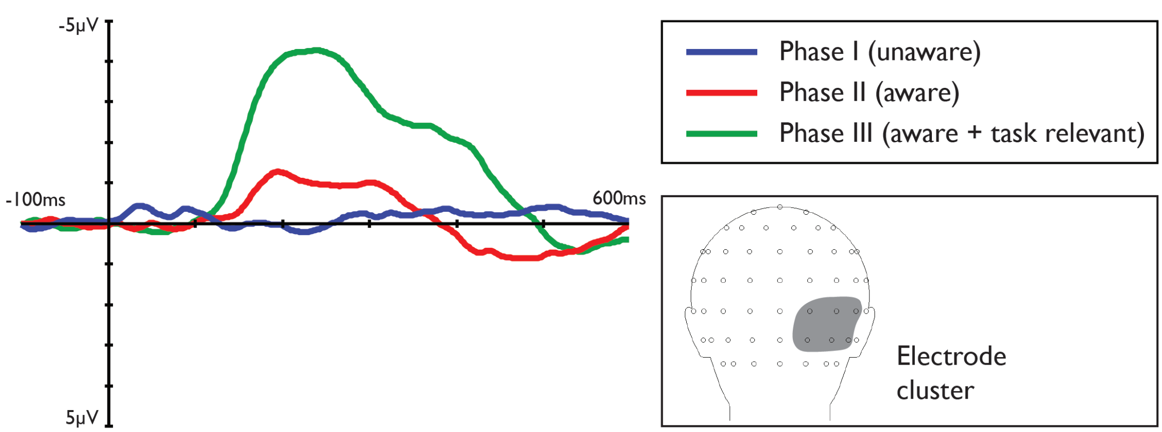


Figure 3.5: Differences waves for group 1, unaware
ERP differences waves (face − scrambled) time-locked to the presentation of face and nonface stimuli for subjects who were inattentionally blind to faces for the entire duration of the first phase $(n = 12)$.

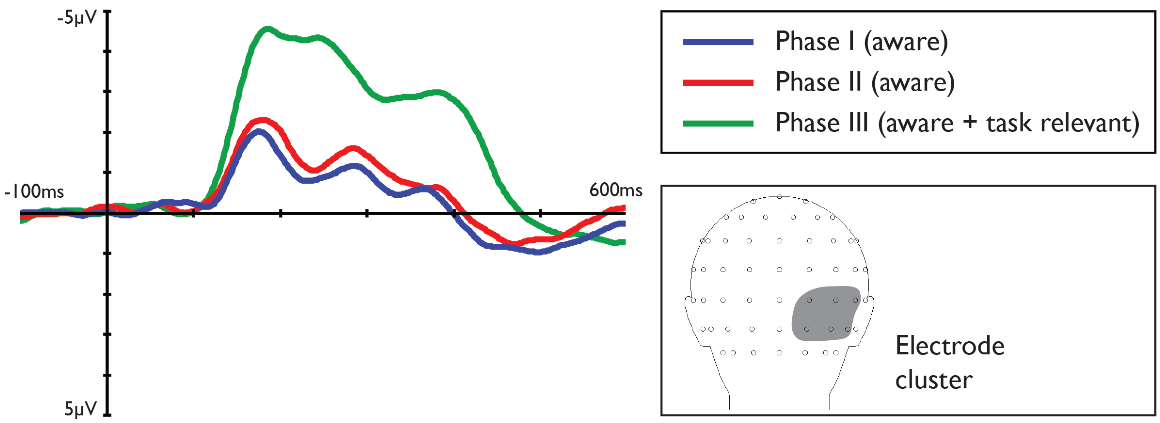


Figure 3.6: Difference waves for group 2, aware
ERP differences waves (face − scrambled) time-locked to the presentation of face and nonface stimuli for subjects who spontaneously noticed faces in the first phase ($n = 14$).

3.2.1 N170 Analysis

Mean amplitude of the N170 was analyzed at a window of 150-190ms. A cluster of lateral occipital electrodes was chosen (60, 61,62, 64, 65, 66, 75, 76, 77, 79, 80) [2]. A repeated measures ANOVA, 2 (hemisphere) × 6 (channel) × 2 (stimulus) × 3 (phase), with one between subjects factor (group) was carried out for this time window. Significant main effects were seen for stimulus and phase, as well as significant interaction effects for group by stimulus, phase by stimulus, phase by hemisphere, stimulus by hemisphere, and phase by stimulus by hemisphere. Planned, paired t-tests revealed significant differences between the average N170 amplitude for face vs. nonface stimuli for aware participants in each phase, (phase 1: $t(13) = -6.53, p < 0.0001$; phase 2: $t(13) = -6.00, p < 0.0001$; phase 3: $t(13) = -8.1759, p < 0.0001$) (see Table 3.2 for mean ERP amplitudes by phase and group).

Meanwhile, unaware subjects only showed significant differences for average amplitude for face vs. nonface stimuli in the second and third phases. (phase I: $t(11) = -0.5282$, ns; phase II: $t(11) = -3.2058, p = 0.0084$; phase 3: $t(11) = -5.1992, p = 0.00029$).

The amplitude of the difference wave (face - nonface stimuli) was compared between groups for each phase (see Figure 3.7). In phase I, this difference was significant $t(17.85) = -5.75, p < 0.0001$. Despite the presence of a significant N170

[2]For electrode locations and comparison with the international system, see Appendix A.

	Phase 1		Phase 2		Phase 3	
	Face	Scrambled	Face	Scrambled	Face	Scrambled
unaware	0.95	1.00	-0.014	0.64	-2.15	0.24
aware	-0.71	0.78	-1.20	0.52	-3.33	-0.21

Table 3.2: ERP amplitudes (N170)
ERP average amplitudes for the 150-190ms time window.

in previously unaware subjects during the second phase, the amplitude was less than that of the aware subjects $t(22.474) = -2.99, p = 0.0067$. The phase III between groups comparison did not reveal significant effects, $t(22.36) = 1.21$, ns.

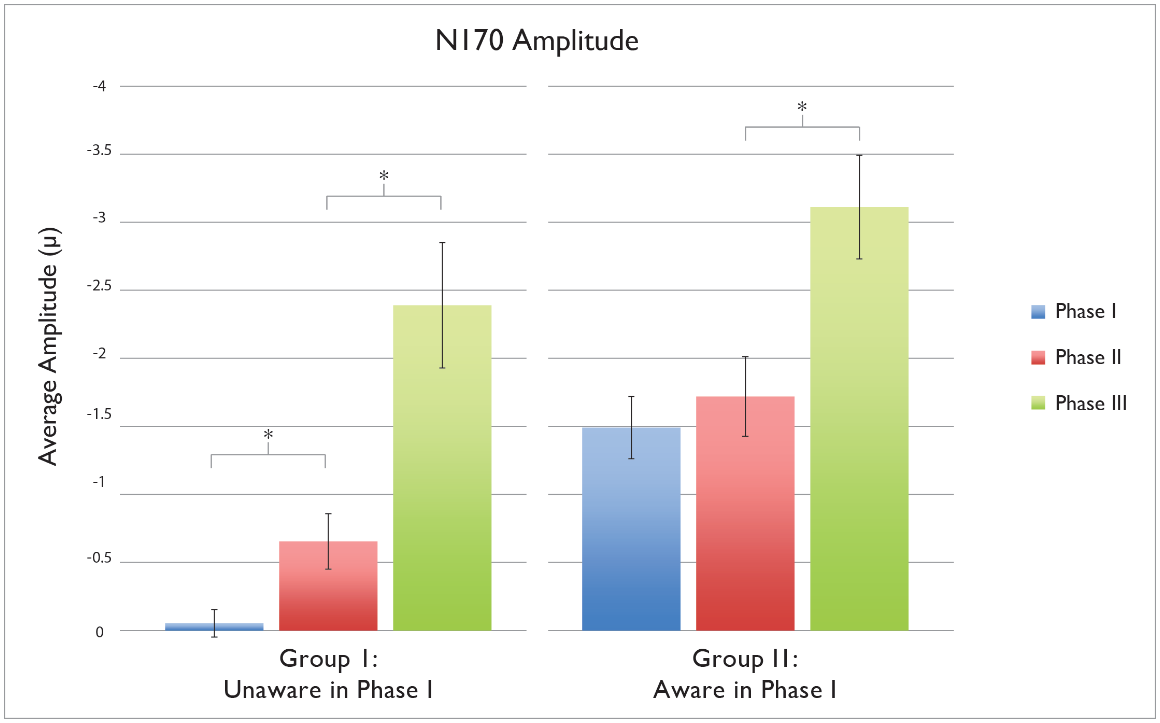


Figure 3.7: Difference wave amplitudes (N170)
This figure shows the N170 difference wave amplitudes for each group over the three phases. Significant differences were between groups in phase I, $t(17.85) = -5.75, p < 0.0001$, and again in phase II, $t(22.47) = -2.99, p = 0.0067$. Phase III did not have significant differences between groups, $t(22.36) = 1.21$, ns

.

Within the group of initially unaware participants, N170 amplitude significantly increased between each subsequent phase (phase I vs. II: $t(11) = 3.72, p =$

0.0034; phase II vs. III: $t(11) = 4.54, p = 0.0008$). For subjects who spontaneously noticed faces during the first phase, no difference in N170 amplitude was found between phases I and II, $t(13) = 1.29$, ns. The N170 was significantly enhanced for task-relevant faces in the phase III when compared with either of the previous phases (phase I vs. III: $t(13) = 4.68, p = 0.0004$; phase II vs. III: $t(13) = 3.93$).

Scalp topographies for the difference wave reveal the distribution of the face-specific activity is consistent with previous studies of the N170, seen over lateral-occipital electrode sites, and stronger on the right (see Figure 3.8).

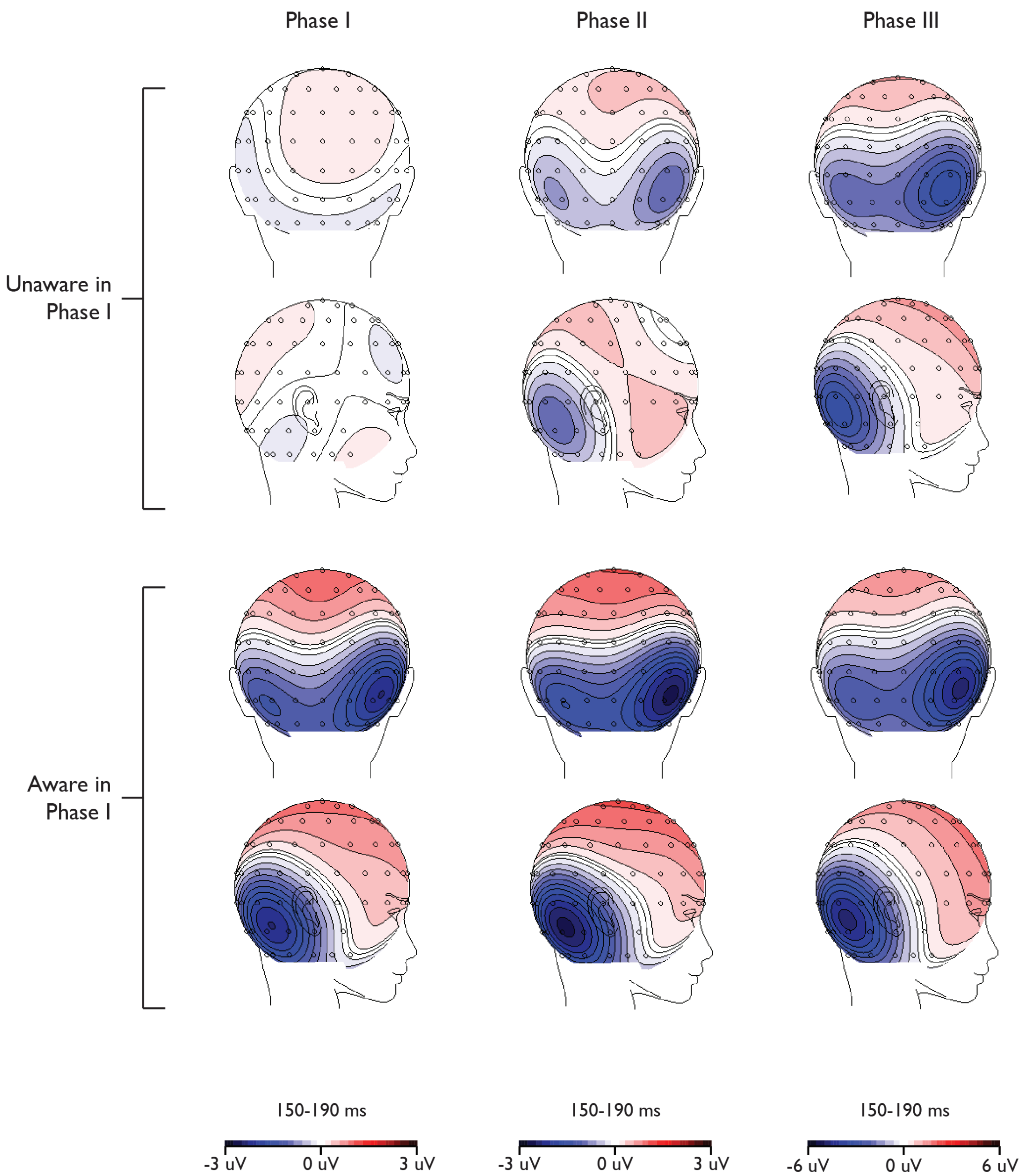


Figure 3.8: Scalp maps for the N170 difference wave.

3.2.2 Nd2 Analysis

A second negative difference (Nd2) following the N170 was observed. The Nd2 appeared at a window of 270-310ms in the first and second phases. In the third phase, this window shifted earlier to 230-250ms. This follows a similar pattern to the one seen in Pitts et al. [41]. The Nd2 was analyzed over the same cluster of lateral-occipital electrodes as the N170. A $2 \times 3 \times 2 \times 2 \times 6$ ANOVA comparing average amplitude over this time window with factors of group (aware vs. unaware), phase, stimulus (face vs. nonface), hemisphere, and electrode revealed significant main effects of phase and stimulus. There were also interaction effects between phase and stimulus, phase and hemisphere, stimulus and hemisphere, and a phase, stimulus, hemisphere 3-way interaction. Paired t-tests were used to assess planned comparisons. These revealed significant differences between the average Nd2 amplitude for face vs. nonface stimuli for aware participants in each phase (phase 1: $t(13) = -3.56, p = 0.004$; phase 2: $t(13) = -5.03, p < 0.001$; phase 3: $t(13) = -8.20, p < 0.0001$)

	Phase 1		Phase 2		Phase 3	
	Face	Scrambled	Face	Scrambled	Face	Scrambled
unaware	-0.75	-0.43	-1.07	-0.076	-3.74	-0.33
aware	-1.26	-0.25	-1.47	-0.065	-4.15	-0.47

Table 3.3: ERP amplitudes (Nd2)
ERP average amplitudes for the 270-310ms time window (Phases I and II), and the 230-270ms time window (Phase III)

Unaware subjects, meanwhile, only showed significant differences in the Nd2 time range for face vs. nonface stimuli for the latter two phases, (phase I: $t(11) = -1.90$, ns; phase II: $t(11) = -4.09, p = 0.002$; phase III: $t(11) = -5.26, p = 0.0003$.) For mean Nd2 amplitudes by phase, stimulus, and group, see Table 3.3.

The amplitude of the difference wave for face vs. scrambled stimuli in this time window differed significantly between groups during the first, but not the second and third phases. During phase I, aware participants had significantly Nd2 amplitude, $t(20.63) = -2.10, p = 0.048$. Nd2 amplitude in phase II, $t(23.90) = -1.13$, ns, and phase III, $t(20.2) = -0.35$, ns, did not differ between groups. Among subjects in the aware group, Nd2 amplitude was significantly greater in the third than in either of the two preceding phases, (phase I vs. III: t = 7.19, df = 13, $p < 0.0001$; phase II vs. III: $t(13) = 6.59, p < 0.0001$, with no difference in amplitude between phases I and II, $t(13) = 1.8011$, ns. For unaware participants, the Nd2 amplitude differed significantly between each combination of phases, phases I vs. II, $t(11) = 2.35, p = 0.038$, phase II vs. III: $t(11) = 4.68, p = 0.00067$. Difference wave amplitudes split by group and phase are shown in Figure 3.9. The difference wave distribution at this time period was very similar to the one seen for the N170, but not identical. The Nd2 difference wave distribution is shown in Figure 3.10.

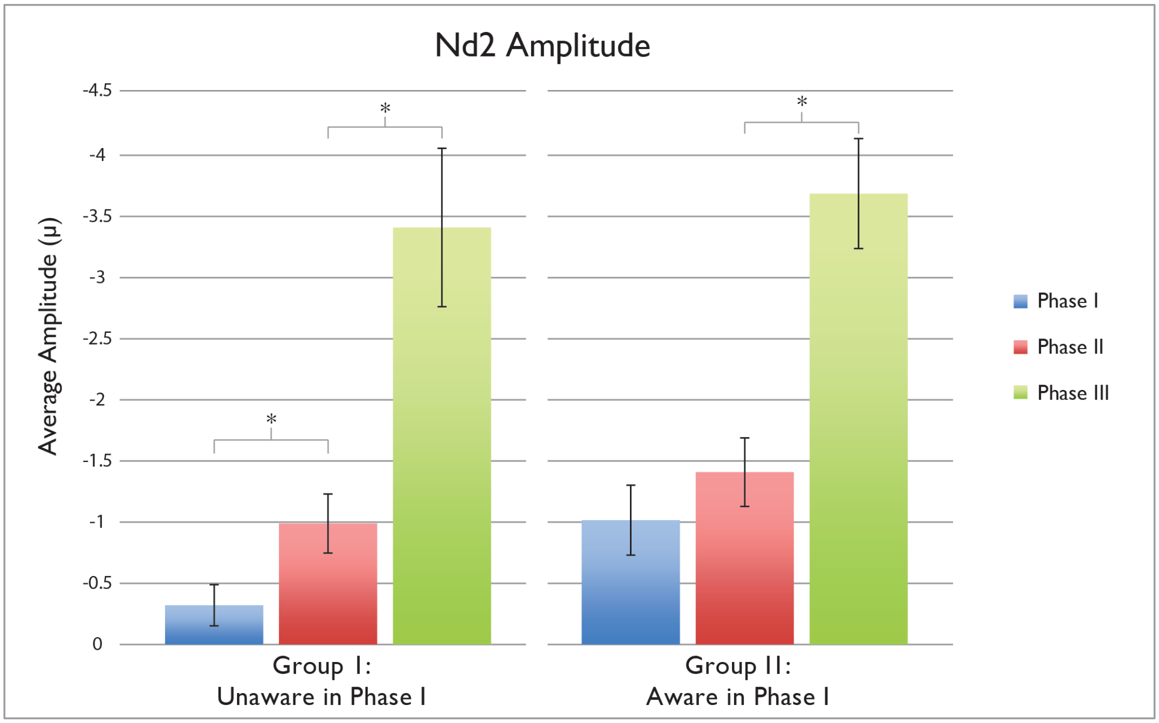


Figure 3.9: Difference wave amplitudes (Nd2)
This figure shows the Nd2 difference wave amplitudes for each group over the three phases. Significant differences were between groups in phase I only, $t = -2.10$, df = 20.63, $p = 0.048$. Nd2 amplitude in phase II, $t(23.90) = -1.13$, ns, and phase III, $t(20.2) = -0.35$, ns, was similar across groups.

3.2.3 P3 Analysis

The P3 was measured at a cluster of 9 posterior central electrodes (14, 1, 13, 27, 28, 29, 44, 44, 46) during the whole 350-450ms, post-stimulus period due to the slow nature of this positivity. An ANOVA by phase, stimulus, and group showed no effects of or interactions with group. Phase $F(2, 48) = 43.64, p < 0.0001$, Stimulus $F(1, 24) = 50.18, p < 0.0001$, and their interaction $F(2, 48) = 28.48, p < 0.0001$ all significantly influenced the average amplitude during this time range. In the first phase, there is no significant effect of stimulus, $t(25) = 1.43$, ns. In the second phase, there is a small, but significant effect of stimulus $t(25) = 2.17, p = 0.0401$. In the third phase, there is a dramatic effect of stimulus on average amplitude, $t(25) = 7.83, p < 0.0001$, with a greatly increased amplitude for face vs. nonface stimuli.

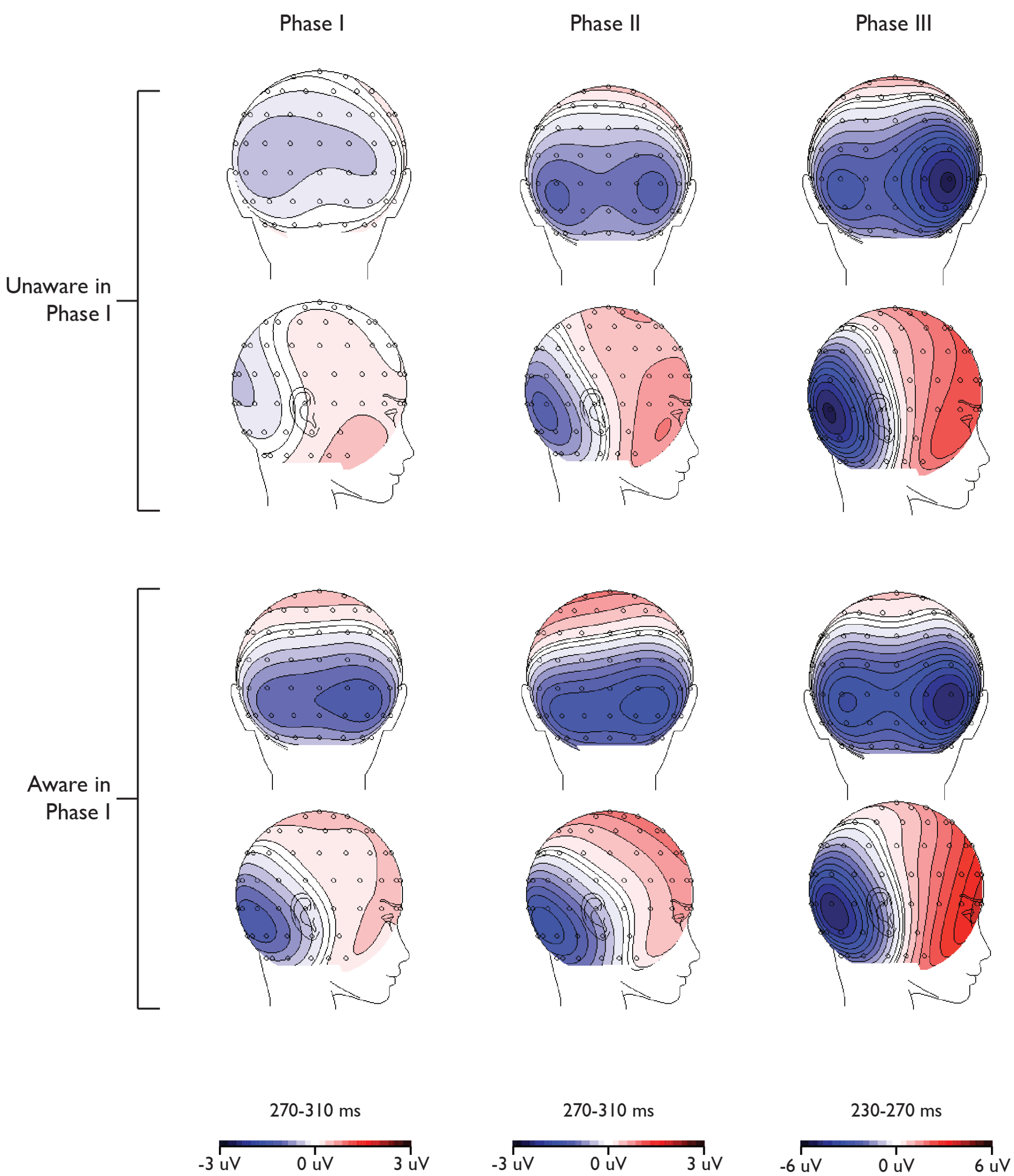


Figure 3.10: Scalp maps for the Nd2 difference wave.

3.2.4 SN Analysis

The SN was measured at a cluster of 14 lateral occipital electrodes, distinct from those used in the N170 and Nd2 analyses (60, 61, 65, 66, 75, 76, 77, 79, 80, 81, 88, 89, 91, 92). It was measured over a period of 380-420ms. ANOVA revealed significant main effect of stimulus, $F(1,24) = 27.30, p < 0.0001$, and a stimulus by phase interaction $F(2,48) = 24.54, p < 0.0001$. Paired t-tests revealed that the only phase in which this effect of stimulus was present was the 3rd phase, when faces were task-relevant, $t(25) = -5.76, p < 0.0001$.

3.2.5 P1 reduction

An unexpected very early negativity was qualitatively observed across all phases and groups. It was measured in a cluster of 15 central occipital electrodes (43, 44, 45, 46, 47, 61, 62, 63, 64, 65, 76, 77, 78, 79, 80) during the 50-90ms period post-stimulus. An ANOVA revealed a significant main effect of stimulus, $F(1,24) = 13.7, p = 0.0011$. Neither group nor phase had a main effect on or an interaction with the appearance of this effect .

Chapter 4

Discussion

4.1 Main findings

A face-related negativity peaking at 170ms was present over occipital electrode sites for consciously perceived faces, and absent when faces were unseen. A second negativity followed, appearing around 100ms later over a similar region of the scalp. Neither component appeared in the absence of conscious perception, and both appeared regardless of task-relevance. This suggests that inattention abolishes ventral-stream, face-specific processing, at least for the face-stimuli used in this study.

When faces were task-relevant, both of these components showed a dramatic increase in amplitude. This provides evidence that the N170 is modulated by task-related attention. Task-relevance also led to a shorter latency of the second component.

4.2 Other findings

Later components, including a selection-related negativity (SN) around 400ms and a P3 appeared consistently for task relevant faces, and were never present in the absence of awareness. When faces were seen but irrelevant, the P3 activity was only sometimes present, and greatly reduced, while the SN was completely abolished. Taken together, these findings suggest that while earlier, ventral stream processing is necessary for awareness, these later components may be more accurately described as consequences of conscious processing (e.g. related to memory or attention), as opposed to correlates of conscious perception per se.

4.3 Interpretations

In the most straightforward interpretation of these findings, any component that was present if and only if a subject was aware would be said to correspond to the process of awareness. The two periods of activity would support a two-stage model of conscious activity. In the first step, around 170ms, the basic categorical information is established, followed by a second, more complex discrimination of identity involving retrieval of visual memory representations. This model is advocated by Rodríguez et al. [43], who recently found, using a backward-masking paradigm, neither N170 effects nor later effects for unseen faces. This interpretation is consistent with the idea that category-specific processing does not occur in the absence of awareness.

While finding the presence of face-specific activity in the absence of awareness could have ruled out the possibility that this activity corresponds to phenomenal awareness, failing to find such activity in the absence of awareness does not conclusively demonstrate that these processes are sufficient for conscious experience. Another possible explanation might instead place the N170 in a preconscious role, engaging attentional mechanisms to make the conscious perception of faces possible. Evidence for this might be drawn from other studies that found awareness of other types of stimuli correlate to a single component, later in time than the N170 [41, 27]. In the current study, faces that were unnoticed were also unattended (as is the case in inattentional blindness); subjects noticed the faces in phase I or phase II when attention was captured by or directed toward the faces. Thus, the fact that the N170 was present only when subjects consciously perceived the faces may not suggest a direct relationship between the N170 and awareness but rather between the N170 and attention, with attention being a prerequisite for awareness.

Additional evidence could be drawn from this study itself—while the Nd2, which possibly corresponds to the visual awareness negativity (VAN) [26], is equal in amplitude in all groups during conscious perception of task-irrelevant faces, the participants who failed to perceive faces in the first phase have smaller N170s when faces are viewed passively. Perhaps those subjects who were capable of remaining unaware of a salient face are less likely to have their attention captured by faces more generally, so they would have less activity related to automatic facial attention. Another pattern that supports this hypothesis is the inconsistent presence of the P3 during awareness. The late, positive difference was sometimes significant for task irrelevant faces for participants from the aware group, but never significant for task-irrelevent faces in the previously unaware participants. If the faces were sometimes actively attended by participants who found their attention more easily stolen by the presence of the faces, it could lead to a slight increase in post-perceptual processing.

Finally, the fact that the face stimuli used in this study were neutral, and only contained high spatial-frequency information may have prevented deeper categorical processing from occurring in the absence of awareness. Evidence suggests that both low spatial frequency information and emotional expressions are processed along different, possibly more automatic routes [52, 37, 50]. It is possible that face-specific cognitive-processing mechanisms that can be engaged in the absence of awareness are contingent upon the pathways for processing emotional stimuli or low spatial-frequency information.

4.4 Future Directions

Further investigation on the early P1 reduction for faces compared to random stimuli is warranted and is currently underway. It seems unlikely, given the otherwise carefully-controlled stimulus design, as well as the lack of face-specific processing before 170ms in the literature, that this activity would be reflective of a high-level categorical discrimination. A follow-up study using modified stimuli with similar repetition characteristics, although lacking all resemblance to face will be used to confirm the hypothesis that the P1 reduction was a low-level stimulus repetition effect.

While the current study focused mostly on the differences in processing related to awareness, further investigation might examine the effects of task-specific attention. The relationship found between later components and awareness (e.g. the P3) was somewhat inconsistent. Further research could determine whether later effects are present for entirely ignored faces whenever subjects are aware of a face, or whether the occasional appearance of the P3 in the absence of task-relevance is because subjects sometimes fail to ignore the unexpected faces. Focusing on how processing differs between irrelevant faces and task-relevant ones might help disentangle the consequences of awareness from the activity that constitutes awareness.

Finally, the face-stimuli used in this study were minimal and well-controlled, containing only a very basic set of information necessary for the perception of a face without loss of salience. This was a strength of the study, however, additional exploration of how other sorts of face-information might be processed under conditions of inattentional blindness would provide more conclusive evidence about the possibility of face-specific ventral stream processing without awareness. Face processing is understood to rely on a combination of low and high spatial-frequency information, processed through the magno- and parvocellular pathways, respectively [50]. If low spatial frequencies can be processed nonconsciously, this would not have been seen with the current stimulus set. Additionally, very few studies rely on task-irrelevant faces in order to examine conscious face perception. It is a mistake to overlook how task-related attention can influence mental processing, even when attention fails to result in awareness. A follow-up study might involve a similar paradigm, but using face-stimuli with emotional or low-frequency information, so as to explore how other aspects of faces are processed in the absence of awareness and attention.

Conclusion

Salient faces frequently appearing in the center of the visual field failed to capture attention due to the presence of a demanding task. In this condition of inattention, no ventral stream face-specific activity was seen. Under identical task parameters, aware subjects—both those who spontaneously noticed faces, and those who had previously been unaware—showed a characteristic face-related N170. A second negativity showed a similar pattern, appearing only during awareness, regardless of task-relevance. These findings suggest a fundamental relationship between early ventral stream, object-specific processing and awareness.

Appendix A

Questionnaire

Post-Test Questionnaire

Phase: _____

Subject: ____________
Date: ____________

1. Describe (or draw) any patterns you observed in the background lines during the target detection task.

2. Some participants were randomly assigned to conditions in which the line segments in the background occasionally formed coherent patterns. Did you see any coherent patterns?

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

3. 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

Violin	☐1	☐2	☐3	☐4	☐5
Face	☐1	☐2	☐3	☐4	☐5
Lightbulb	☐1	☐2	☐3	☐4	☐5
Flower	☐1	☐2	☐3	☐4	☐5
Car	☐1	☐2	☐3	☐4	☐5

4. 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

Violin	☐1	☐2	☐3	☐4	☐5
Face	☐1	☐2	☐3	☐4	☐5
Lightbulb	☐1	☐2	☐3	☐4	☐5
Flower	☐1	☐2	☐3	☐4	☐5
Car	☐1	☐2	☐3	☐4	☐5

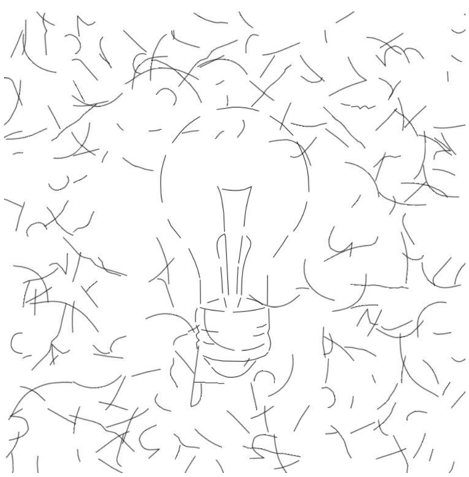
5. At what point in the experiment did you see each of the following patterns start appearing?

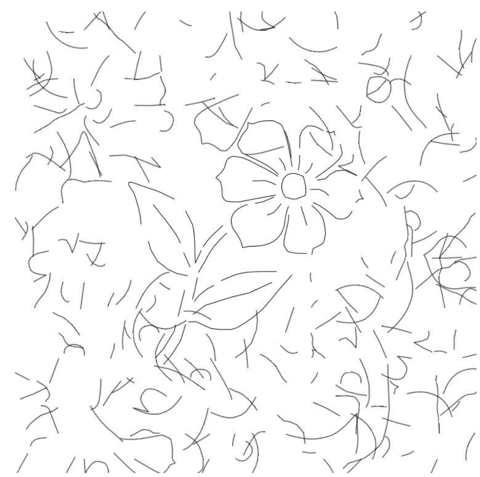
Please use the following scale:
1 = training
2 = a previous phase
3 = first half of this phase
4 = second half of this phase
5 = never

Violin	☐1	☐2	☐3	☐4	☐5
Face	☐1	☐2	☐3	☐4	☐5
Lightbulb	☐1	☐2	☐3	☐4	☐5
Flower	☐1	☐2	☐3	☐4	☐5
Car	☐1	☐2	☐3	☐4	☐5

6. Any additional comments about this phase may go here.

Figure A.1: Questionnaire

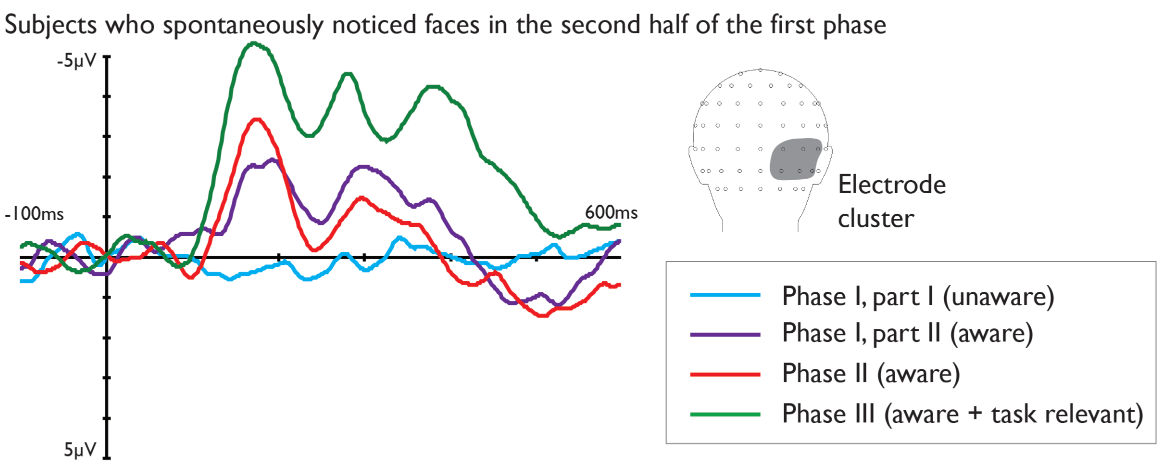




Appendix B

Half-Aware Participants: Brief examination

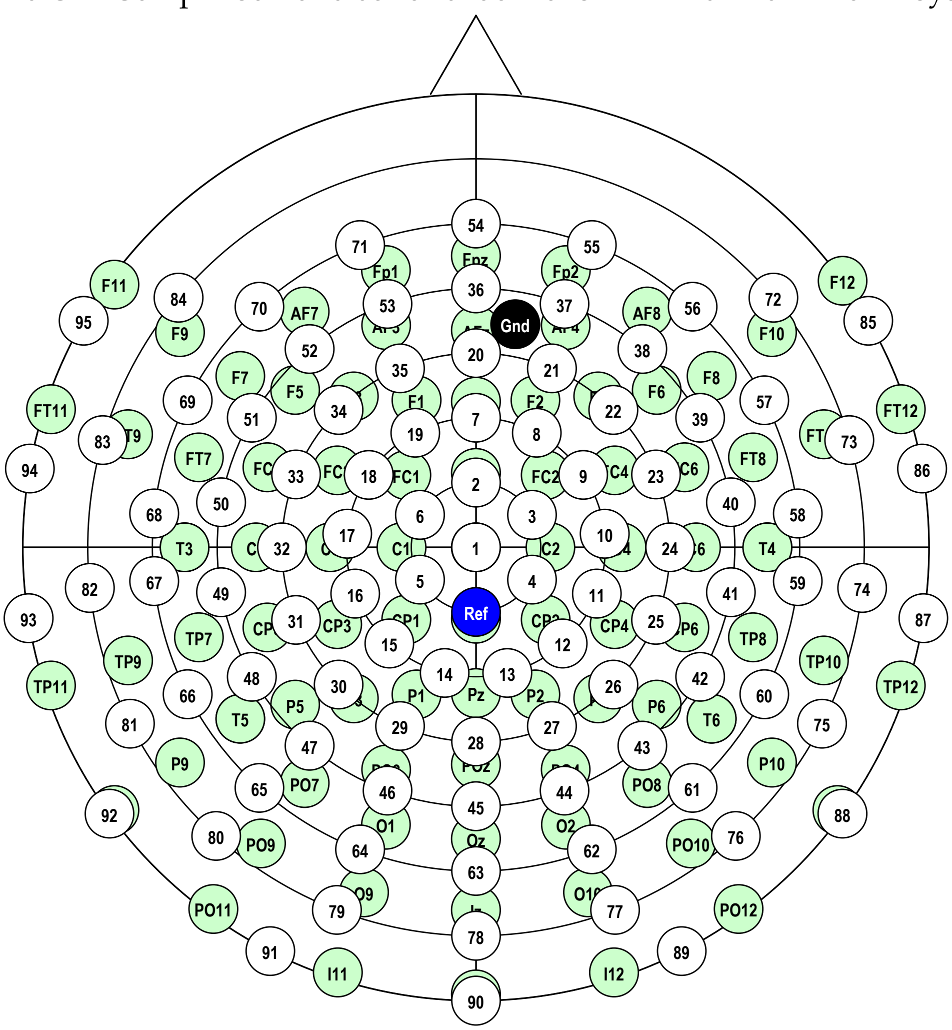
Four subjects reported noticing the faces after the break in the middle of the first phase. Approximately 90 trials were possible in each half of a phase before the rejection of artifact trials—an inadequate quantity to warrant inclusion with the regular analyses. While four subjects is too few for meaningful quantitative analysis, their data is strikingly consistent with the findings of this study.



Appendix C

Complete list of electrode locations

Figure C.1: Comparison of electrode locations with the international system



Name	Theta	Phi	Name	Theta	Phi	Name	Theta	Phi
1	0	0	33	-60	-22	65	-100	48
2	20	90	34	-60	-45	66	-100	27
3	20	30	35	-60	-67	67	-100	6
4	20	-30	36	80	90	68	-100	-6
5	-20	30	37	80	70	69	-100	-27
6	-20	-30	38	80	50	70	-100	-48
7	40	90	39	80	30	71	-100	-69
8	40	62	40	80	10	72	120	40
9	40	34	41	80	-10	73	120	16
10	40	6	42	80	-30	74	120	-6
11	40	-21	43	80	-50	75	120	-27
12	40	-48	44	80	-70	76	120	-48
13	40	-76	45	80	-90	77	120	-69
14	-40	76	46	-80	70	78	120	-90
15	-40	48	47	-80	50	79	-120	69
16	-40	21	48	-80	30	80	-120	48
17	-40	-6	49	-80	10	81	-120	27
18	-40	-34	50	-80	-10	82	-120	6
19	-40	-62	51	-80	-30	83	-120	-16
20	60	90	52	-80	-50	84	-120	-40
21	60	67	53	-80	-70	85	140	30
22	60	45	54	100	90	86	140	10
23	60	22	55	100	69	87	140	-9
24	60	0	56	100	48	88	140	-36
25	60	-22	57	100	27	89	140	-63
26	60	-45	58	100	6	90	140	-90
27	60	-67	59	100	-6	91	-140	63
28	60	-90	60	100	-27	92	-140	36
29	-60	67	61	100	-48	93	-140	9
30	-60	45	62	100	-69	94	-140	-10
31	-60	22	63	100	-90	95	-140	-30
32	-60	0	64	-100	69	ECG	-180	55
Gnd	70	80	Ref	20	-90			

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