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Profiling Attention's Pure Effect on the Sensory-Evoked P1 and N1 Event-Related Potentials of Human Electroencephalography

by

Allison Elisabeth Connell

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Psychology

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Lynn C. Robertson, Chair
Professor Richard Ivry
Professor Michael A. Silver

Spring 2013

Profiling Attention's Pure Effect on the Sensory-Evoked P1 and N1 Event-Related Potentials of Human Electroencephalography

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Allison Elisabeth Connell

Abstract

Profiling Attention's Pure Effect on the Sensory-Evoked P1 and N1 Event-Related Potentials of Human Electroencephalography

by

Allison Elisabeth Connell

Doctor of Philosophy in Psychology

University of California, Berkeley

Chair: Lynn C. Robertson

In this dissertation, I will discuss my research on the effect of spatial and feature attention effects on human electrophysiological responses to visual stimuli. This work involved minimizing previous sensory confounds in the physical structure in attention tasks, as well as separately analyzing how the brain responds to an orienting cue and a target that requires an overt behavioral response. By controlling for previous confounds, I was able to examine the effect of attention on sensory-evoked components in the absence of a sensory account for brain modulation.

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To the people who kept me sane through the crazy ride that is grad school: Thank you!

1. Introduction

Attention is a crucial mechanism that modulates the visual perception of objects and scenes. When a person views a computer screen, they are able to selectively attend to different items on the screen, moving their attention from location to location. When attention is pre-cued to a spatial location, visual processing of a stimulus presented at that location is facilitated (Mangun, 1995), discrimination of a stimulus in a multi-item display is improved (Henderson, 1991), a stimulus can be detected and responded to more quickly (Posner, 1980), and event-related potentials (ERPs) to that stimulus location are increased in amplitude (Hillyard & Münte, 1984).

One classic paradigm for studying spatial attention is the spatial-cueing task (Posner, 1980; Posner, Nissen, & Ogden, 1978) in which attention is briefly engaged by a central or peripheral cue to one of several possible target locations. A target then appears in the cued location (valid trial) or in an uncued location (invalid trial). Proportional variation of valid to invalid trials manipulates the informative value of the cue. For instance, when there are two possible target locations and 70% of the trials are valid, a participant should benefit from using the cue to orient attention to the probable target location. If, however, the cue is 50% valid (chance), then there is no consistent benefit to orienting to the cued location.

This type of trial-by-trial, transient cueing is distinct from sustained attention, in which a participant is instructed to attend to part of space for a longer period of time. Many tasks exist to study this type of attention (Sarter, Givens, & Bruno, 2001), but a common method involves asking a participant to maintain their attention to the left or right side of fixation (where the gaze is directed) for an entire block of trials during which stimuli are briefly presented on either side of space. The participant needs only respond to a target when it appears in the half of space to which they are attending. Hillyard and Münte (1984) used a dual attribute sustained attention task in which they asked their participants to attend to a specific stimulus color and location combination, e.g., blue bars appearing to the left of fixation. Participants were asked to respond to infrequent targets (shorter bars among taller standards) that matched their color/location assignment. These authors recorded the electroencephalographic (EEG) response from scalp electrodes as their participants performed the attention tasks and found a consistent effect of spatial attention on the early event-related potentials (ERP). ERP amplitudes to the attended stimuli were greater than amplitudes to the unattended stimuli, a finding consistent with many studies of spatial attention (Eason, 1981; Harter, Aine, & Schroeder, 1982; Harter, Miller, Price, LaLonde, & Keyes, 1989; Hillyard & Anllo-Vento, 1998; Hillyard, Vogel, & Luck, 1998; Luck & Hillyard, 1995, Mangun, 1995; Mangun & Hillyard, 1987; Mangun & Hillyard, 1990, 1991).

A second consistent finding of spatial attention in the ERP literature is a relative amplitude modulation in which the voltage at electrode sites contralateral to the attended stimulus increases relative to the electrodes ipsilateral to the stimulus, showing a sensitivity to the direction of attention (Harter, et al., 1982; Heinze, Luck, Mangun, & Hillyard, 1990; Hillyard & Anllo-Vento, 1998; Luck, Heinze, Mangun, Hillyard, 1990; Luck, & Hillyard, 1994; Mangun & Hillyard, 1990; Mangun, & Hillyard, 1991; Martinez, DiRusso, Anllo-Vento, Sereno, Buxton, & Hillyard, 2001). These spatial attention effects typically occur for the sensory-evoked P1 and

N1 components, which peak quickly after stimulus onset (approximately 100-130 ms and 150-200 ms, respectively). These components are called sensory-evoked because they are automatically generated by the appearance of a visual stimulus. They are also the earliest components to show modulation by spatial attention. Both of these characteristics make them the ideal brain response measure for the following experiments.

The experiments in this dissertation investigate transient spatial attention. As such, two important implications concerning the composition of the spatial-cueing task need to be considered. First, in most spatial-cueing task designs, there is a physical difference between cueing conditions. An informative cue that flashes at a given location predicts that a target will appear in that cued location more often than in the uncued location; whereas a noninformative cue predicts an equal number of targets appearing in the cued and uncued locations. Thus, there are two onsets at the same location more often in the informative than noninformative cueing conditions. Second, invalid trials have a different physical composition (cue and target appear in different locations) than valid trials (cue and target appear in the same location). On valid trials, the same groups of neurons are visually stimulated successively, once by the cue and once by the target. On invalid trials, the visual activation is divided between different brain regions, even between different hemispheres. This physical difference occurs within a cueing condition, regardless of the cue's informative value. As has been noted by previous researchers (e.g., Mangun, 1995; Nobre, Sebestyen, & Miniussi, 2000), differences in attentional effects on the sensory-evoked components must naturally contain sensory information from the trial structure itself. Mangun (1995) dubbed this the "sensory-sensory interaction," meaning the sensory event of the cue's appearance interacts with the sensory event of the target. In these previous studies, the ERPs were aligned to the onset of the target. These physical differences in trial structure present a special challenge when interpreting electrophysiological data of sensory-evoked potentials.

Previous designs have been used to control for one or the other of these two physical differences during an attention task. Heinze, Luck, Mangun, and Hillyard (1990) used a sustained attention task in which they presented bilateral letters, thus equating the target appearance on both sides of space (see also Luck, Heinze, Mangun, & Hillyard, 1990). Other researchers using a transient attention task have presented their cues centrally at fixation (also called symbolic cueing), rather than in the periphery (e.g., Sauseng, et al. 2005). This manipulation has the effect of separating the cue location from the target location for both valid and invalid trials. Interestingly, even when the cue is spatially separated from the target, areas representing the future target's location become active during the cue period (Martinez, et al., 2001). However, as previous studies presented a single cue and/or a single target, the relative dominance of contralateral over ipsilateral activity must still reflect some amount of visual stimulation leading to greater amplitude response relative to no visual stimulation, making it difficult to interpret the ERP modulations.

The challenge of equating physical trial composition in spatial-cueing tasks has made it unclear whether previous findings of the sensory-evoked P1 and N1 components' amplitude modulations reflect the orienting of attention, physical differences in trial composition, or more likely their interplay. Importantly, very few researchers have reported cue-related ERPs (Eimer,

1993; Harter, et al., 1989; Nobre, et al., 2000; Yamaguchi, Tsuchiya, & Kobayashi, 1994). Rather ERPs are typically time-locked to the target's appearance. One notable exception was a study reported by Nobre and colleagues (2000) in which they were concerned both with the physical confound that a solitary cue presents and how cue processing affects ERPs. They designed a spatial-cueing task in which bilateral cues were presented at fixation. Their cues were two colored arrowheads (red and green) that together formed a diamond. One color predicted a peripheral target with 80% validity. Participants were instructed to attend to a different informative color in different blocks. Variable cue-target intervals (CTIs) were used including 100 ms, 300 ms, and 700 ms. Cue-related ERPs were constructed in the 300 and 700 ms conditions. These authors found greater cue-related negativity contralateral to the direction of attention within a time range consistent with the N1 component (starting at 160 ms post-cue). No comparable cue-related P1 modulation occurred. The authors also analyzed target-related ERPs, however, their target event was still a solitary stimulus.

In Experiments 1 and 2 of this proposal, we investigate the separate effects of cue and target processing on the sensory-evoked P1 and N1 components when trial composition is identical. Importantly, a long cue-target interval (600 ms) was used to temporally separate cue and target activation in the ongoing EEG response. Bilateral peripheral cues and bilateral targets were presented on every trial to equate the physical appearance of both events within and between cueing conditions. The cues were presented together in time but separated in space on the left and right sides of fixation. For the Informative cue group, one of these cues predicted the target's location and participants were instructed to attend this cue, while in the Noninformative cue group neither cue was more predictive than the other. The target was always accompanied by a non-target stimulus in the opposite location. Thus, both the attended and the unattended locations always contained a stimulus with similar sensation received by the right and left hemispheres on every trial.

Despite the presence of two cues preceding the targets, the present studies are not dual attribute designs (e.g., Hillyard & Münte, 1984), nor are they divided attention tasks meant to vary the amount of attention allocated across space (e.g., Mangun & Hillyard, 1990). Rather, Experiments 1 and 2 employ a transient spatial-cueing task in which the physical composition of all trials within and between conditions has been equated. The purpose of this design is to investigate attentional modulations of the sensory-evoked P1 and N1 components when all other "sensory" accounts of modulation have been ruled out. To our knowledge, these experiments represent the first instance of a single task correcting both physical confounds while also allowing for the separation of cue-related and target-related processing.

2. Bilateral Color Cueing in EEG (Experiment 1)

Using this bilateral-cueing procedure, attentional modulation of the peak amplitudes of P1 and N1 could be investigated when stimulus parameters were visually the same on every trial. The P1 and N1 components are known to be affected by sensory input (Luck, 2005). Having equated the sensory appearance of the cue and target events both within and between conditions, our design controls for any sensory-driven amplitude modulation, leaving a purer profile of attention's effects.

If these ERP components reflect the focus of spatial attention, we would predict a general amplitude modulation between conditions with the amplitudes in the Informative condition being greater than those in the Noninformative condition. If these components reflect spatial attention's effect, we would also predict relative amplitude modulation with greater activation contralateral to the Informative cue than ipsilateral. If, however, previous effects on these components reflected the physical composition of the trial structure (e.g., single onset cue and/or single onset target), then we would not expect to find either amplitude effect in the present study, which has equated all physical aspects of the trial structure.

2.1. Method

2.1.1. Participants

Thirty-two undergraduate and graduate students from the University of California, Berkeley volunteered to participate in this study. Sixteen participants were in the Informative condition (mean age = 21.1 years, 8 female). Sixteen participants were in the Noninformative condition (mean age = 22.1 years, 8 female). Different participants were selected to perform in the two cueing conditions due to behavioral carry-over effects during pilot testing. All participants were self-described as right-handed and had normal or corrected-to-normal vision. All participants gave signed informed consent approved by the Committee for Protection of Human Subjects at the University of California, Berkeley.

2.1.2. Procedure

In both the Informative and Noninformative conditions, participants performed a letter discrimination task. Each trial began with a centrally presented fixation cross and two empty boxes, one presented to the left and one to the right of fixation. Participants were instructed to maintain fixation across all trials. Bilateral cues were presented by filling in one of the boxes in blue and the other box in red. Blue appeared randomly 50% of the time on the left (red on the right) and 50% on the right (red on the left). Either a T or an F subsequently appeared at one of the two locations accompanied by a non-target O in the opposite location. The color cues were presented 600 ms before the appearance of the letter stimuli. Letters appeared for 80 ms and offset with cues (see Figure 1). Instructions were to determine whether the target was a T or F. Every trial was followed by a blank fixation inter-trial interval of 1,000 ms. After each block, percent correct and average reaction time (RT) for that block were given as feedback. Both speed and accuracy were emphasized.

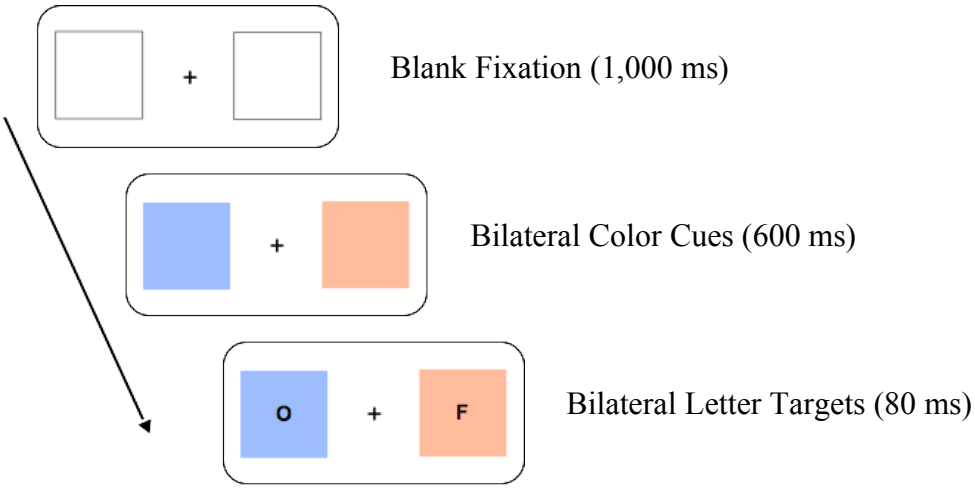


Figure 1. **Experiment 1, trial structure.**

In the Informative condition, 9 participants were instructed to pay attention to the blue cue (valid trials for these participants) and 7 were instructed to pay attention to the red cue.[1] The target letter appeared in the informative color's box on 75% of the trials. On 25% of the trials, the target letter appeared in the uninformative color's box (invalid trials). Ten blocks of 64 trials were completed. In the Noninformative condition, the target letter appeared in the red box 50% of the time and in the blue box 50% of the time. These participants were instructed to ignore the color cues. Eight blocks of 64 trials were completed.

2.1.3. Stimuli

Stimuli were presented on a 20-inch monitor at a viewing distance of 60 cm, held constant by a chin rest. At this distance, the cues appeared at 6.65 degrees visual angle and the letters appeared centered in these cues at 8.06 degrees visual angle as measured from fixation to the inside edges. Cues were square boxes (3.3 x 3.3 degrees). Letters appeared in bold Helvetica font, size 14 (.48 degrees). RGB values for Blue cues were 155, 185, and 255. RGB values for Red cues were 255, 185, and 155. Cues were presented on a light grey background. Luminance values for the Red and Blue cues when viewed in the darkened EEG booth were 13.93 cd/m^2 and 11.33 cd/m^2, respectively. Stimuli were presented using E-Prime software.

2.1.4. EEG Acquisition and Processing

EEG was recorded at a sampling rate of 1024 Hz with a Biosemi Active View system. Data were collected from 64 scalp electrodes of a modified 10-20 system montage. Additional electrodes were placed at the left and right external canthi, which served as the horizontal electro-oculographic (EOG) signals. Vertical EOG was recorded from an electrode placed

[1] The number of participants attending red and blue differ due to random assignment of informative cue color. Differences between attending red and blue were analyzed and found to have no effect on any of the other variables.

beneath the right eye and electrode Fp1 above the right eye. An electrode at the end of the nose served as the reference for all data processing.

Brain Vision Analyzer was used for all preprocessing. Correctly-performed trials were segmented from 200 ms before the cues' onset to 1,100 ms after cues' onset. These segments were then checked for artifacts resulting from blinks or horizontal eye movements. Artifacts were semi-automatically identified using a strict criterion of +/- 50 microvolts (μv). Segments with an artifact were rejected from subsequent analysis.

In order to compare peak amplitudes between conditions (Luck, 2005), the number of trials in the Information and Noninformative conditions were equated. These epochs were then baseline corrected from -200 to 0 ms, bandpass filtered from 1.5 to 17 Hz, and averaged separately for each condition. As has been the method in previous studies with a unilateral cue/target, this pre-cue activity was used as the baseline for the cue-related and target-related analyses. The comparable pre-target baseline was also used to analyze the target-related peaks. All results remained unchanged; therefore, all of the reported results for Experiment 1 are with reference to the pre-cue baseline.

For each participant, cue-related and target-related peak amplitudes were selected. The cue-related P1 peak was selected from 70-180 ms post-cue onset, and the cue-related N1 was selected from 115-220 ms post-cue onset. The target-related P1 peak was selected from 680-800 ms post-cue onset, which is equivalent to 80-200 ms post-target onset. The target-related N1 peak was selected from 750-840 ms post-cue onset, which is 150-240 ms post-target onset. Specific peak timings were determined from examining the grand average waveforms. All peaks were selected from electrodes O1/O2, PO3/PO4, PO7/PO8, P7/P8, and P9/P10 located over the left and right hemispheres, respectively

2.2. Results

All analyses were completed on correctly-performed trials. All ERP analyses were performed on a randomly sampled 120 trials per condition. Each electrode's P1 and N1 peak amplitudes were identified (see Figure 3). These individual electrode amplitudes were then pooled for the P1 and N1 and used for the reported analyses. The same analyses were also performed on the individual electrode pairs, the results of which are presented in Tables 1 and 2.

2.2.1. Behavioral Results

High accuracy occurred in both conditions (M_{Inform} = 95.1% correct, $M_{\text{Noninform}}$ = 95.5% correct). As expected, in the Informative condition targets in the location of the valid colors were responded to faster (78 ms) than those in the location of the invalid colors ($t_{(15)} = -5.3$, $p < .001$). There were no "valid" and "invalid" cues for the Noninformative case due to the bilateral nature of the cueing, but participants were slightly faster (6 ms) responding to targets appearing in the red cue's location ($t_{(15)} = -3.8$, $p < .01$; see Figure 2).

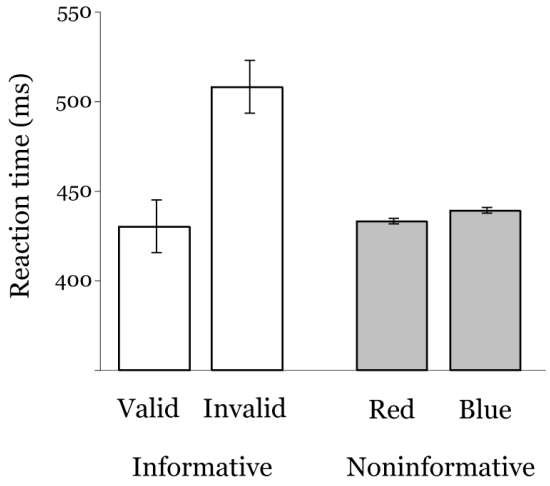


Figure 2. **Experiment 1, behavioral reaction time results.** There was a significant cueing effect in the Informative condition, with Valid trials being responded to much faster than Invalid trials ($p < .001$). There was a small, but significant, difference between response times to targets appearing in the Red versus Blue box in the Noninformative condition ($p < .01$). Error bars are the standard error of the mean for the within-subjects analyses.

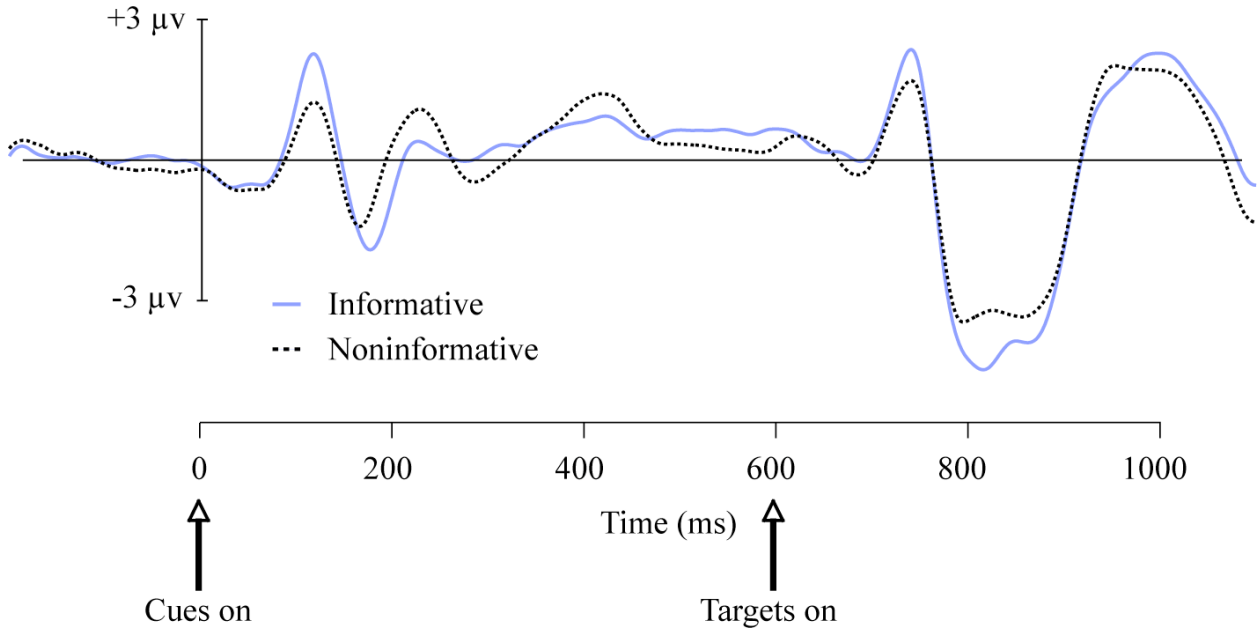


Figure 3. **Experiment 1, grand average waveform.** Average evoked response from the 10 analyzed electrodes (O1, O2, PO3, PO4, PO7, PO8, P7, P8, P9, and P10). This waveform shows a clear separation between the cue-related and target-related responses with a return to baseline activity in between.

2.2.2 Cue-Related ERP Results

Cue-Related P1 Effects

General amplitude modulation due to attending the cues was tested with an independent-means t-test (see Figure 4). This comparison between the Informative and Noninformative conditions revealed a significant effect of attention ($t_{(30)}$ = -2.06, p = .05, Pearson's r = .35, Hedges' g = .75) with the mean amplitude for Informative (M_{Inform} = 2.84 μv) being greater than Noninformative ($M_{\text{Noninform}}$ = 1.93 μv). Laterality effects were tested with a dependent-means t-test of Contralateral versus Ipsilateral activity in the Informative cue condition (see Figure 5). This test revealed no modulation with the direction of attention ($t_{(15)}$ = -1.23, p = .24, Cohen's d = .31), suggesting that focused spatial attention was not directed to the location of the color cue even in the Informative case (M_{Contra} = 2.89 μv; M_{Ipsi} = 2.79 μv).

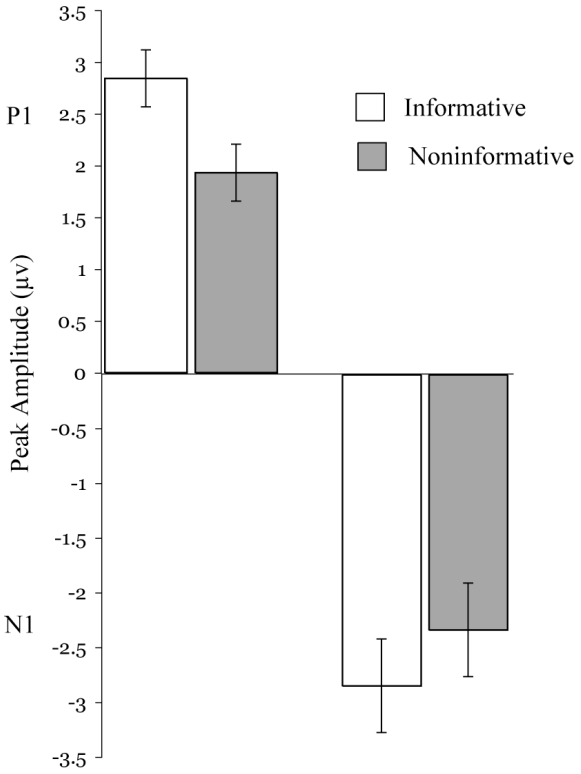


Figure 4. **Experiment 1, cue-related general amplitude effects.** For the P1 component, there was a significant difference between the evoked responses in the two cueing conditions ($p \leq .05$). There was no significant difference on the N1 component ($p > .05$). Error bars are the standard error of the mean for the between-subjects analyses.

Cue-Related N1 Effects

An independent-means t-test was used to determine if a general amplitude effect was present (see Figure 4). Contrary to the cue-related P1, this comparison between the Informative and Noninformative conditions revealed no general effect of attention ($t_{(30)}$ = .92, p = .36, Pearson's r = .17, Hedges' g = .34); the mean amplitude was not significantly greater for

Informative than Noninformative cues (M_{Inform} = -2.84 μv; $M_{Noninform}$ = -2.33 μv). The dependent-means t-test for laterality within the Informative condition revealed no modulation with the direction of attention ($t_{(15)}$ = -.38, p = .71, Cohen's d = -.31, see Figure 5), again suggesting that spatial attention was not directed to the location of the color cue even in the Informative case (M_{Contra} = -2.86 μv; M_{Ipsi} = -2.82 μv). This interpretation will be discussed below.

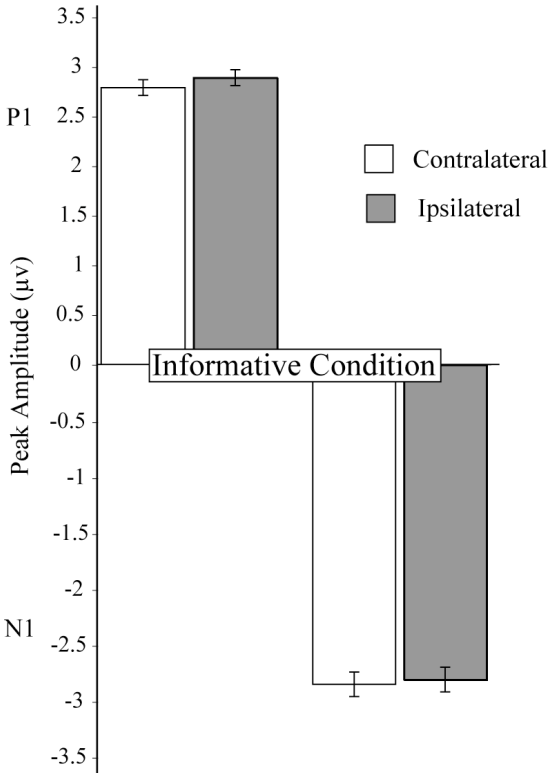


Figure 5. **Experiment 1, cue-related laterality effects in the Informative condition.** Contralateral refers to the electrodes over the hemisphere contralateral to the attended color cue. Neither the P1 nor the N1 component showed a significant difference between the evoked laterality responses (p > .05). Error bars are the standard error of the mean for the within-subjects analyses.

2.2.3 Target-Related ERP Results

Target-Related P1 Effects

An independent-means t-test between the Informative and Noninformative conditions revealed no general effect of attention ($t_{(30)}$ = -.63, p = .53, Pearson's r = .11, Hedges' g = .23) although the mean amplitude for Informative (M_{Inform} = 2.97 μv) was slightly greater than Noninformative ($M_{Noninform}$ = 2.51 μv, see Figure 6). General amplitude modulation was further tested using a dependent-means t-test for Cue Validity within the Informative condition. This analysis also revealed no general effect of attention ($t_{(15)}$ = -.62, p = .55, Hedges' g = -.15). Valid trials generated nearly identical P1 amplitude as Invalid trials (M_{Valid} = 2.90 μv; $M_{Invalid}$ = 3.03 μv).

A mixed-model ANOVA of Cue Condition (Informative, Noninformative) and Laterality (Contralateral, Ipsilateral to the target) revealed a highly-significant main effect of Laterality ($F_{(1,30)}$ = 27.78, p < .001, r^2 = .48), suggesting that spatial attention was oriented toward the target, producing a greater evoked response Contralateral (M_{Contra} = 2.86 μv) than Ipsilateral (M_{Ipsi} = 2.62 μv, see Figure 7). There was no significant interaction between Cue Condition and Laterality indicating that this effect was not further modulated by attentional condition ($F_{(1,30)}$ = .18, p = .68, r^2 = .01). An additional repeated-measures ANOVA was run within the Informative cues condition to test whether Cue Validity modulated the observed laterality effect. There was no significant interaction between Laterality and Validity ($F_{(1,15)}$ = .36, p = .56, r^2 = .02), meaning the amplitude difference between valid and invalid trials was not greater for contralateral targets.

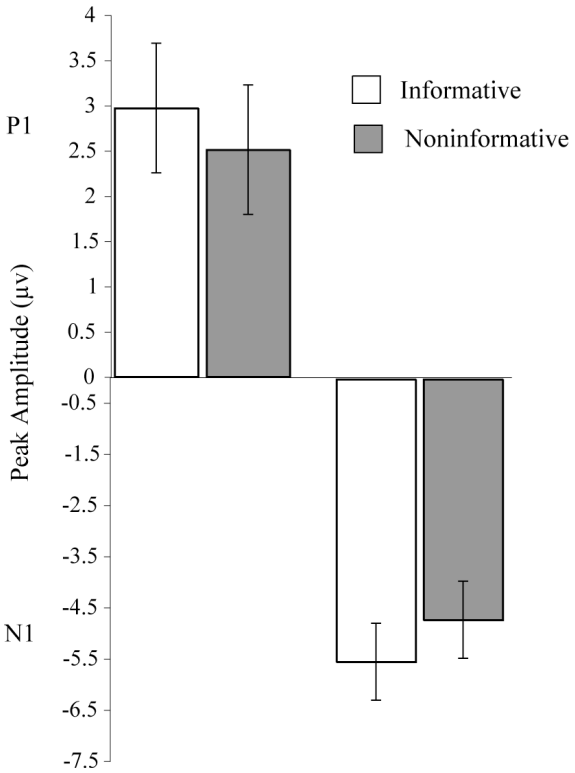


Figure 6. **Experiment 1, target-related general amplitude effects.** Neither the P1 nor the N1 component showed a significant difference between the evoked responses in the two cueing conditions (p > .05). Error bars are the standard error of the mean for the between-subjects analyses.

Target-Related N1 Effects

An independent-means t-test between the Informative and Noninformative conditions revealed no general effect of attention ($t_{(30)}$ = 1.12, p = .27, Pearson's r = .20, Hedges' g = .41) although the mean amplitude for Informative (M_{Inform} = -5.52 μv) was slightly greater than Noninformative ($M_{Noninform}$ = -4.70 μv, see Figure 6). In contrast, a dependent-means t-test of Cue Validity within the Informative cue condition did reveal a significant general amplitude

modulation ($t_{(15)}$ = -2.53, p = .02, Cohen's d = .63) with Valid trials eliciting a greater evoked response (M_{Valid} = -5.76 μv) than Invalid trials ($M_{Invalid}$ = -5.30 μv).

A mixed-measures ANOVA of Cue Condition and Laterality revealed a significant main effect of Laterality ($F_{(1,30)}$ = 18.11, p < .001, r^2 = .38), such that activation Contralateral to the target (M_{Contra} = -5.34 μv) was greater than that Ipsilateral to the target (M_{Ipsi} = -4.85 μv, see Figure 7). A nonsignificant interaction between Cue Condition and Laterality shows that this effect was not further modulated by attentional condition ($F_{(1,30)}$ = 1.85, p = .18, r^2 = .06). An additional repeated-measures ANOVA was run within the Informative cue condition to test whether the observed laterality effect was modulated by Cue Validity. There was a marginal interaction between Laterality and Validity ($F_{(1,15)}$ = 3.64, p = .08, r^2 = .20).

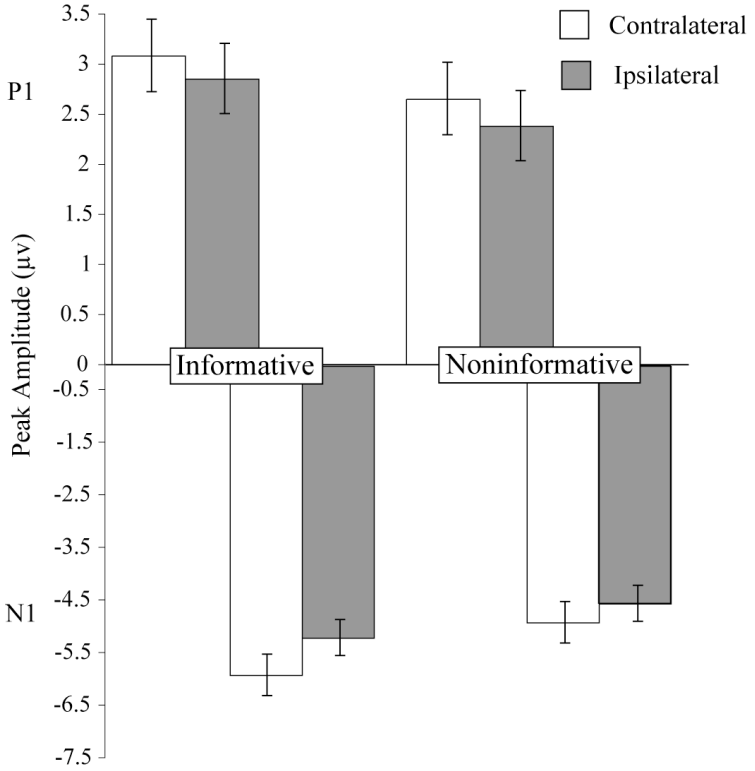


Figure 7. **Experiment 1, target-related laterality effects.** Contralateral refers to the electrodes over the hemisphere contralateral to the letter target. Both the P1 and the N1 component showed a significant difference between the evoked laterality responses (p < .001 for both). This effect did not interact with cue condition for either component (p > .05 for both). Error bars are the standard error of the mean for the within-subjects analyses.

Cue-Related P1	Avg of 10 Electrodes	P7	P8	P9	P10	PO3	PO4	PO7	PO8	O1	O2
General Amplitude: Non vs Inform	Non < Inform*	Non < Inform**			Non < Inform*	Non < Inform*		Non < Inform†		Non < Inform*	
Laterality: Inform: Contra vs Ipsi											

Cue-Related N1	Avg of 10 Electrodes	P7	P8	P9	P10	PO3	PO4	PO7	PO8	O1	O2
General Amplitude: Non vs Inform											
Laterality: Inform: Contra vs Ipsi		Ipsi > Contra*			Ipsi < Contra*						

***Table 1*. Experiment 1, cue-related amplitude results.** Uncorrected p-values: * $p \leq .05$, ** $p \leq .01$, † $p \leq .005$

Target-Related P1	Avg of 10 Electrodes	P7	P8	P9	P10	PO3	PO4	PO7	PO8	O1	O2
General Amplitude: Non vs Inform											
General Amplitude: Inform: Valid vs Invalid											
Laterality: Inform: Contra vs Ipsi	Ipsi < Contra†										

Target-Related N1	Avg of 10 Electrodes	P7	P8	P9	P10	PO3	PO4	PO7	PO8	O1	O2
General Amplitude: Non vs Inform										Non < Inform*	
General Amplitude: Inform: Valid vs Invalid	Invalid < Valid*		Invalid < Valid†	Invalid < Valid*			Invalid < Valid*				Invalid < Valid*
Laterality: Inform: Contra vs Ipsi	Ipsi < Contra*	Ipsi < Contra†		Ipsi < Contra†	Ipsi < Contra*	Ipsi < Contra†		Ipsi < Contra†		Ipsi < Contra**	

Table 2. **Experiment 1, target-related amplitude results.** Uncorrected p-values: * $p \leq .05$, ** $p \leq .01$, † $p \leq .005$

2.3. Discussion

We investigated sensory-evoked ERP responses to cues and targets in a modified cueing task that equated the physical appearance of both events on all trials. A long cue-target interval was used to separate each event in time, allowing for the separate analysis of cue- and target-related activity, while bilateral cues and bilateral target displays were presented to equate the visual appearance of both events. This designed allowed for the pure effects of attention to be determined without the confounds of unilateral cue or target displays.

2.3.1. Cue-Related Findings

The cue-related P1 and N1 components differed in whether they showed a general amplitude modulation between the Informative and Noninformative conditions. Attending to the Informative color cues modulated the P1 component, but not the N1. Perhaps surprisingly, there was no advantage for contralateral cue-related activity over ipsilateral activity for either component in the Informative condition.

Nobre et al. (2000) found significantly greater negativity contralateral to cue processing in a time range corresponding to the N1 component (starting 160 ms post-cue) when the cue was a colored portion of a diamond centered on fixation. They did not find a laterality effect on the cue-related P1 time range. These particular laterality effects relative to the direction of attention are consistent with the few studies reporting cue-related ERP amplitudes using a single onset peripheral cue (Eimer, 1993; Harter, et al., 1989; Yamaguchi, et al., 1994). As Nobre was the first to use bilateral, foveal cues, thus equating the physical appearance of cues, the authors interpreted their N1 laterality effect as representing attention's pure modulation on the ERP waveform independent of the physical nature of the cueing stimuli. Their study had two conditions, both of which involved an informative cue. Without a noninformative cue control condition, the general amplitude modulation effect of attention (attended > unattended) could not be explored as it was here.

It is possible that the difference in N1 results between Nobre's cue-related amplitude modulations and our own finding of no cue-related laterality effects is due to the central versus peripheral cueing designs employed. Nobre's central cues may have elicited a more "spatial" shift of attention to the indicated peripheral location. Our peripheral cues were presented at the future target and non-target locations and as such may have elicited a less spatial shift of attention. However, we did find a significant general amplitude modulation effect on the P1 and a highly-significant behavioral cueing effect from which we can infer that our cues were attended in some manner.

It is possible that spatial attention was allocated toward the Informative color cues, but did not generate a laterality effect because the P1 and N1 components peaked too soon after the cues to be modulated. This interpretation seems less likely in light of the significant general amplitude difference between attention conditions during cue processing, though the general amplitude effect may reflect an enhanced cognitive state across the block rather than a trial-by-trial shift of attentional resources. An alternative interpretation for our general amplitude

modulation and null effect of contralateral dominance during cue processing comes from the work of Eimer (1994; 1998). Eimer has demonstrated that when a target requires a response regardless of its location (e.g., validly-cued and invalidly-cued targets), it may be advantageous for the participant to withhold orienting attention until the target appears, as a potential cost exists for orienting to an ultimately incorrect location. This interpretation seems unlikely due to the 78 ms RT difference we found between the valid and invalid trials in the Informative cue condition.

Based on the P1 peak amplitude difference between the attention conditions, we suggest that our cue-related ERPs reflect a general ramping up of attention that is not spatially bound. When a feature color is relevant for a task, more attention is allocated to that color, but this does not necessitate that spatial attention need be engaged (Hamker, 2004; Hopf, Boelmans, Schoenfeld, Luck, & Heinze, 2004; Müller, Heller, & Ziegler, 1995; Zhang & Luck, 2009). Taking this into account, we suggest that the pattern of our cue-related ERPs reflect non-spatial, feature-based attention for the Informative color (see e.g., Kumada, 2001; Rossi & Paradiso, 1995; Sàenz, Buraĉas, & Boynton, 2003; Treue & Martinez-Trujillo, 2007). Color has been proven to be highly effective at separating a target from distractors in a visual search array and to "pop-out" more quickly when it is the focus of attention (Treisman & Gelade, 1980; Treisman, 1985). The color cues in the present study were easy to discriminate and did not require selective attention to the location. The finding of an absent contralateral dominance to the cue in the ERP components supports the argument that spatial attention was not engaged at the color cue's location during cue processing, but rather to the color feature that was more likely to contain the subsequent target.

In support of this interpretation, it has been noted by Eimer (1995) that when spatial and non-spatial attentional processes are simultaneously engaged that spatial attention may be less focused compared to situations when only spatial information is relevant for a particular stimulus. In the present study, bilateral color cues were presented in the periphery. One of these cues was made informative about the probable spatial location of a future target. But in order to use that spatial information, the cues had to be processed based on their non-spatial, color identity. These cues may have therefore been simultaneously activating spatial and non-spatial attentional processing, which could have led to a dampening of the component amplitudes. When the targets subsequently appeared and only spatial attentional processes were required, we found a different ERP profile.

2.3.2. Target-Related Findings

The target-related P1 and N1 components displayed no general amplitude modulation between the Informative and Noninformative conditions, a finding in line with some previous studies. For example, Landau and colleagues (2007) used a spatial-cueing task with faces as targets and found no difference in peak amplitudes of the P1 or N170 between Informative and Noninformative conditions (see also Doallo, et al., 2004; 2005). We did, however, find a general amplitude effect on the N1 component between valid and invalid trials in the Informative condition, perhaps reflecting the discriminatory processing of the target from the non-target letter (Vogel, & Luck, 2000).

Contrary to cue processing, there was a strong effect of spatial orienting to the targets in which contralateral activity was greater than ipsilateral activity after the target appeared. This effect was present to the same degree in both cueing conditions and for both the P1 and N1 components. It is important to note that the physical appearance of the two conditions was identical. A visual difference between conditions cannot account for this amplitude effect. Instead, this result can be taken as evidence that target processing involved focal spatial attention, which selectively increased the strength of the ERP response in the contralateral hemisphere. The targets were difficult to discriminate from the distractor without deployment of spatial attention. These results are consistent with previous spatial-cueing studies showing contralateral dominance when spatial attention is employed (here, to perform a letter discrimination under identical visual stimulation).

2.3.3. General Comments on Experiment 1

When relating the cue and target effects to each other, a double dissociation on the P1 component emerges in which cue processing displays a non-specific modulation by attention and target processing displays a selective modulation. This double dissociation implies selective attentional operations are supporting the processing of the two events.

The non-selective modulation during the cue period implies a general ramping up of attention in the brain in response to the color cues. This effect could represent a sustained tuning for the informative color. Conceptualizing the attention effect in this way corresponds with the interpretation that the color cues were attended via feature attention.

The selective modulation during the target period, seen both on the P1 and N1 components, implies that spatial attention was selectively focused on the location of the target stimulus. This focusing on the target's location caused a selective increase in the peak amplitude contralateral to the target. This finding is consistent with previous studies of spatial attention, though here the effect could only be caused by attention and not sensory differences in the display.

Additionally, the finding of a general attention effect on the cue-related P1 but not the N1 could suggest that these two sensory-evoked potentials may actually be differently sensitive to sensory information. In particular, as the P1 was modulated and the N1 was not, it is possible that the P1 is more "sensory" than the N1. Perhaps these two components should not be grouped into one seemingly homogeneous "sensory-evoked" category. This idea is speculative and will require further testing.

3. Bilateral Letter Cueing in EEG (Experiment 2)

Experiment 2 changes the stimulus type used during the cue and target events to further test attentional processing in the absence of sensory differences. Participants were presented bilateral letter cues (instead of color cues) and performed a color discrimination task (instead of a letter discrimination). The two letter cues (T and F) were presented in peripheral locations followed by one of two target colors (Red or Blue) along with a non-target Green. In the Informative condition, participants were instructed to attend to either the T or the F, which predicted the spatial location of the color target. In the Noninformative condition, participants were instructed to ignore the letter cues, as they had no informative relationship to the color target's location.

This design modification allows for the further profiling of the effect of attention on the sensory-evoked P1 and N1 components under conditions of identical visual stimulation. It also allows the interpretations of Experiment 1 to be tested. By inverting the cue and target stimulus types, we intend to test for a reversal in the ERP results of the processing of each event. With the letter cues presumably requiring primarily spatial attention, we should see selective modulation of the peak amplitudes by spatial attention. The appearance of color targets in the periphery should elicit feature attention to the color, or more moderately a combination of feature and spatial attention. We should therefore observe a dampening of the classic spatial attention effects. In other words, there may be a null effect of laterality consistent with the cue-related results from Experiment 1.

3.1. Method

3.1.1. Participants

Thirty-two undergraduate and graduate students from the University of California, Berkeley volunteered to participate in this study. Sixteen participants were in the Informative condition (mean age = 22.56 years, 6 females). Sixteen participants were in the Noninformative condition (mean age = 20.75 years, 5 females). Different participants were selected to perform in the two conditions due to behavioral carry-over effects during pilot testing in Experiment 1. All participants were self-described as right-handed, had normal or corrected-to-normal visual acuity, and self-reported normal color vision. All participants gave signed informed consent approved by the Committee for Protection of Human Subjects at the University of California, Berkeley.

3.1.2. Procedure

In both the Informative and Noninformative conditions, participants performed a color discrimination task (see Figure 8). The instructions were the same as in Experiment 1. Participants were instructed to maintain fixation across all trials. Each trial began with a centrally presented fixation cross and two black outlined boxes against a grey background, one presented to the left and one to the right of fixation. Bilateral letter cues were presented in the centers of these boxes with a T in one box and an F in the other. These letters were black, size 14 Arial

font. The T appeared randomly 50% of the time on the left (F on the right) and 50% on the right (F on the left). The letter cues were presented 600 ms before the onset of the color targets. The Red and Blue color targets were identical to the Red and Blue cues from Experiment 1. These targets remained on the screen for 80 ms and offset together with the letter cues. Instructions were to determine whether the target was the color Red or Blue. There was always a non-target color Green presented in the other box (RGB values of 155, 255, 155 and a luminance value of 18.02 cd/m^2). Every trial was followed by a blank fixation inter-trial interval of 1,000 ms. After each block, percent correct and average reaction time (RT) for that block were given as feedback. Both speed and accuracy were emphasized.

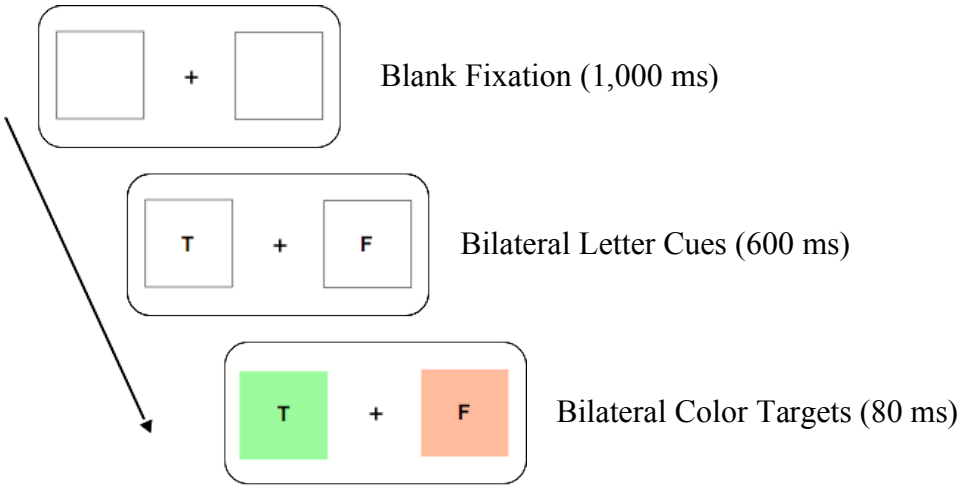


Figure 8. **Experiment 2, trial structure.**

3.1.3. EEG Acquisition and Processing

The EEG recording and processing parameters were the same as in Experiment 1. All experimental parameters were identical to those in Experiment 1, with the exception of the inversion of cue and target stimulus types.

3.2. Results

All analyses were completed on correctly-performed trials. All ERP analyses were performed on a randomly sampled 120 trials per condition[2]. Each electrode's P1 and N1 peak amplitudes were selected. These individual electrode amplitudes were then pooled for the P1 and N1 analyses (see Figure 10). The same analyses were also performed on the individual electrode pairs, the results of which are presented in Tables 3 and 4.

[2] Due to the lower accuracy in Experiment 2, five participants had fewer than 120 correctly-performed and artifact-free trial epochs (2, 2, 10, 10, and 20 fewer trials specifically). To adjust for this problem, a participant in the Noninformative condition was randomly selected to have their number of epochs matched to a particular participant from the Informative condition. Therefore, an equal number of trials contributed to all analyses.

3.2.1. Behavioral Results

Participants achieved high accuracy in both conditions (M_{Inform} = 92.5% correct, $M_{Noninform}$ = 95.6% correct), which significantly differed from each other ($t_{(30)}$ = 2.07, p = .05). Within the Informative condition, participants were more accurate on Valid trials (94.7% correct) than Invalid trials (90.4% correct; $t_{(15)}$ = 3.78, p = .002). These participants also showed the expected cueing effect in which they were on average 73.6 ms faster at responding on Valid trials than Invalid trials ($t_{(15)}$ = -6.07, p < .001). In the Noninformative condition, there was no significant difference between trial types in either RTs or accuracy (RTs: $t_{(15)}$ = -.06, p = .95; Accuracy: $t_{(15)}$ = -1.01, p = .33, see Figure 9).

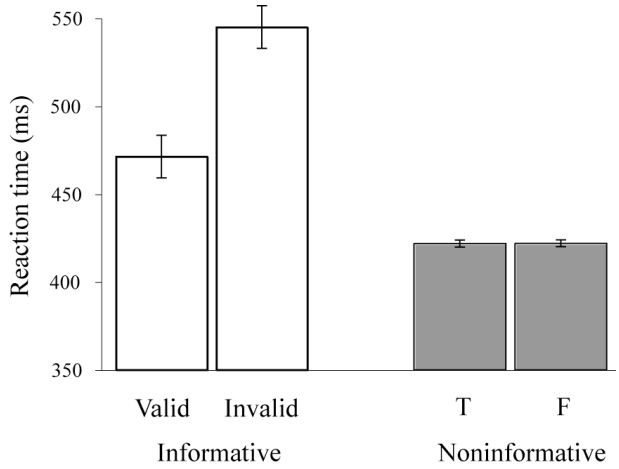


Figure 9. **Experiment 2, behavioral reaction time results.** There was a significant cueing effect in the Informative condition, with Valid trials being responded to faster than Invalid trials (p < .001). There was no significant difference between response times to targets appearing in the T versus F box in the Noninformative condition (p > .05). Error bars are the standard error of the mean for the within-subjects analyses.

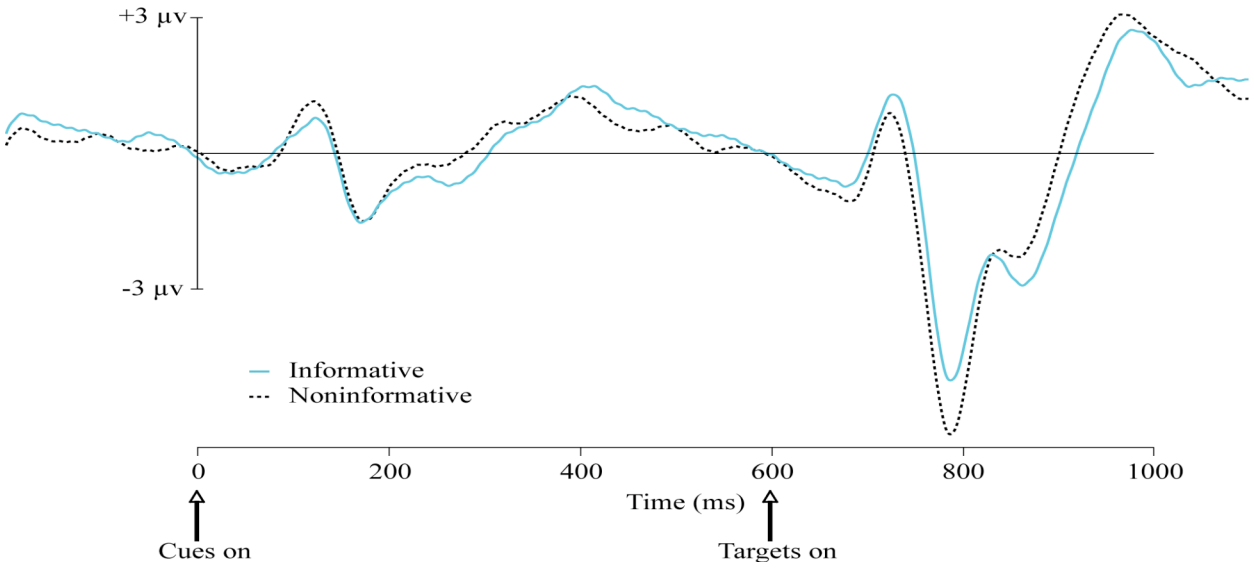


Figure 10. **Experiment 2, grand average waveform.**

3.2.2. Cue-Related ERP Results

Cue-Related P1 Effects

An independent-means t-test between the Informative and Noninformative conditions tested for general amplitude modulation due to attending during the cue period (see Figure 11). This analysis revealed no evidence of a general attention effect ($t_{(30)}$ = .11, p = .92, Pearson's r = .02, Hedges' g = .04) with the mean amplitude for Informative (M_{Inform} = 1.84 μv) being nearly identical to the Noninformative condition ($M_{\text{Noninform}}$ = 1.88 μv). A dependent-means t-test between Contralateral and Ipsilateral activity within the Informative condition did not reveal a laterality effect ($t_{(15)}$ = 1.06, p = .31, Cohen's d = .27). Attending the letter cues led to nearly identical peak amplitudes (M_{Contra} = 1.88 μv; M_{Ipsi} = 1.80 μv, see Figure 12).

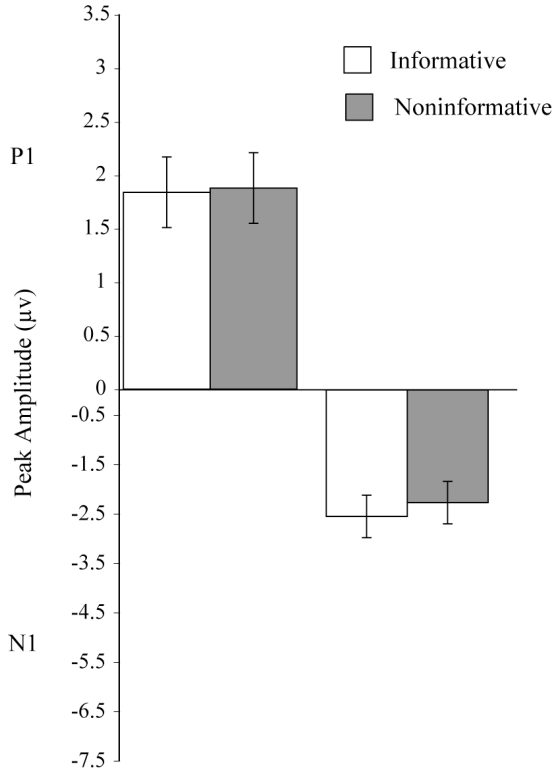


Figure 11. **Experiment 2, cue-related general amplitude effects.** Neither the P1 nor the N1 component showed a significant difference between the evoked responses in the two cueing conditions (p > .05). Error bars are the standard error of the mean for the between-subjects analyses.

Cue-Related N1 Effects

General amplitude modulation due to attending the cues was tested with an independent-means t-test between the Informative and Noninformative conditions (see Figure 11). This analysis revealed no effect of attention ($t_{(30)}$ = .78, p = .44, Pearson's r = .14, Hedges' g = .29) though the mean amplitude in the Informative condition (M_{Inform} = -2.56 μv) was slightly greater

than the Noninformative ($M_{Noninform}$ = -2.28 μv). The dependent-means t-test for laterality within the Informative condition did not reveal peak modulation with the direction of attention ($t_{(15)}$ = 1.14, p = .27, Cohen's d = .29). Attending the letter cues led to no peak difference between Contralateral (M_{Contra} = -2.51 μv) and Ipsilateral (M_{Ipsi} = -2.61 μv) activity (see Figure 12).

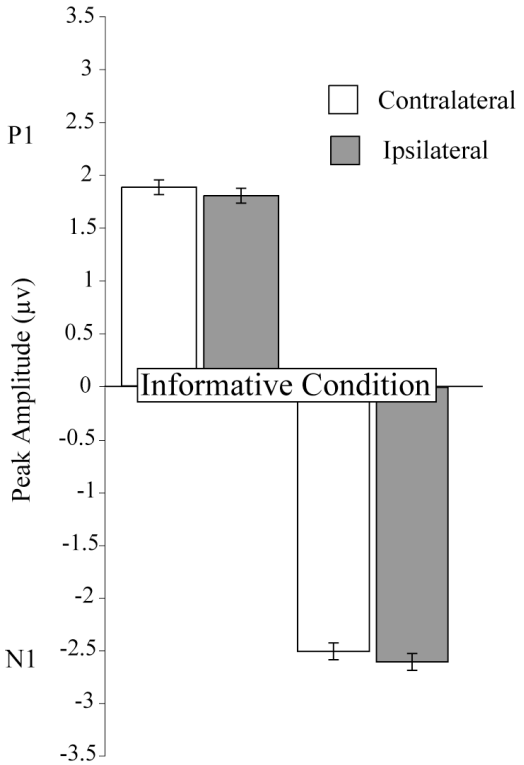


Figure 12. **Experiment 2, cue-related laterality effects in the Informative condition.** Contralateral refers to the electrodes over the hemisphere contralateral to the attended letter cue. Neither the P1 nor the N1 component showed a significant difference between the evoked laterality responses (p > .05). Error bars are the standard error of the mean for the within-subjects analyses.

3.2.3 Target-Related ERP Results

Target-Related P1 Effects

An independent-means t-test between the Informative and Noninformative conditions found no general effect of attention ($t_{(30)}$ = -.52, p = .61, Pearson's r = .09), although the mean amplitude for Informative (M_{Inform} = 2.09 μv) was slightly greater than Noninformative ($M_{Noninform}$ = 1.72 μv, see Figure 13). A general amplitude effect was further analyzed using a dependent-means t-test for Cue Validity (Valid, Invalid) within the Informative condition. This analysis also revealed no general effect of attention ($t_{(15)}$ = .65, p = .52, Cohen's d = .16); Valid trials (M_{Valid} = 2.18 μv) were not significantly different from Invalid trials ($M_{Invalid}$ = 3.03 μv).

A mixed-model ANOVA of Cue Condition (Informative, Noninformative) and Laterality (Contralateral, Ipsilateral to the color target) found a significant main effect of Laterality ($F_{(1, 30)}$ = 17.48, p < .001, r^2 = .37). This effect was in the opposite direction than expected with

Ipsilateral activity (M_{Ipsi} = 2.10 μv) being greater than Contralateral activity (M_{Contra} = 1.76 μv, see Figure 14). There was no significant interaction between Cue Condition and Laterality ($F_{(1, 30)}$ = .08, p = .78, r^2 = .00) indicating that this effect was not further modulated by attentional condition. An additional repeated-measures ANOVA within the Informative condition analyzed whether Cue Validity modulated this observed laterality effect. There was no interaction between Laterality and Cue Validity ($F_{(1,15)}$ = .01, p =.92, r^2 = .00).

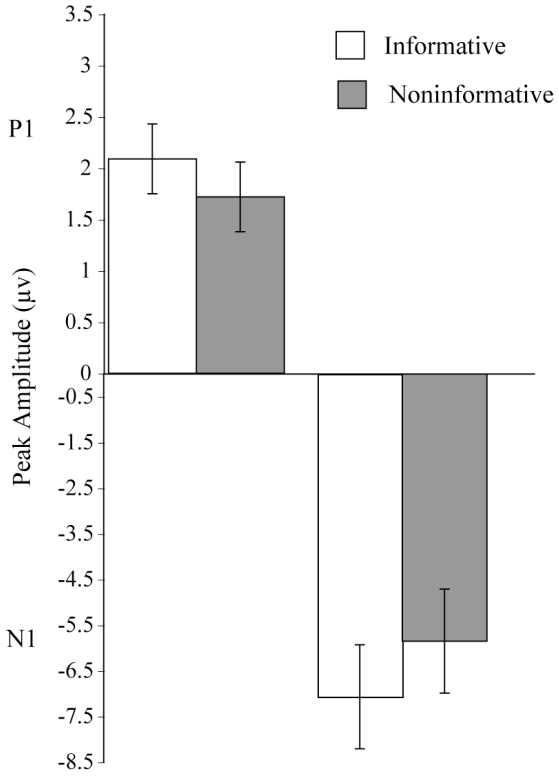


Figure 13. **Experiment 2, target-related general amplitude effects.** Neither the P1 nor the N1 component showed a significant difference between the evoked responses in the two cueing conditions (p > .05). Error bars are the standard error of the mean for the between-subjects analyses.

Target-Related N1 Effects

An independent-means t-test between the Informative and Noninformative conditions revealed no general effect of attention ($t_{(30)}$ = -1.60, p = .12, Pearson's r = .28), although the mean amplitude for Noninformative ($M_{Noninform}$ = -7.07 μv) was greater than Informative (M_{Inform} = -5.85 μv, see Figure 13). An additional dependent-means t-test for a general amplitude effect within the Informative condition found that Valid trials (M_{Valid} = -6.18 μv) evoked a significantly larger response than Invalid trials ($M_{Invalid}$ = -5.52 μv; $t_{(15)}$ = -2.13, p = .05, Cohen's d = .53).

A mixed-model ANOVA of Cue Condition and Laterality found no effect of laterality ($F_{(1, 30)}$ = .11, p =.74, r^2 = .00). Contralateral activity (M_{Contra} = -6.45 μv) was nearly identical to ipsilateral activity (M_{Ipsi} = -6.48 μv, see Figure 14). Laterality did not interact with Cue

Condition ($F_{(1, 30)}$ = .09, p =.77, r^2 = .00). Within the Informative condition, there was also no interaction between Laterality and Cue Validity ($F_{(1, 15)}$ = .38, p = .55, r^2 = .02).

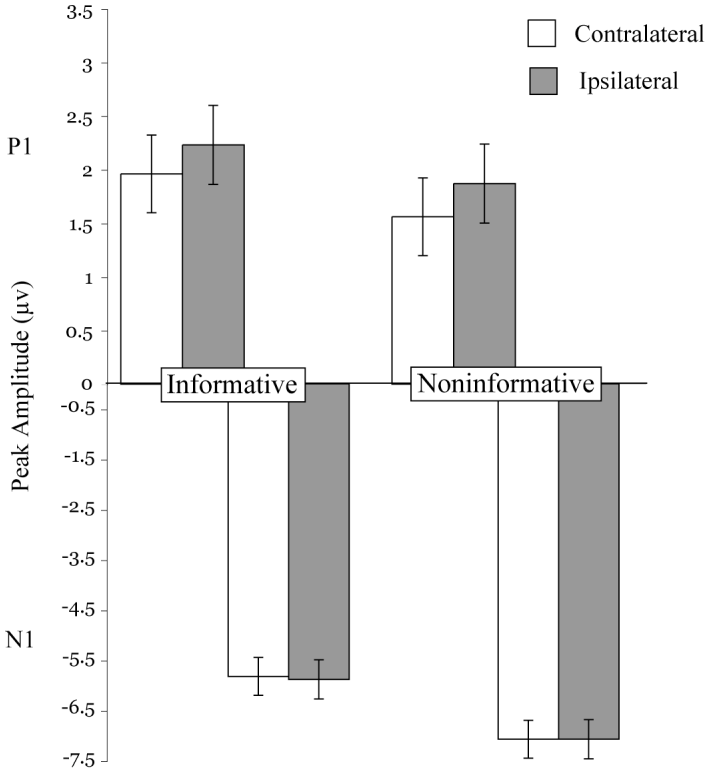


Figure 14. **Experiment 2, target-related laterality effects.** Contralateral refers to the electrodes over the hemisphere contralateral to the color target. The P1 component had significantly larger evoked responses ipsilateral to the target (p < .001). The N1 component had no significant laterality difference (p > .05). These laterality effects did not interact with cue condition for either component (p > .05 for both). Error bars are the standard error of the mean for the within-subjects analyses.

Cue-Related P1	Avg of 10 Electrodes	P7	P8	P9	P10	PO3	PO4	PO7	PO8	O1	O2
General Amplitude: Non vs Inform											
Laterality: Inform: Contra vs Ipsi											

Cue-Related N1	Avg of 10 Electrodes	P7	P8	P9	P10	PO3	PO4	PO7	PO8	O1	O2
General Amplitude: Non vs Inform											
Laterality: Inform: Contra vs Ipsi											

Table 3. **Experiment 2, cue-related amplitude results.** Uncorrected p-values: * $p \leq .05$, ** $p \leq .01$, † $p \leq .005$

Target-Related P1	**Avg of 10 Electrodes**	**P7**	**P8**	**P9**	**P10**	**PO3**	**PO4**	**PO7**	**PO8**	**O1**	**O2**
General Amplitude: Non vs Inform											
General Amplitude: Inform: Valid vs Invalid											
Laterality: Inform: Contra vs Ipsi	**Ipsi > Contra***				Ipsi > Contra†				Ipsi > Contra*		

Target-Related N1	**Avg of 10 Electrodes**	**P7**	**P8**	**P9**	**P10**	**PO3**	**PO4**	**PO7**	**PO8**	**O1**	**O2**
General Amplitude: Non vs Inform				Non > Inform*	Non > Inform*						
General Amplitude: Inform: Valid vs Invalid	**Invalid < Valid***	Invalid < Valid*		Invalid < Valid**				Invalid < Valid*			
Laterality: Inform: Contra vs Ipsi											

***Table 4*. Experiment 2, target-related amplitude results.** Uncorrected p-values: * $p \leq .05$, ** $p \leq .01$, † $p \leq .005$

3.3. Discussion

Experiment 2 used bilateral letter cues and bilateral color targets to further test attention's modulation of the sensory-evoked P1 and N1 components in the absence of sensory differences. We predicted that processing of the letter cues would require focused spatial attention leading to a relative amplitude difference between contralateral and ipsilateral activity. We additionally predicted that the color targets would not require focused attention, but rather a non-spatial, feature attention to the defining characteristic of color. This feature attention should not lead to a laterality effect in the brain response. The observed pattern of results was more complicated.

3.3.1. *Cue-Related Findings*

As predicted, there was no general amplitude difference between participants attending the letter cues and those ignoring the cues for either the P1 or the N1 component. Counter to our predictions, there was also no selective difference between contralateral and ipsilateral activity for either component within the Informative condition.

A few interpretations for this null effect seem possible. First, it is possible that spatial attention is not being directed to the informative letter cue's location. This seems unlikely due to the large behavioral cueing effect obtained in this study. Second, it is possible that spatial attention is being deployed, but that the sensory-evoked P1 and N1 components are not sensitive to this orienting process. Third, as proposed in the Discussion of Experiment 1, it is possible that spatial attention is being deployed, but that these components are peaking too soon to be modulated by this process. These latter two possibilities cannot be distinguished within this study but should be tested further.

3.3.2. *Target-Related Findings*

Counter to our predictions, there was no general amplitude effect elicited by the target event. Target processing of the color targets did not generate a greater evoked response in the Informative condition versus the Noninformative condition on either component.

Also counter to our predictions, there was a selective difference between the evoked P1 amplitude contralateral versus ipsilateral to the color target. Unlike in previous studies, this laterality effect resulted in greater ipsilateral activity. This effect was only present on the P1 component; there was no significant laterality effect on the N1 component.

This surprising result is likely due to a sensory confound present in Experiment 2. The non-target Green color had a higher luminance value than both the Red and Blue target colors (18.02 cd/m^2 versus 13.93 cd/m^2 and 11.33 cd/m^2, respectively). "Ipsilateral" is defined relative to the location of the target stimulus, but it is also always "contralateral" to the non-target Green. Therefore, the finding of ipsilateral activity being greater than contralateral activity is the same as the activity contralateral to the more-luminous Green being greater than ipsilateral to the more-luminous Green.

There was no laterality difference for the N1 component. It is difficult to interpret a null result like this, but it is possible that it reflects an interaction between this sensory confound and attention. Previous studies have shown that the N1 displays a strong attention effect, especially when discrimination is required (Vogel, & Luck, 2000). These signals could be counteracting the luminance effect, ultimately canceling each other out and leading to the observed null effect.

An alternative interpretation for ipsilateral dominance on the P1 component could be that it represents an active suppression signal. The non-target Green is always present. The visual system could be inhibiting this salient, but irrelevant, signal in order to process the target colors. We cannot currently distinguish between these two possibilities.

3.3.3. *General Comments on Experiment 2*

The results from the present experiment did not support the predictions based on the findings from Experiment 1. However, in the Discussion of Experiment 1, we proposed that the P1 component might be more sensitive to sensory information. The present target-related P1 results seem to support this idea given the laterality effect that was likely caused by the more luminous non-target Green. Only the P1 was significantly affected by this sensory confound, while the N1 was either invariant to it or less affected by it. Feature and spatial attention's affects on cue and target processing should be further tested, as should the proposal that the P1 is more affected by sensory information. If this is true, it casts an even more critical eye on previous findings of P1 attention effects in the presence of sensory confounds.

4. Dual Task in Behavior (Experiment 3)

Experiment 3 was a behavioral experiment and used the bilateral color cueing paradigm with the addition of a secondary task making this a dual-task design. Participants performed a peripheral letter discrimination following either Informative color cues or Noninformative cues. In addition to this primary task, on some trials a colored dot appeared at fixation that required participants to press a button as quickly as possible indicating that they detected it.

This dual-task design was used to address the question: When there are simultaneous color cues preceding a target, are these cues processed on the basis of their color (feature attention) or their location (spatial attention)? Taking the condition when a participant is attending to the Informative Red cue as an example, we can make predictions consistent with a feature-based or spatial-based interpretation of cue processing. First, participants should display a significant cueing effect such that they are faster responding to the peripheral target appearing in the validly-cued location than in the invalidly-cued location. This behavioral cueing effect would indicate that "attention" was engaged by the cues. From there we can investigate what type of attention was utilized by examining the response times to the fixation change detection task.

If the Informative Red cue is processed via spatial attention to the cue's location, then there should be no color priming benefit in detecting the red change at fixation. Despite matching the attended cue's color, this red fixation change appears in a different position from the red cue and thus should not benefit from the focused spatial attention on the peripheral cue. This would manifest as a nonsignificant reaction time difference between the red and blue fixation changes, indicating no color priming benefit.

If, however, the Informative Red cue is attended on the basis of its color feature, then we should find significant color priming at fixation. Feature attention is not bound to a spatial location (Hamker, 2004; Hopf et al., 2004; Müller et al., 1995; Zhang & Luck, 2009), meaning the benefit of attending red in the periphery should also benefit detection of a red change at fixation. This would manifest as significantly faster detection of the red fixation changes compared to the blue changes.

4.1. Method

4.1.1. *Participants*

Thirty-six undergraduate students from the University of California, Berkeley volunteered to participate in this study. Twenty-four participants were in the Informative condition (mean age = 21.54 years, 15 female). Half of these participants attended to the Informative Red cue, and half attended to the Informative Blue cue. Twelve participants were in the Noninformative condition (mean age = 20.08 years, 11 female). All participants were self-described as right-handed, had normal or corrected-to-normal visual acuity, and self-reported normal color vision. All participants gave signed informed consent approved by the Committee for Protection of Human Subjects at the University of California, Berkeley.

4.1.2. *Procedure*

This is a dual-task design that adds a fixation detection component to the bilateral color cueing task from Experiment 1 (see Figure 15). In both the Informative and Noninformative conditions, participants performed a letter discrimination task in the periphery and a change detection task at fixation. On every trial, the two peripheral boxes were bilaterally cued by being filled in as red on one side and blue on the other for 600 ms. On most trials (78% of total trials), these cues were followed by bilateral target stimuli requiring the participants to identify whether the target T or F was presented in the presence of the ubiquitous non-target O. On the other 22% of total trials, after the color cues appeared for 600 ms, a change occurred at fixation requiring detection. This change was the presentation of a colored dot slightly larger than fixation which merely required the participants to press a third button signaling their detection of this change. On these fixation change trials, the dot appeared with equal probability in red or blue. The red and blue matched the RGB values of the red and blue color cues.

On both trial types, the target was presented for 80 ms and the target and cues offset together. Therefore, the timing of a trial was as follows: the color cues appeared for 600 ms, while these remained on the screen either letters appeared in the periphery (78% of trials) or a colored dot was flashed at fixation (22% of trials), all stimuli then offset together.

On the trials requiring peripheral letter discrimination, the cue probabilities in both the Informative and Noninformative conditions were maintained from Experiment 1. In the Informative condition, participants were instructed to pay attention to the Blue cue (valid trials for these participants) or to attend to the Red cue (valid for them). The target letter appeared in the informative color's box on 75% of these trials. On 25% of these trials, the target letter appeared in the other color's box (invalid trials). In the Noninformative condition, the peripheral target letter appeared in the Red box 50% of the time and in the Blue box 50% of the time. In both Informative and Noninformative conditions, ten blocks of 82 trials were completed: 64 trials in each block required peripheral letter discrimination and 18 required fixation change detection.

Data were analyzed for a cueing effect in the primary letter discrimination task in the periphery and a color priming effect for the target detection task at fixation.

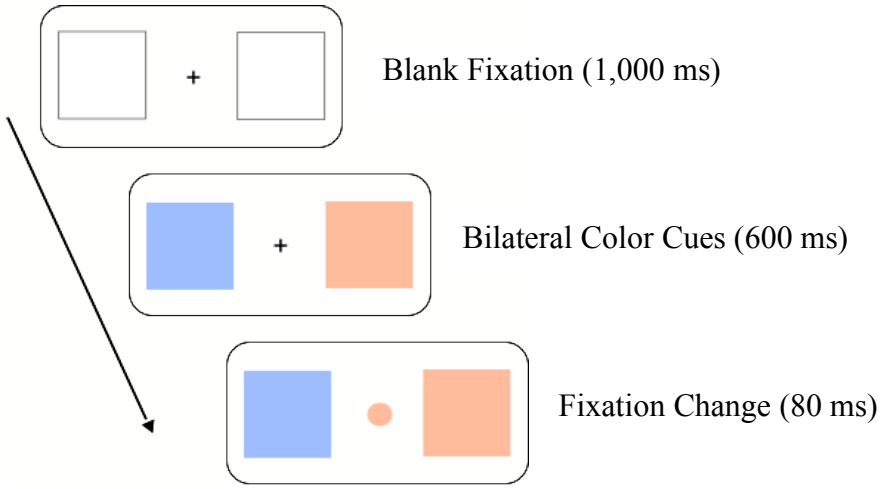


Figure 15. **Experiment 3, trial structure for the change detection task at fixation.**

4.2. Results

4.2.1. *Peripheral Cueing Task Results*

In the Informative condition, Valid trials (M_{RT} = 483.5 ms) were responded to significantly faster than Invalid trials (M_{RT} = 568.3 ms; $t_{(23)}$ = -8.37, p < .0001, Cohen's d = 1.72). This significant cueing effect indicates that participants were attending the color cues in the periphery. In the Noninformative condition, there was a nonsignificant 3.5 ms difference between the peripheral trials ($t_{(11)}$ = 1.52, p = .16, Cohen's d = .44, see Figure 16). This suggests that this Noninformative condition serves as a good control condition.

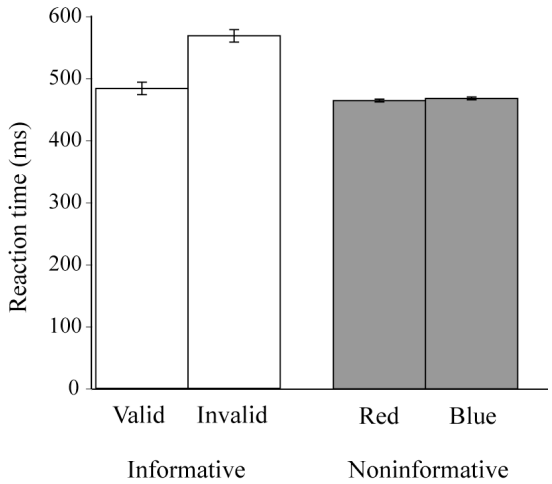


Figure 16. **Experiment 3, reaction time results for the peripheral cueing task.** There was a significant cueing effect in the Informative condition, with Valid trials being responded to faster than Invalid trials (p < .001). There was no significant difference between response times to targets appearing in the Red versus Blue box in the Noninformative condition (p > .05). Error bars are the standard error of the mean for the within-subjects analyses.

Analysis of accuracy in the peripheral task revealed that participants were better at reporting the letter target when it appeared in the colored location to which they were attending ($t_{(23)}$ = 6.51, p < .0001, Cohen's d = 1.25, M_{Valid} = 96.4%, M_{Invalid} = 91.7%). There was no difference in accuracy in the Noninformative condition ($t_{(11)}$ = .22, p = .83, Cohen's d = .06, M_{Blue} = 96.3%, M_{Red} = 96.3%).

4.2.2. *Fixation Detection Task Results*

There was no significant difference between detecting the red (M_{RT} = 459.8 ms) and blue (M_{RT} = 462.0 ms) changes at fixation in the Noninformative condition ($t_{(11)}$ = .45, p = .66, Cohen's d = .13). In the Informative condition there was no evidence of color priming in detecting the colored changes at fixation ($t_{(23)}$ = .95, p = .35, Cohen's d = .03). Detection of the attended color averaged 494.3 ms while detection of the unattended color averaged 491.6 ms (see Figure 17). The average response times in the Informative and Noninformative conditions did not significantly differ from each other ($t_{(34)}$ = -1.67, p = .10, Pearson's r = .28), though the participants in the Noninformative condition ($M_{\text{Noninform}}$ = 460.91 ms) were marginally faster than the participants in the Informative condition (M_{Inform} = 492.98 ms).

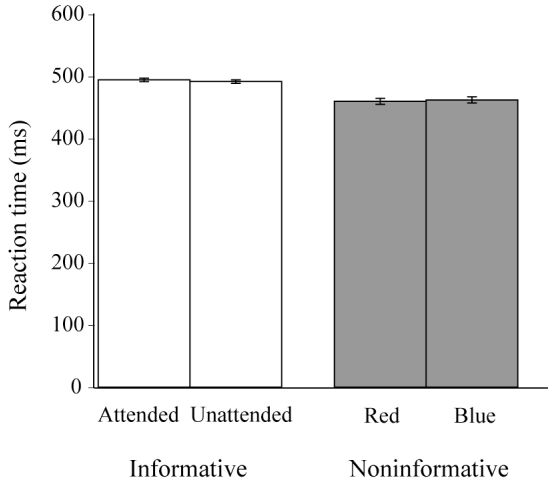


Figure 17. **Experiment 3, reaction time results for the fixation change detection task.** There was no significant difference between responding to the attended versus unattended color change at fixation in the Informative condition (p > .001). There was also no significant difference between color changes in the Noninformative condition (p > .05). Error bars are the standard error of the mean for the within-subjects analyses.

Analysis of accuracy in the change detection task revealed that there was a small but significant difference between detecting the attended color versus the unattended color at fixation ($t_{(23)}$ = -2.41, p = .02, Cohen's d = .62) such that participants were better at detecting the unattended color change (M_{Attended} = 96.6%, $M_{\text{Unattended}}$ = 97.8%). There was no difference in accuracy in the Noninformative condition ($t_{(11)}$ = .30, p = .77, Cohen's d = .09).

4.3. Discussion

Experiment 3 tested for color priming at fixation in order to determine whether the peripheral color cues were processed more on the basis of the color feature or spatial location. To accomplish this goal, the same bilateral cueing task from Experiment 1 was used with the addition of a colored change detection task at fixation. There was no evidence of color priming at fixation when participants were attending a color cue in the periphery. While this may be interpreted as evidence that the peripheral cues were processed with spatial attention, we think it more likely that these results are due to a floor effect in the response times for detecting the fixation changes. This interpretation is supported by the nonsignificant response time difference for the fixation detections between the two conditions. Despite the dual nature of the experiment, with practice, participants found performing both tasks to be easily accomplished. This floor effect likely obscured any color priming effects at fixation. Therefore, we were unable to determine whether feature or spatial attention was used to process the peripheral cues.

5. Concluding Remarks

This dissertation examined the influence of attention on the sensory-evoked P1 and N1 components of human brain activity when sensory differences were minimized. A new experimental paradigm was designed to eliminate sensory confounds that were present in previous electrophysiology cueing studies of spatial attention. This was accomplished by using bilateral cueing and bilateral target stimuli such that every trial was as physically identical as possible.

We conclude that there can be differential attention signals operating during the processing of an orienting cue or a target that requires an overt behavioral response. The exact way in which these two events are processed interacts with the sensory nature of the display. When the cues were informative because of their color, an effect of feature attention was found (Exp 1). When the cues were informative because of their shape, no effect of feature attention was found (Exp 2). This type of interaction between the appearance of a display and attention could be more impactful during the orienting cue event than the target event. The target effects were generally the same in both experiments, regardless of whether the target stimulus was defined by its shape or its color.

We propose that the sensory-evoked P1 and N1 are perhaps differentially sensitive to the sensory input of the display. The P1 may be more affected by sensory information. This interpretation is based on the cue-related effects in Experiment 1 and the target-related effects in Experiment 2. In Experiment 1, the P1 amplitude was greater for attending the color cues than ignoring the cues. In Experiment 2, the P1 amplitude was greater contralateral to the non-target, but luminous, Green than ipsilateral. The N1 component showed neither of these effects.

Future work should continue to investigate how cue and target events are selectively processed in the brain and in particular how attention modulates these brain responses in the absence of sensory confounds. Additionally, the proposal of a more "sensory" P1 should be further tested.

These bilateral cueing tasks could be especially useful tools for investigating attention signals in the brains of populations with disrupted attention abilities, e.g., unilateral spatial neglect. Neglect is a neuropsychological disorder that typically results from right hemisphere damage, especially to the parietal lobe (Bartolomeo, de Schotten, & Doricchi, 2007; Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005). This damage results in disorders of orienting toward, attending, and processing information on the contralesional (e.g., left) side of space.

Researchers have shown that neglect patients are affected by the appearance of a display or the appearance of real objects in the world. They can be automatically attracted to a unilateral stimulus appearing in their spared visual field (usually the right). This engagement to the good field makes it more difficult to shift their attention to an object in the bad field (usually the left). When a unilateral stimulus is presented in their bad field, they often can orient to it, but when there is competing information in their good field, they have difficulty orienting to the object in the bad field, perhaps completely neglecting it (Bartolomeo, et al., 2007; Rafal, 1994).

Many researchers interpret behaviors such as these as attentional effects. However, the visual appearance of the task (e.g., unilateral stimulus versus bilateral competing stimuli) is clearly affecting the patients' performance. These bilateral cueing tasks could therefore be used to provide a purer test of attention in these patients, independent of sensory effects. This would be interesting both in terms of their behavioral performance on the task as well as the electrophysiology of attention effects on the brain processing of the cue and target events.

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