THE ELECTROPHYSIOLOGY OF SELECTIVE TARGET AND DISTRACTOR PROCESSING IN VISUAL SEARCH

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ABSTRACT

The eyes provide more information than ever reaches awareness. Selection of relevant information for processing relies on a cognitive mechanism known as attention. In this thesis, two electrophysiological studies of visual attention are reported. Both studies focused on an electrical brain response called the N2pc that has been linked to attentional selection. The first study showed that when a salient nontarget and a less salient target are presented among distractors, the task-irrelevant nontarget elicits an N2pc. This demonstrates that attention can be captured by salient, task-irrelevant stimuli. The second study further investigated the electrophysiology of attentional selection by decomposing the N2pc into target-related and distractor-related sub-components. The same stimulus was found to elicit a contralateral ERP negativity when attended and a contralateral ERP positivity when ignored. These results suggest that attentional selection in visual search involves both distractor suppression and selective target processing and that the N2pc reflects both processes.

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CHAPTER 1
GENERAL INTRODUCTION

In every moment that our eyes are open our visual sensory system is inundated with information. Some of this information is relevant to our behaviour, most of it is not. The sheer quantity, however, has the potential to overwhelm the limited capacity of higher level cognitive mechanisms. In order for us to achieve our goals we must mark sources of relevant information for preferential processing and filter out sources of irrelevant information. The mechanisms that underlie this ability are collectively known as visual attention.

In the vision sciences, the experimental investigation of attention has traditionally relied on the observation of overt behaviour. Analysis of behaviour is, however, limited by the fact that participant response is based on a series of processing stages. Change in behaviour can reflect modulation of processing at any one of these stages. For example, the attention literature has seen a rather extended debate regarding the ability of highly salient stimuli to capture attention when the non-targets are known to be task irrelevant. Reaction times (RTs) to targets are longer when such non-targets are concurrently presented. Some have suggested that this increase in RT reflects the capture of attention, representing the time it takes for attention to be oriented to the salient non-target before being reoriented to the target. Others have proposed that this RT cost reflects a need for increased perceptual processing of the display. Debate over this issue stems from the fact that behavioural measures alone cannot distinguish between the two hypotheses.

Techniques that directly assess the neural activity associated with cognition bypass some of the limitations of behavioural measures. The measurement of event-related potentials (ERPs) is one such technique. ERPs reflect postsynaptic potentials that are produced by activity of pyramidal cells in cerebral cortex. These voltage signals propagate through the head such that they can be recorded with electrodes on the scalp. ERPs are computed from the electroencephalogram (EEG), the ongoing measure of brain electricity as it is recorded at scalp surface. Raw EEG voltage is of an order of magnitude larger than ERP voltage and reflects the sum potential of large areas of cortex. ERPs are extracted from the EEG through a process of signal averaging, in which EEG epochs time-locked to a relevant experimental event are mean averaged. This averaging removes random activity in the EEG, resulting in an ERP that reflects brain activity that is reliably elicited by a relevant experimental event.

ERPs allow for an insight into the stages at which a psychological phenomenon occur that is not allowed for by behavioural measures alone. The ERP technique thus seems like a good tool to use in deciding whether or not attention can be captured by salient non-target stimuli. In chapter 2 a component of the visual ERP, the N2pc, is used to address this issue.

The N2pc is a negativity in the visual ERP elicited over cortex contralateral to an attended stimulus. Extensive research has shown that the component reflects processing involved in the application of spatial attention. Though the N2pc is becoming a popular tool in cognitive neuroscience its precise functional significance is as of yet somewhat unclear. Some studies have suggested that the N2pc is tied to a suppression of non-target stimuli that allows for selection of the target. Other studies have suggested that the N2pc rather reflects processing that is directly tied to target processing. To date, no interpretation of the component has resolved this apparent conflict.

In chapter 3 a study is reported in which the underlying function of the N2pc is investigated. This study was premised on the idea that, consistent with results linking the N2pc to both target and distractor processing, the component might reflect both processes.

CHAPTER 2
ELECTROPHYSIOLOGICAL EVIDENCE OF ATTENTIONAL CAPTURE

The following chapter is reproduced with permission from the following journal article:

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience, 18*(4), 604 – 613.

2.1 Abstract

We investigated the ability of salient yet task-irrelevant stimuli to capture attention in two visual search experiments. Participants were presented with circular search arrays that contained a highly salient distractor singleton defined by colour and a less-salient target singleton defined by form. A component of the event-related potential (ERP) called the N2pc was used to track the allocation of attention to lateralized positions in the arrays. In Experiment 1, a lateralized distractor elicited an N2pc when a concurrent target was presented on the vertical meridian and thus could not elicit lateralized components such as the N2pc. A similar distractor-elicited N2pc was found in Experiment 2, which was conducted to rule out certain voluntary search strategies. Additionally, in Experiment 2 both the distractor and the target elicited the N2pc component when the two stimuli were presented on opposite sides of the search array. Critically, the distractor-elicited N2pc preceded the target-elicited N2pc on these trials. These results demonstrate that participants shifted attention to the target only after shifting attention to the more salient but task-irrelevant distractor. This pattern of results is in line with theories of attention in which stimulus-driven control plays an integral role.

2.2 Introduction

The human visual system is subject to a torrent of sensory information, with only a small subset of this data important at any given moment. In order for us to act efficiently, relevant visual information must be preferentially selected via the application of attention. In our phenomenological experience this process of attentional selection seems tied to particular tasks and challenges. We feel that we select information that relates to our goals and helps us make necessary decisions. In an apparent inconsistency, however, we also feel that certain stimuli have a fundamental ability to capture our attention. A flash of light, a bright colour, or the appearance of a moving object leaves us with the idea that we can not help but attend to these events, regardless of their relevance to our immediate goals.

In the field of vision research, these two experiences correspond to two conceptualizations of attentional control. On the one hand, we can think of attention as being under *goal-driven* control, oriented to objects and events that are relevant to the current goals of the observer. Alternatively, we can consider attention under *stimulus-driven* control, oriented to salient environmental stimuli. A vast amount of prior research has examined the ways in which these two types of control processes interact. Within this literature an important and ongoing debate has arisen concerning the ability of stimuli to elicit a purely stimulus-driven orientation of attention to their location. This phenomenon is known as *attentional capture* (see recent reviews, e.g. Theeuwes & Godijn, 2002; Rauschenberger, 2003; Ruz & Lupiañez, 2002; Yantis, 2000).

In the early 1990s, Theeuwes (1991, 1992, 1994a) presented data from a series of visual-search experiments that were consistent with the notion of attentional capture. Participants were presented with *singleton* stimuli defined by a single featural difference from neighbouring stimuli. In one experiment, participants were presented with circular displays consisting either of six circles and a single diamond or six diamonds and a single circle (Theeuwes, 1991). The task was to discriminate the orientation of a line segment contained within the uniquely shaped stimulus. In addition to the shape singleton, an irrelevant colour singleton was presented on half of the trials. Namely, one of the non-target stimuli was red while the others were green or vice versa. Critically, the presence of the irrelevant colour singleton increased the time required to respond to the relevant form singleton. This response time (RT) cost led Theeuwes (1991) to theorize that the colour singleton captured attention automatically because of its high level of saliency. Attention was thus oriented to the task-relevant shape singleton only after an initial shift of attention to the distractor was completed and this more salient stimulus was determined irrelevant.

The RT cost associated with the presentation of an irrelevant singleton has been observed in the majority of studies using variants of the *additional singleton paradigm* described above (Bacon & Egeth, 1994; Theeuwes, 1991, 1992, 1994a, 2004). While Theeuwes has consistently proposed that this cost is a product of attentional capture by the highly-salient distractor singleton (Theeuwes, 1991, 1992, 1994a, 2004), other researchers have provided interpretations that challenge this *automatic capture hypothesis*. Perhaps the strongest alternative was proposed by Folk and Remington (1998), who suggested that the RT costs observed in the additional singleton paradigm are a product of filtering costs, similar to those reported in Kahneman, Treisman, and Burkell (1983). By this idea, the inclusion of a salient non-target in the stimuli array increases the complexity of the visual search display, with a corresponding increase in pre-attentive processing requirements. This additional processing takes time and thus delays shifts of attention to the target. Crucially, this *contingent capture hypothesis* does not rely on automatic orientation of attention to the non-target singleton to explain increases in RT. Rather, the theory proposes that top-down attentional set allows for highly salient non-target stimuli to be effectively ignored, so long as these irrelevant stimuli are defined in a featural dimension different from that of the target (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Folk, Remington & Wright, 1994).

The present study was designed to determine whether task-irrelevant singletons do, in fact, capture attention. To date researchers have investigated this issue by observing the effects of irrelevant singletons on behavioural responses to task-relevant stimuli. There are two limitations to this approach. First, capture by the irrelevant singleton must be inferred indirectly because no behavioural response is made to that stimulus. Second, modulations in behavioural performance indicators such as RTs may result from processing changes at any number of stages. Thus is it difficult to determine whether the appearance of an irrelevant singleton influences processing of the target singleton at early perceptual stages, as would be expected if the irrelevant singleton introduced perceptual filtering costs, at mid-latency attentional stages, as would be expected if the irrelevant singleton captured attention, or at later post-perceptual stages, as would be expected if the irrelevant singleton biased response. To distinguish between these possibilities, we recorded event-related potentials (ERPs) from participants while they performed a visual search task. ERPs are scalp-recorded voltage fluctuations that reflect moment-to-moment changes in neural processing. As such, they provide a means of evaluating the time course of activity related to different stages of perception and can be used to investigate the processing of both task-relevant stimuli and task-irrelevant stimuli.

To investigate whether salient but irrelevant stimuli capture attention, we focused on a specific component of the visual ERP that has been linked to the deployment of attention in visual space (Luck & Hillyard, 1994a, 1994b; Woodman & Luck, 1999, 2003). This component, known as the N2pc, is a negative-going deflection that is observable in the ERPs recorded over the posterior scalp roughly 175-300 ms post-stimulus. Specifically, the N2pc is defined as a larger negative voltage at electrodes contralateral to an attended stimulus than at electrodes ipsilateral to that stimulus, and is named for its polarity, latency, and topography (*p*osterior *c*ontralateral negativity in the latency of the N2 component). The N2pc is thought to reflect the attentional selection of an item in a search array via the suppression of surrounding items (Luck, Girelli, McDermott, & Ford, 1997; Luck & Hillyard, 1994b; see Eimer, 1996, for a different attentional explanation), a hypothesis that is supported by results showing that the target-elicited component is larger in amplitude when surrounded by highly salient distractor stimuli (e.g. Luck et al., 1997; Hopf et al., 2002). Because it is closely associated with attentional processes, the N2pc has been widely used as a tool to study the deployment of attention in visual space.

In each of two experiments reported below, participants were presented with visual search arrays that contained a target shape singleton and, on some trials, an irrelevant colour singleton. As in the design used by Theeuwes (1991), the irrelevant colour singleton was designed to be more salient than the target shape singleton. Following the well-documented RT cost associated with the presence of highly salient distractor singletons, we expected to find delayed responses to the target when the irrelevant colour singleton was present. The N2pc component was then isolated in order to chronicle the spatial deployment of attention following the presentation of the search arrays. Our strategy was to compare the N2pc elicited by several different types of search arrays, including those containing (1) a lateralized target and no distractor, (2) a lateralized target and a contralateral distractor, (3) a vertical target and a lateralized distractor, and (4) a vertical distractor and a lateralized target. By including trials on which either the distractor or target singleton was presented on the vertical meridian, we were able to independently measure the allocation of attention to the two stimuli using a method introduced by Woodman and Luck (2003). This method relies on the fact that stimuli on the vertical meridian do not elicit the N2pc. Thus, by presenting one singleton on the vertical we were able to determine whether the other, lateralized singleton elicited the N2pc.

Following our general strategy, we considered a number of predictions stemming from the automatic and contingent capture hypotheses. If the automatic capture hypothesis is valid, attention should be initially oriented to the location of the distractor, followed by a reorientation to the location of the target. Thus, when the target and distractor singletons are presented on opposite sides of fixation, the ERP waveform should initially be more negative at electrodes contralateral to the distractor (i.e., a distractor-elicited N2pc) only later becoming more negative at electrodes contralateral to the target (i.e., a subsequent target-elicited N2pc; cf. Woodman & Luck, 2003). Further, given the automatic capture of attention by the distractor singleton, a distractor-elicited N2pc should be apparent in conditions in which the target singleton is presented on the vertical meridian of the visual search display.

In contrast, if the contingent capture hypothesis is valid there should be no distractor-elicited N2pc in any experimental condition. Instead, variation in the onset of the target-elicited N2pc should be apparent. Specifically, the target-elicited N2pc should onset later in time in conditions in which the salient distractor is present, reflecting a delay in the orientation of attention. Additionally, given that the N2pc is an index of distractor suppression (cf. Luck et al., 1997; Hopf et al., 2002), a larger target-elicited N2pc should be evident when a salient distractor is present.

2.3 Experiment 1

2.3.1 Methods

2.3.1.1 Participants

Eighteen healthy students of the Vrije Universiteit Amsterdam gave informed consent before beginning Experiment 1. All participants reported normal or corrected-to-normal vision and normal colour vision and were paid for their participation. Data from two participants were discarded due to excessive eye movement artefacts in the EEG, and data from one participant were discarded as the N2pc was not evident in any experimental condition. Two of the remaining fifteen participants (five women; mean age = 21 years ± 2.4 years s.d.) were left handed.

2.3.1.2 Stimuli

The primary experimental display was a visual search array consisting of ten discrete shape stimuli, each presented equidistant (9.1°) from a central fixation point (see figures for examples). Shape stimuli were unfilled diamonds (4.2° x 4.2°) and circles (1.7° radius) with thin (0.3°) red or green outlines. A grey line (0.3° x 1.5°) randomly oriented either vertically or horizontally was contained within each of the shape stimuli. All stimuli were presented on a black background.

The colour and shape of the ten stimuli were randomly varied within the following confines. In every trial, one stimulus was different in shape than the other nine. This could mean that in a given trial a diamond was presented among circles, or that a circle was presented among diamonds. In 33% of total trials, this shape singleton was the only unique stimulus and was randomly presented to one of eight lateralized screen positions. In the remaining 66% of total trials, one of the nine identically-shaped stimuli was of a different colour than all other stimuli, either red among green stimuli or green among red stimuli. In one quarter of these trials (~17% of total trials) the colour singleton was presented on the vertical meridian while the shape singleton was lateralized. In another quarter of these trials the situation was reversed, with the shape singleton presented on the vertical meridian and the colour singleton lateralized. In the remainder of colour-singleton-present trials (~33% of total trials) the shape singleton was randomly presented at one of eight lateralized positions with the colour singleton randomly presented to one of 4 lateral positions in the contralateral visual hemifield.

2.3.1.3 Procedure

Experimental stimuli were presented on a CRT monitor located 60 cm. from the observer's eyes. Each experimental trial began with the presentation of a fixation point for a random duration of 600 to 1600 ms, followed by the presentation of a visual search array. The visual search array remained on the screen until 100 ms after a response was made, at which point the next trial began. Participant response was based on orientation of the line contained within the shape singleton. As line orientation was randomised, the target contained a vertical line in approximately half of trials and a horizontal line in the remainder.

Participants were instructed to respond as quickly as possible while maintaining an average accuracy of 90% or better, and feedback regarding accuracy and response latency was given at the end of each experimental block. Participants were instructed to maintain eye fixation throughout the experiment, and were told that eye movements were being monitored. Each experimental block consisted of 48 trials, and each participant completed 30 experimental blocks, for a total of 1440 experimental trials per participant. Prior to beginning the experiment, each participant completed at least one practice block of 48 trials.

Response was made via a custom designed serial response box on which the left hand button was separated from the right hand button by 32 cm. Response mapping was counterbalanced across participants: Eight participants were required to respond with the left hand when the target line was vertical and with the right hand when the target line was horizontal, with the remaining participants given the opposite response map.

2.3.1.4 Recording and Analysis

EEG was recorded from 30 tin electrodes mounted on an elastic cap (Electro-cap International). Electrode positions were a subset of the international 10/10 system sites (FPz, F7, F3, Fz, F4, F8, C7, C3, Cz, C4, C8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO7, PO3, POz, PO4, PO8, O1, Oz, O2, Iz, and M2). The vertical electro-oculogram (VEOG) was bipolarly recorded from electrodes above and below the right eye, and the horizontal electro-oculogram (HEOG) was bipolarly recorded from electrodes one centimetre lateral to the external canthi. The VEOG was used in the detection of blink artefacts, and the HEOG was used in the detection of eye movement artefacts. All electrode impedances were kept well below 15 kΩ. All electrodes (except VEOG and HEOG) were referenced during recording to the left mastoid and were later digitally re-referenced offline to an algebraic average of the left and right mastoids. The electrophysiological signals were amplified with a gain of 500 and a pass-band of 0.05 – 500 Hz, digitised at 500 Hz., and stored on a microcomputer. An automated artefact-rejection process was applied to the EEG in order to remove trials containing eye movement, blink or amplifier blocking artefacts. All trials containing such artefacts in a 1,000 ms epoch beginning 200 ms before stimulus onset were rejected. The automatic rejection of trials containing eye movements was further verified via inspection of the averaged HEOG signal for individual participants. The averaged HEOG did not exceed 2 μV for any analysed participant, which suggests that any eye movements contained in trials that were not rejected were less than 0.3° visual angle in size (see McDonald & Ward, 1999, for HEOG calibration). Following the creation of ERPs, a Gaussian finite impulse function (3 dB attenuation at approximately 40 Hz) was used to digitally low-pass filter the data, effectively removing high-frequency noise produced by muscle activity and external electrical sources. For statistical purposes ERP amplitude was computed with respect to a 100-ms pre-stimulus period. This period was also used to calculate the baseline of the ERPs presented in the figures.

2.3.2 Results

2.3.2.1 Behavioural Results

A total of 16.4% of trials were excluded from analysis due to erroneous behaviour, 1.0% due to excessively slow response (>2000 ms) and 15.4% due to incorrect response. A further 8.2% of trials were excluded due to eye movement artefacts in the electroencephalogram (EEG). Behavioural and ERP analyses were conducted on the remaining data.

Table 1a presents the RT and error rate data observed in each of the four conditions of Experiment 1. The inter-participant mean RT observed across distractor-singleton-present conditions was 691 ms, while the mean RT in the distractor-singleton-absent condition was 588 ms. This 103-ms difference was found to be statistically significant in a repeated-measures analysis of variance (ANOVA) with a single factor for distractor presence (present, absent) [$F(1,14) = 60.52, p < 0.001$]. A similar analysis of error rates revealed that participants made fewer errors when the distractor singleton was absent (14.3%) than when it was present (16.3%) [$F(1,14) = 10.99, p < 0.01$]. The convergence of RT and accuracy data indicates that there was no speed-accuracy trade-off. These behavioural results closely parallel those observed in several previous studies of attentional capture (Bacon & Egeth, 1994, Exp. 1; Theeuwes, 1991, 1992, 1994a).

2.3.2.2 Electrophysiological Results

In order to examine the possibility that the observed RT difference was a product of the capture of spatial attention, we first examined the difference between the target-elicited N2pc found when visual search arrays contained only a lateral target singleton, and the target-elicited N2pc found when visual search arrays contained both a lateral singleton target and a contralateral singleton distractor (Figures 1a and 1b, respectively). In both conditions, the ERP waveforms at lateral occipital electrodes (PO7 and PO8) consisted of a series of positive and negative peaks oscillating at approximately 10 Hz, including prominent P1 (120 ms), N1 (180 ms), P2 (230 ms), and N2 (280 ms) components.

As illustrated in Figure 1a, the P1 component was somewhat larger at posterior electrodes contralateral to the target than at posterior electrodes ipsilateral to the target when the search array contained a lateral target but no singleton distractor. A repeated-measures ANOVA with electrode location (contralateral versus ipsilateral, relative to the target) as the sole factor indicated that this laterality was statistically significant [100 – 150 ms interval: $F(1,14) = 13.61, p < 0.01$]. This may have been caused by an imbalance in sensory energy rather than an automatic capture of attention by the target (Luck & Hillyard, 1994a). As illustrated in Figure 1b, the P1 was laterally symmetric when the search array contained a lateral target and contralateral distractor [100 – 150 ms interval: $F(1,14) < 1$].

The N2pc component was elicited by the lateralized target both when it appeared in the absence of a distractor singleton (Figure 1a) [225 – 310 ms interval : $F(1,14) = 17.41, p < 0.01$] and when it appeared with a distractor singleton in the opposite field (Figure 1b) [225 – 310 ms interval: $F(1,14) = 6.34, p < 0.05$]. Visual inspection of the two ERPs suggests that the N2pc component was substantially smaller when an irrelevant distractor singleton was presented contralateral to the target (Figure b) as compared to when no distractor singleton was presented (Figure 1a). This pattern was confirmed by statistical analysis of the N2pc peaks. The mean ERP amplitude was measured in a 245-275 ms latency range at lateral occipital electrodes (PO7 and PO8) contralateral and ipsilateral to the target for both lateralized-target trials containing no distractor singleton and lateralized-target trials containing a contralateral distractor. A two-way ANOVA with repeated-measures factors for electrode location (contralateral versus ipsilateral, relative to target location) and contralateral distractor (present, absent) revealed a significant interaction between the factors [Location x Distractor: $F(1,14) = 4.90, p < 0.05$], evidence that the observed reduction in N2pc amplitude between conditions was statistically reliable.

To independently examine the N2pc waves elicited by the target and distractor stimuli, we created separate ERPs for search arrays that contained either a target or distractor singleton on the vertical meridian (cf. Woodman & Luck, 2003). Figure 2a illustrates the ERP obtained when the distractor was presented on the vertical meridian and the target was presented to one of the eight lateralized positions, whereas Figure 2b illustrates the ERPs obtained when the target was presented on the vertical meridian and the distractor was presented to one of the eight lateralized positions. An N2pc can be observed contralateral to the target in Figure 2a [230 – 290 ms interval: $F(1,14) = 5.28, p < 0.05$] and contralateral to the distractor in Figure 2b [230 – 290 ms interval: $F(1,14) = 8.97, p < 0.01$].

2.3.3 Discussion

As is apparent in a comparison of Figures 1a and 1b and an examination of Table 1, the concurrent presentation of a distractor singleton to the visual hemifield contralateral to the target resulted in both an increase in response latency and a reduction in target-related N2pc amplitude. Further, when only the distractor was presented to a lateral screen position, a distractor-elicited N2pc was apparent (Figure 2b). The presence of the distractor singleton did not, however, have any clear effects on the latency of the N2pc component. In Figures 1a and 1b, for example, the contralateral waveforms diverge from the ipsilateral waveforms at very similar latency points, and later converge at very similar latency points.

While the results of Experiment 1 are generally supportive of the automatic capture hypothesis, they are not entirely conclusive. The existence of a distractor-elicited N2pc, as shown in Figure 2b, suggests that attention was often oriented to the irrelevant colour singleton. If attention was invariably oriented to the distractor before the target, however, we would expect to observe a polarity reversal in the N2pc latency period when the target and distractor were presented in contralateral visual hemifields, reflecting an initial shift of attention to the distractor followed by a reorientation to the target. The absence of this pattern is puzzling.

One possible explanation for the lack of an N2pc reversal is that participants adopted a search strategy in which the distractor was used as a cue to the general location of the target stimulus. Adoption of such a strategy would have been less likely if the presentation of stimuli had been completely random, but this was not the case in Experiment 1. To maximize signal-to-noise ratios in the most critical experimental conditions (e.g., distractor-present trials), some other conditions were eliminated.

Specifically, participants were never presented with visual search arrays in which the two singletons were on the same side of fixation. This resulted in a situation in which the distractor singleton, though not accurately predictive of target location, identified the visual hemifield to which the target *would not* be presented. This situation may have produced two undesirable effects. First, it may have counteracted the stimulus-driven processes that result in a strong capture effect, thereby reducing the distractor-elicited N2pc. Second, it may have facilitated the attentional engagement of the target, thereby increasing the target-elicited N2pc.

We conducted an additional experiment to control for the confound resulting from the elimination of same-hemisphere trials and to further test the predictions stemming from the automatic and contingent capture hypotheses. In Experiment 2, trials in which the target and distractor were in the same hemifield or in opposite hemifields were equally likely.

2.4 Experiment 2

2.4.1 Methods

2.4.1.1 Participants

Eighteen healthy students of Simon Fraser University gave informed consent before participating in Experiment 2. All reported normal or corrected-to-normal vision and colour vision and received class credit for their participation. Data from two participants were discarded due to excessive eye movement artefacts in the EEG, and data from a further two participants were discarded as the N2pc was not evident in any experimental condition. All of the remaining fourteen participants (six women; mean age = 21 years ± 3.2 years s.d.) were right handed.

2.4.1.2 Stimuli

The experimental stimuli used in Experiment 2 were identical to those in Experiment 1 with the following exception. In Experiment 2, the colour singleton was presented in approximately 16% of total trials at one of three lateral positions in the same visual hemifield as the shape singleton.

2.4.1.3 Procedure

The experimental procedure used in Experiment 2 was identical to that in Experiment 1 with the following exceptions. In Experiment 2 response was made via the left and right buttons on a standard computer mouse. Response mapping was not counterbalanced across participants: All participants responded with their dominant hand (right in the case of all 14 analysed participants), and responded with the left mouse button when the target line was vertical and the right mouse button when the target line was horizontal.

2.4.1.4 Recording and Analysis

EEG was recorded from 63 tin electrodes mounted in an elastic cap (Electro-cap International). Electrode positions were a subset of the international 10/10 system sites (FP1, FPz, FP2, AF3, AF4, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FC5, FC3, FC1, FCz, FC2, FC4, FC6, T7, C5, C3, C1, Cz, C2, C4, C6, T8, CP5, CP3, CP1, CPz, CP2, CP4, CP6, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO3, POz, PO4, PO8, O1, Oz, O2, I5, I3, Iz, I4, I6, SI3, SIz, SI4, and M2). The horizontal electro-oculogram (HEOG) was bipolarly recorded from electrodes one centimetre lateral to the external canthi. The HEOG was used in the detection of eye movement artefacts, while electrode site FP1 was used in the detection of blink artefacts. All electrode impedances were kept well below 10 kΩ. All electrodes (except HEOG) were referenced during the recording to the left mastoid and were later digitally re-referenced offline to an algebraic average of the left and right mastoids. The electrophysiological signals were amplified with a gain of 2000 and a pass-band of 0.1 – 100 Hz., digitised at 500 Hz., stored on a microcomputer, and averaged offline. All other analysis procedures, such as filtering and artefact rejection, were as in Experiment 1.

2.4.2 Results

2.4.2.1 Behavioural Results

A total of 10.2% of trials were excluded from analysis due to erroneous behaviour, 0.8% due to excessively slow response (>2000 ms) and 9.4% due to incorrect response. A further 16.6% of trials were excluded due to eye movement artefacts in the EEG.

Table 1b presents the RT and error rate data observed in each of the five conditions of Experiment 2. The inter-participant mean RT observed across the distractor-singleton-present conditions was 1010 ms, while the mean RT observed in the distractor-singleton-absent condition was 689 ms. This 321 ms difference was found to be statistically significant [$F(1,13) = 409.50, p < 0.001$], and an analysis of error rates provided evidence that fewer errors were made when the distractor singleton was absent (present: 10.5%, absent: 7.5%) [$F(1,13) = 26.61, p < 0.001$].

The pattern of behavioural results observed in Experiment 2 is roughly congruent with that observed in Experiment 1, in that participants were both slower and more error prone when the distractor singleton was present. Participants in Experiment 2 were generally slower but more accurate than those in Experiment 1 (see Table 1), suggesting that acceptable speed-accuracy trade-off rates differed between the groups.

2.4.2.2 Electrophysiological Results

Figures 3 and 4 present the ERPs elicited in the five conditions of Experiment 2. The ERP presented in Figure 3a was produced by trials in which the target stimulus was presented to one of eight lateralized positions and the distractor was presented to one of two positions on the vertical meridian. The ERP presented in Figure 3b was produced in the reverse situation, when the target was presented to one of two vertical positions and the distractor was presented to one of eight lateralized positions. When the distractor singleton was presented on the vertical meridian, the ERP to the search array was more negative at posterior electrodes contralateral to the target in the interval of the N2pc [260 – 290 ms: $F(1,13) = 5.97$, $p < 0.05$, Figure 3a]. By comparison, when the target singleton was presented on the vertical meridian, the ERP to the search array was more negative at posterior electrodes contralateral to the *distractor* in the interval of the N2pc [260 – 290 ms: $F(1,13) = 7.27$, $p < 0.05$, Figure 3b]. A two-way ANOVA with repeated-measures factors of electrode location (contralateral versus ipsilateral, relative to the lateralized stimulus) and condition (lateral target with vertical distractor versus lateral distractor with vertical target) did not approach significance level, suggesting that the amplitude of the distractor-related and target-elicited N2pc components are not reliably different [260 – 290 ms, Condition x Location: $F(1,13) = 0.12$].

Figure 4 shows ERPs elicited by the search array in the remaining three conditions. Search arrays that contained a lateralized target singleton elicited a posterior ERP negativity in the latency of the N2pc at electrodes contralateral to the target, both when the distractor was absent [230 – 295 ms: $F(1,13) = 16.79, p < 0.01$], and when the distractor was on the same side of the vertical meridian [230 – 295 ms interval: $F(1,13) = 4.66, p < 0.05$, Figures 4a and 4b, respectively). In contrast, search arrays that contained a lateralized target and a contralateral distractor elicited a posterior ERP negativity in the latency of the N2pc that was initially contralateral to the *distractor* and only later contralateral to the target. The initial distractor-elicited N2pc was significant in the 220-265 ms interval [$F(1,13) = 7.10, p < 0.05$], and the subsequent target-elicited N2pc was significant in the 275-350 ms interval [$F(1,13) = 5.63, p < 0.05$], with the polarity reversal at approximately 270 ms.

To investigate the effect of distractor laterality on the magnitude of the target-elicited N2pc, we made a planned comparison between the target-elicited N2pc observed when a concurrent distractor was presented on the vertical meridian (Figure 3a) and the target-elicited N2pc observed when a concurrent distractor was presented in the same visual hemifield (Figure 4b). A two-way ANOVA with repeated-measured factors of electrode location (contralateral versus ipsilateral, relative to the target) and condition (lateral target with vertical distractor versus both stimuli lateral to same visual hemifield) showed a significant interaction between the factors, indicating the target-elicited N2pc was larger when both the target and distractor were presented in the same hemifield [245 – 255 ms, Location x Condition: $F(1,13) = 4.73, p < 0.05$].

2.4.3 Discussion

As in Experiment 1, a distractor-elicited N2pc was found in Experiment 2 when the target was presented on the vertical meridian. In addition, when the target and distractor were presented to opposite visual hemifields the N2pc was initially observed contralateral to the distractor, and only subsequently contralateral to the target (Figure 4c). The data thus suggests that attention was initially oriented to the distractor stimulus before being reoriented to the target, and provides compelling evidence for the automatic capture hypothesis. The absence of such an N2pc reversal in Experiment 1 indicates that the exclusion of some conditions in that experiment had a detrimental effect on the processes that generate the distractor-elicited N2pc.

The presence of a distractor in the same visual hemifield as the target can be observed to substantially increase the magnitude of the target-elicited N2pc in Experiment 2 (cf. Figures 3b and 4b), suggesting that a greater degree of distractor suppression was required when the distractor and target were presented close to one another (Luck et al., 1997). Note that this pattern was not observed in Experiment 1 when the target was presented to the contralateral visual hemifield (cf. Figure 1a and 1b); here, the presence of the distractor resulted in a *decrease* in target-related N2pc amplitude. This apparent inconsistency can be accounted for by the automatic capture hypothesis; when the target and distractor were presented to opposite visual hemifields in Experiment 1, attention was often directed to the distractor. When the N2pc elicited on these trials was averaged with the N2pc elicited in trials in which attention was directed to the target, the net result was a small target-related effect. The contingent capture hypothesis, in contrast, does not present an obvious solution to this pattern in the data.

The results of Experiment 2 provide one puzzle. While the distractor-elicited N2pc observable in Figure 3b onsets at approximately 240 ms and offsets at approximately 290 ms, that observed in Figure 4c begins at approximately 220 ms and ends around 265 ms. This is the case even though, regardless of whether our predictions are based on the contingent or automatic capture hypotheses, the pattern of attentional orientation in these two conditions should not differ. A post-hoc repeated measured ANOVA was applied to the peak latencies of the distractor-elicited N2pc components in these two conditions in order to ascertain the reliability of the latency difference [$F(1,13) = 0.11$]. The results leave open the possibility that the pattern is a product solely of chance. If the observed difference in N2pc onset does in fact have functional significance, it should be noted that it presents no challenge to the automatic capture hypothesis. If attention was initially oriented to the target when participants were presented with search displays containing a vertical target and lateral distractor (Figure 3b), engagement of the target would have occurred significantly earlier than can be observed when participants were presented with search displays containing a lateral target and contralateral distractor (Figure 4c). We would expect earlier engagement of the target stimulus to result in an RT advantage; in fact, mean RT in the vertical target, lateral distractor condition (Figure 3b) is 45 ms longer than that observed in the lateral target, contralateral distractor condition (Figure 4c). These results raise the possibility that the delay in orientation of attention to the distractor stimulus in Figure 3b created a subsequent delay in the orientation of attention to the target stimulus, which ultimately led to a slowing of manual response.

2.5 General Discussion

The goal of the present study was to shed new light on a long-standing debate regarding the ability of salient non-targets to capture attention in visual search tasks. In both Experiments 1 and 2 we presented participants with visual search arrays containing either a target singleton among low saliency non-targets or both a target and distractor singleton among low saliency non-targets, in a design taken from the additional singleton paradigm (Theeuwes, 1991). Target and distractor singletons were defined by shape and colour, respectively. Participants were required to respond to oriented lines contained within target singletons only; the distractor singletons, defined by colour, were irrelevant to the task. Brain electricity was recorded using scalp EEG electrodes while participants completed the task and the ERPs elicited by the search arrays were extracted from the EEG using standard signal averaging procedures. A particular component of the visual ERP that is known to reflect the spatial deployment of attention – the N2pc – was used to determine whether attention was captured by the irrelevant colour singleton.

In both Experiments 1 and 2, responses were slower and more error-prone when a salient distractor was concurrently presented with the target. The ERP data demonstrated that this well-documented RT cost is due to attentional capture by the irrelevant target. In Experiment 1, the target-elicited N2pc component was smaller in magnitude when a salient distractor was concurrently presented with the target. Further, a distractor-elicited N2pc was evident when the target was presented on the vertical meridian of the visual search display and thus was unable to elicit a lateralized N2pc (cf. Woodman & Luck, 1999, 2003). These results suggest that attention was often oriented to the distractor singleton. This is in spite of the fact that, due to a confound in Experiment 1, the distractor singleton was predictive of the visual hemifield to which the target singleton *would not* be presented. In contrast, the presence of a distractor singleton was not found to result in latency shifts in the onset of the target-elicited N2pc, as would be expected if the initial orientation of attention were slowed by the presence of a distractor singleton.

The results of Experiment 1 are generally consistent with the automatic-capture hypothesis. One important predicted pattern, however, is notably absent. Specifically, if, when both target and distractor were presented to opposite visual hemifields, attention was oriented to the distractor before the target, the ERP elicited in these trials should initially be more negative contralateral to the distractor singleton before reversing polarity to become more negative contralateral to the target singleton. The absence of this pattern in Experiment 1 suggests either that attention was captured in only a subset of total trials or that capture by the distractor was not consistently reflected in the N2pc.

One possibility is that the processes responsible for the distractor-elicited N2pc were somehow minimized in Experiment 1, possibly due to the unexpected adoption by participants of a search strategy based on distractor location. In Experiment 2 the ability of participants to adopt such a strategy was removed. The results of Experiment 1 were reproduced in Experiment 2. Furthermore, a clear distractor-elicited N2pc was observed to precede the target-elicited N2pc in Experiment 2 when the target and distractor were presented to opposite visual hemifields, a pattern predicted by the automatic capture hypothesis. Taken together, Experiments 1 and 2 provide strong support for the idea that salient non-target stimuli capture spatial attention even when they are defined by an irrelevant visual feature.

It is important to point out that the displays used in the present study were not completely symmetric. On some trials, a singleton appeared on one side of fixation but not on the other, which would have caused a slight lateral imbalance in stimulus energy. Even when the target and distractor were both lateralized, there may have been some laterally imbalanced stimulus energy because the distractor singleton on one side was perceptually more salient than the target singleton on the other side. This leaves open the possibility that the distractor-elicited N2pc components observed in both experiments 1 and 2 may have been caused by imbalanced stimulus energy rather than by shifts of attention. This alternative explanation can be assessed to some degree by determining whether the early sensory-evoked ERP components were lateralized. The results of Experiment 1 show that the early P1 component (100 ms) elicited by lateralized targets presented in the absence of distractors (Figure 1a) was slightly larger at occipital electrodes contralateral to the target. No hint of a lateralized P1 is apparent, however, in the ERP elicited when the target and distractor were presented on opposite sides of fixation. Consequently, though the larger N2pc on lateralized-target/no-distractor trials may have been caused in part by the difference in lateralized stimulus energy, the same cannot be said of the N2pc elicited on lateralized-target/lateralized-distractor trials because this ERP does not show any stimulus-induced lateral asymmetries prior to the N2pc latency range. This same reasoning applies to the other ERPs presented in the study. The general absence of early laterality, particularly in the ERPs in which a distractor-elicited N2pc is apparent, argues against a non-attentional interpretation of the results.

The results reported above are in line with other electrophysiological research providing evidence of the involuntary orienting of attention to task-irrelevant stimuli. It is now known that sudden but spatially non-predictive cue stimuli not only facilitate overt responses to subsequent visual targets appearing nearby but also modulate target-elicited ERP activity in sensory cortical areas (for recent reviews, see Hopfinger & Mangun, 2001; Spence & McDonald, 2004). Such effects occur even when attention is captured by a cue in another task-irrelevant modality (Kennett, Eimer, Spence, & Driver, 2001; McDonald, Teder-Sälejärvi, Di Russo & Hillyard, 2003; McDonald, Teder-Sälejärvi, & Hillyard, 2000; McDonald & Ward, 2000). These results, along with those reported in the current study, suggest that stimulus-driven control processes play a very important role in the control of visual attention, and provide evidence for models of attention in which these control processes play an integral role (e.g. Koch and Ullman, 1985; Theeuwes, 1994b).

2.6 Tables

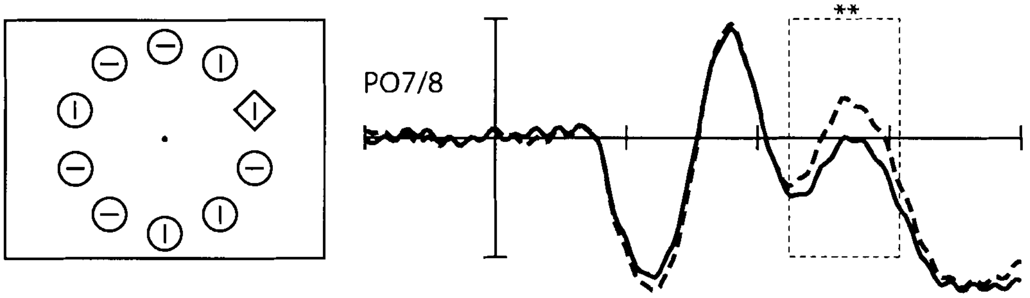
Table 1 **Behavioural results.** Mean correct response times (in milliseconds) and error rates (in percentage) for Experiments 1 and 2 by experimental condition.
(a.) Experiment 1. (b.) Experiment 2.

Experimental Condition	Mean RT (s.d.)	Error Rate (s.d.)
A - Experiment 1		
Lateral Target, Vertical Distractor	695 (93)	16 (6)
Lateral Target, No Distractor	588 (91)	14 (6)
Lateral Target, Contralateral Distractor	666 (88)	16 (6)
Vertical Target, Lateral Distractor	729 (92)	17 (6)
B - Experiment 2		
Lateral Target, Vertical Distractor	999 (156)	10 (5)
Lateral Target, No Distractor	689 (106)	8 (3)
Lateral Target, Contralateral Distractor	970 (141)	10 (3)
Lateral Target, Ipsilateral Distractor	1,054 (169)	12 (5)
Vertical Target, Lateral Distractor	1,015 (149)	10 (4)

2.7 Figures

Figure 1 **Experiment 1, ERPs A.** Grand averaged ERPs elicited in Experiment 1 by circular search arrays containing (a) a lateral target and no distractor, and (b) a lateral target and contralateral distractor. The distractor-singleton, defined by colour, is represented by a broken circle. Actual experimental stimuli were composed of colour outlines on a black background. As with all ERPs presented in this paper, these ERPs were recorded at posterior lateral electrode sites PO7 and PO8. Note that negative is plotted upwards, and that stimulus onset was at 0 ms.

A. Experiment 1 - Lateral target, no distractor



B. Experiment 1 - Lateral target, contralateral distractor

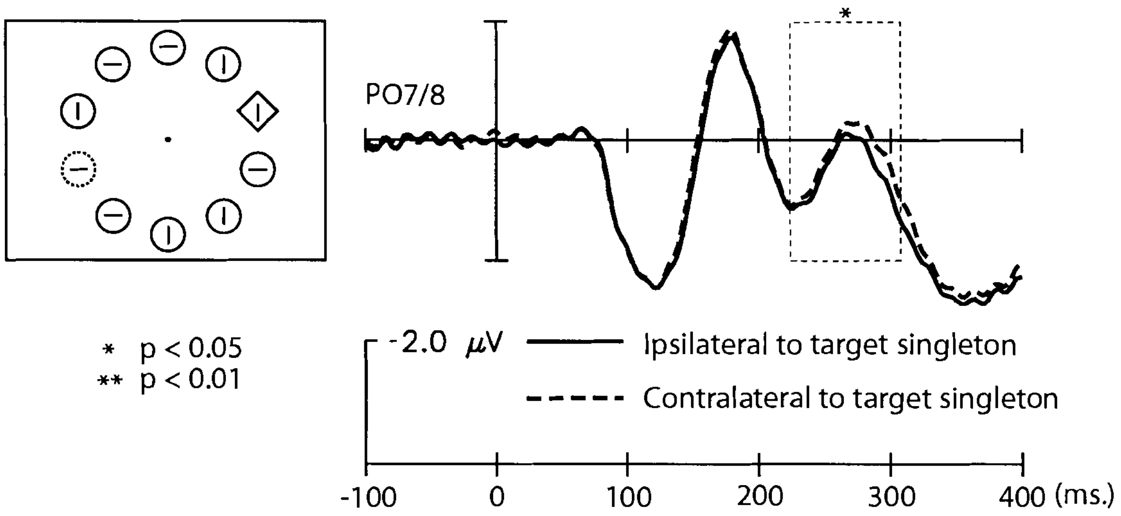


Figure 2 **Experiment 1, ERPs B.** Grand averaged ERPs elicited in Experiment 1 by circular search arrays containing (a) a lateral target and vertical distractor, and (b) a vertical target and lateral distractor.

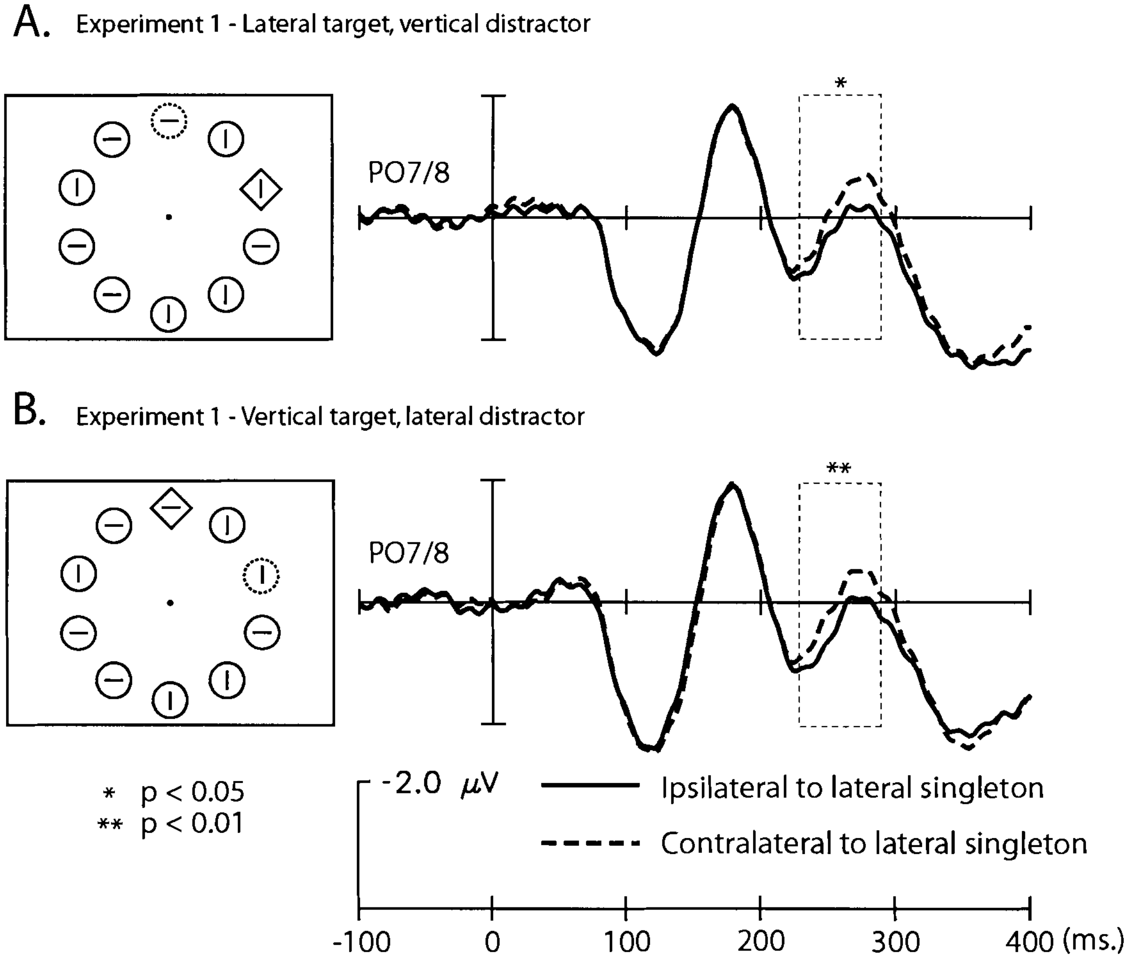


Figure 3 **Experiment 2, ERPs A.** Grand averaged ERPs elicited in Experiment 2 by circular search arrays containing (a) a lateral target and vertical distractor, and (b) a vertical target and lateral distractor.

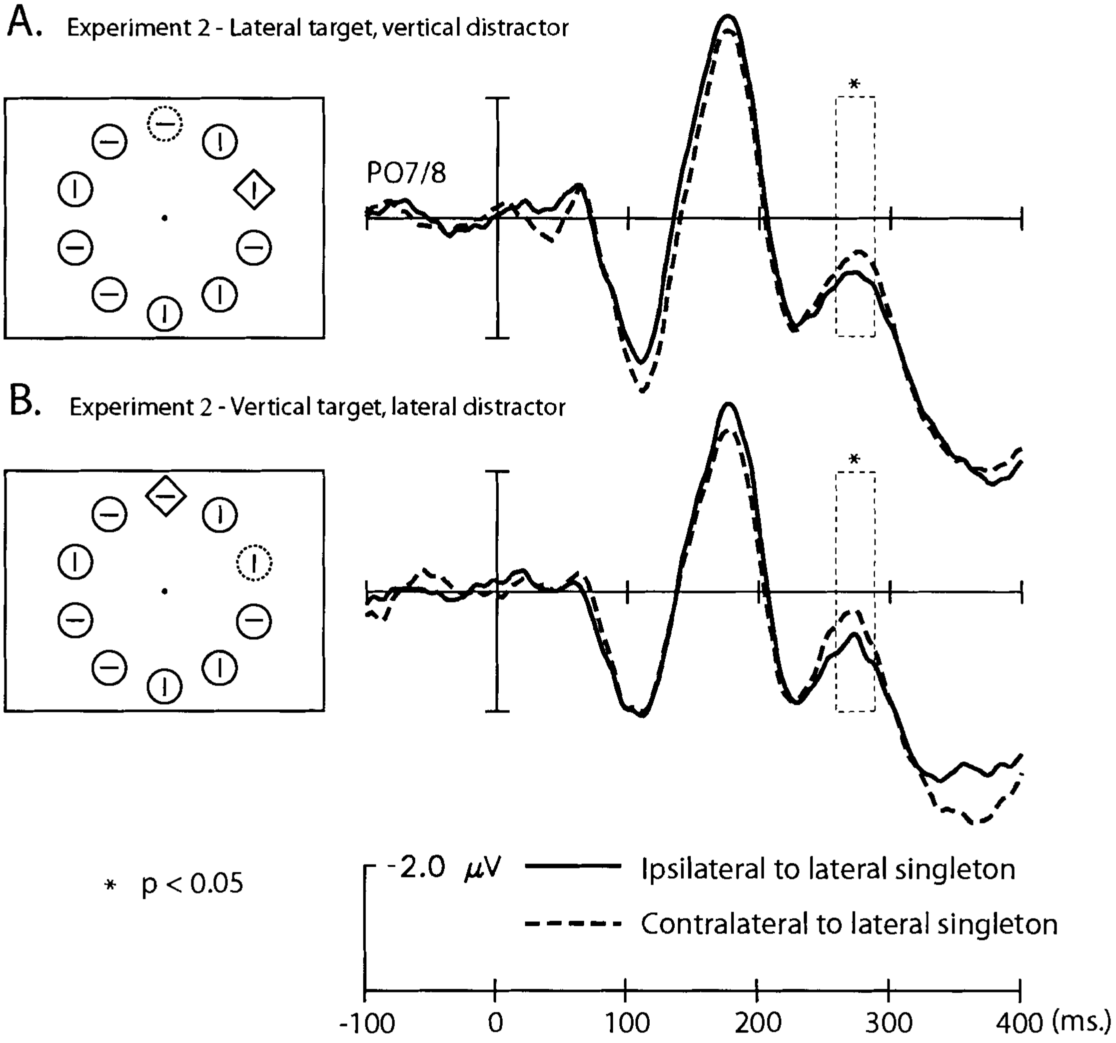
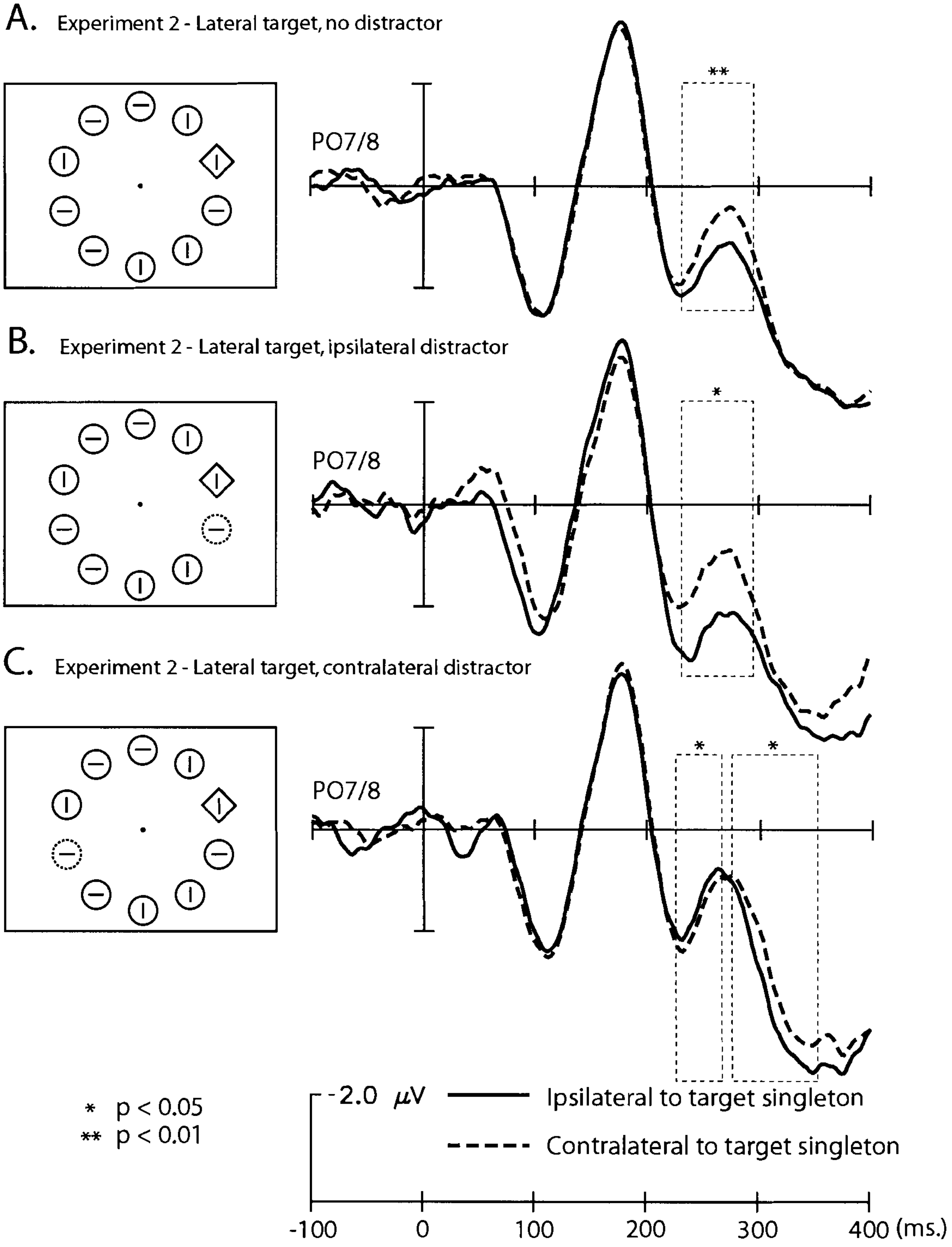


Figure 4 Experiment 2, ERPs B. Grand averaged ERPs elicited in Experiment 2 by circular search arrays containing (a) a lateral target and no distractor, (b) a lateral target and ipsilateral distractor, and (c) a lateral target and contralateral distractor.



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CHAPTER 3
TARGET AND DISTRACTOR PROCESSING IN VISUAL SEARCH : DECOMPOSITION OF THE N2PC

3.1 Abstract

Attentional selection of a stimulus can be indexed with an event-related potential (ERP) component known as the N2pc. The N2pc is thought to reflect the suppression of distractor stimuli, even though animal electrophysiological studies suggest that selection relies on both target and distractor processing. We conducted two visual search experiments designed to identify and isolate the ERP activity associated with target and distractor processing in visual search. ERPs were recorded while participants viewed sparse search arrays containing only a target and single distractor. In Experiment 1 a positive contralateral component was elicited by a lateral non-target when the target was presented on the vertical meridian of the display, and was thus unable to elicit lateralized ERP activity. This positivity, which we call the P_D, appears to index the suppression of distractor processing. In Experiment 2 the same visual search displays were found to elicit a contralateral negativity when participants were instructed to attend to the lateral stimulus, rather than ignore it. This negativity, which we call the N_T, appears to index target processing. We believe that the N_T and P_D are functionally distinct sub-components of the N2pc.

3.2 Introduction

In everyday experience we are confronted with a wide range of visual stimuli from which to select objects of interest. Within vision research, identification of the mechanisms that underlie our ability to select objects is a driving goal. In laboratory studies an experimental paradigm known as *visual search* has been extensively used for this purpose. In a typical visual search experiment observers are presented with a display containing a number of items and are asked to respond based on the presence or characteristics of a target. Insight into the mechanisms underlying target selection has been gained through analysis of the behaviour of participants completing visual search tasks. More recently, non-invasive electrophysiological techniques have been used to achieve this same goal.

In human electrophysiological studies of visual search the general approach has been to compute event related potentials (ERPs) that are time-locked to the onset of visual search displays. ERP components related to visual selection can be identified in the resulting waveforms by looking for modulation as a function of factors such as the location of the target or type of distractors presented. With this approach investigators have identified a specific component of the visually evoked ERP that appears to reflect the allocation of attention to objects in the search display (Luck, Girelli, McDermott, & Ford, 1997; Eimer, 1996; Luck & Hillyard, 1994a, 1994b). Commonly referred to as the N2pc, this component is a negative ERP difference beginning ~175 ms post-stimulus at electrode sites contralateral to a target relative to electrode sites ipsilateral to a target. The label stems from the latency of the component, which is in the range of the visual N2, and its scalp topography, which is posterior and contralateral to an attended stimulus.

The N2pc is thought to reflect distractor suppression involved in the spatial selection of a target. An early study provided two key pieces of evidence for this hypothesis (Luck & Hillyard, 1994b). First, targets that elicited the N2pc in the presence of distractors failed to elicit the N2pc when distractors were absent. Second, targets also failed to elicit the N2pc when the distractors provided essential information about the presence or absence of the target and thus could not be suppressed (Luck & Hillyard, 1994b). Subsequent research has provided additional support for the distractor suppression hypothesis. For example, researchers have reported a close correspondence between the characteristics of the scalp-recorded N2pc and the suppressive effect of attention that has been observed within monkey visual cortex (Moran & Desimone, 1985; Luck, Chelazzi, Hillyard, & Desimone, 1997; Chelazzi, Miller, Duncan, & Desimone, 1993). Both the suppression of monkey cortical activity and the N2pc emerge approximately 175 ms after the onset of a stimulus array and are larger in magnitude for difficult discrimination than for simple detection, when distractors are near rather than far away, and when the target is in the lower visual field rather than the upper visual field (Luck, Girelli, et al., 1997).

The similarities between the N2pc and the suppressive effect of attention in monkey visual cortex have led to a theory of visual attention called *ambiguity resolution* (Luck, Girelli, et al., 1997). According to this idea, ambiguities regarding object features arise when the binding of features to individual stimuli is required, as occurs in the discrimination of fine details but not in the detection of simple features, and multiple objects are presented such that they share neural receptive fields. In this situation information encoded in the output of individual neurons cannot be attributed to discrete stimuli. This ambiguity of neural coding is resolved through suppression of information arising from unattended stimuli, and this process is indexed by the N2pc.

By the ambiguity resolution theory, the N2pc is a direct result of distractor suppression. Not all ERP results, however, are consistent with a distractor-related role for this component. For example, N2pc magnitude has been found to be unaffected by the number of distractors (Eimer, 1996), and has been observed in response to a single lateralized stereoscopic stimulus in the absence of standard distractors (Shedden & Nordgaard, 2001). Moreover, an N2pc has been observed contralateral to a target in the presence of a single distractor in the opposite visual hemifield (Eimer, 1996). This finding is important for two reasons. First, it conflicts with the commonsensical notion that an electrophysiological correlate of suppression should be observed contralateral to the suppressed item. Second, it conflicts with the idea that the N2pc reflects the resolution of ambiguity that is required when the encoding of target and distractor stimuli relies on a similar population of neurons because stimuli presented to separate visual hemifields would be largely processed by independent groups of neurons. In contrast to the idea that the N2pc reflects the suppression of distractors, these results associate the N2pc more closely with selective processing of the target.

Results linking the N2pc to target processing on the one hand and distractor suppression on the other raise the possibility that the N2pc in fact reflects processing of both the target and distractor. This possibility is consistent with what we know of attentional selection from other experimental results. In animal electrophysiology, for example, studies have shown that selection not only relies on distractor suppression (Moran & Desimone, 1985; Luck, Chelazzi, Hillyard, & Desimone, 1997; Chelazzi, Miller, Duncan, & Desimone, 1993) but also on the modulation of neural activity tied to target stimuli (for a recent review, see Treue, 2001). Algorithms identified in this work have ranged from enhancement via increases in neural firing rates (Spitzer, Desimone, & Moran, 1988; Roelfsema, Lamme, & Spekreisje, 1998; Treue & Maunsell, 1999; Khayat, Spekresijse, & Roelfsema, 2006) to more complicated mechanisms such as the modulation of single neuron response selectivity to target characteristics (Spitzer, Desimone, & Moran, 1988; though see McAdams & Maunsell, 1999). Recent functional magnetic resonance imaging (fMRI) and magnetoencephalographic (MEG) work has further suggested that these mechanisms of enhancement and suppression may occur concurrently, with spatial attention reflected in a circumscribed inhibitory field with an excitatory centre (Slotnick, Hopfinger, Klein, & Sutter, 2002; Hopf, Boehler, Luck, Tsotsos, Heinze, & Schoenfeld, 2006).

The goal of the present study was to identify the electrophysiological correlates of target-related and distractor-related processes that underlie selection in visual search. In order to isolate target-related and distractor-related activity we employed visual search displays that had three key characteristics. First, the displays contained only two stimuli, one target and one distractor. Second, each stimulus was presented on the vertical meridian on some trials such that lateralized ERP activity could be attributed to the other, lateralized stimulus (Woodman & Luck, 2003; see also Hickey, McDonald, & Theeuwes, 2006). Third, the brightness of one stimulus, either the target or distractor, was matched with that of the display background in order to minimize lateralized ERP activity resulting from sensory imbalance rather than attention (e.g. when a stimulus is presented to a lateral location with no corresponding stimulus in the contralateral visual hemifield).

3.3 Experiment 1

3.3.1 Methods

3.3.1.1 Participants

Twelve healthy students of Simon Fraser University gave informed consent before beginning the experiment. All participants reported normal or corrected-to-normal vision and normal colour vision and received course credit for their participation. Ten of twelve participants (four men; mean age = 18.8 years ± 1.4 years s.d.) were right handed.

3.3.1.2 Stimuli and Procedure

Before beginning the experiment each participant was required to complete a modified method-of-limits procedure designed to psychophysically match the luminance of two colours. This involved adjusting the luminance of a grey box presented on the computer screen such that it matched the brightness of a concurrently presented red box. Participants could increase the luminance of the grey box by pressing the left button of a standard computer mouse, decrease it with the right button, and accept it as equiluminant to the red by pressing the middle mouse button. Four matches were made. In two instances, the initial luminance of the grey box was ~2.5 cd/m^2 higher than that of the red, and participants were instructed to decrease the brightness of the grey box until it matched the red box. In the remaining instances the initial luminance of the grey box was ~2.5 cd/m^2 lower than the red, and participants were instructed to increase the brightness of the grey box until it matched the red. The numeric values associated with the shade of grey created in each of these matches were averaged to create the background luminance used in the experiment.

The experiment itself consisted of 20 blocks of 60 trials, for a total of 1200 trials per participant. All stimuli were presented on a CRT monitor located 60 cm from the observer's eyes. Trials began with the presentation of a fixation point for 1350 - 1650 ms, followed by the presentation of a simple visual search array. The array contained two stimuli, a green square that could be rotated 45° to have a diamond form (0.6° x 0.6°) and a red line that could be either long (1.2° x 0.15°) or short (0.8° x 0.15°). While the shade of green used to define the shape stimulus (42.41 cd/m^2) was substantially more luminous than the background, the shade of red used to define the line stimulus (3.92 cd/m^2) was the exemplar colour used in the brightness matching procedure described above, and was thus perceived by participants as equally bright to the display background.

Individual stimuli could be presented to one of six screen positions. These positions were equidistant from a central fixation point and each other (5°), and included two positions on the vertical meridian (ie. directly above or below fixation). The stimuli remained on the screen until either a participant response was detected or 750 ms passed, following either of which a new trial began.

Stimuli locations were pseudo-randomly varied from trial to trial such that in one third of trials the shape stimulus was presented on the vertical meridian, in another third the line stimulus was presented on the vertical meridian, and in the remaining third the shape stimulus was laterally presented in one visual hemifield with the line stimulus laterally presented in the opposite visual hemifield (see figures for examples of search arrays).

In each trial, the form of the shape stimulus and length of the line stimulus were randomly chosen. Participant response was based on the form of the shape stimulus. Responses were made with the right hand via a standard computer mouse. Half of participants pressed the left mouse button with their index finger when the target was of diamond shape and the right mouse button with their middle finger when it was of square shape, with the remaining half of participants using the opposite response map. Participants were instructed to respond as quickly as possible while maintaining an average accuracy of 90% or better and accuracy feedback was given following each block of trials.

3.3.1.3 Recording and Analysis

Electroencephalogram (EEG) was recorded from 64 tin electrodes, 63 of which were mounted in an elastic cap (Electro-cap International, Eaton, OH). Electrode positions were a subset of the international 10/10 system sites (FP1, FPz, FP2, AF3, AF4, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FC5, FC3, FC1, FCz, FC2, FC4, FC6, T7, C5, C3, C1, Cz, C2, C4, C6, T8, CP5, CP3, CP1, CPz, CP2, CP4, CP6, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO3, POz, PO4, PO8, O1, Oz, O2, I5, I3, Iz, I4, I6, SI3, SIz, SI4, and M2). Horizontal electro-oculogram (HEOG) was bipolarly recorded from electrodes 1 cm lateral to the external canthi. All other electrodes were referenced during recording to the left mastoid and later digitally re-referenced to the algebraic average of the signals recorded at the left and right mastoids. The EEG was amplified with a gain of 2000 and pass-band of 0.1-100 Hz, digitized at 500 Hz, stored on a microcomputer, and averaged offline.

An automated artefact-rejection process was applied to the EEG in order to remove trials containing eye movement, blink, or amplifier-blocking artefacts. Electrode site FP1 was used in the detection of blinks and vertical eye movements and HEOG was used in the detection of horizontal eye movements. All trials containing artefacts in a

1000-msec epoch beginning 200 msec before stimulus onset were removed from further analysis, as were all trials in which participants made incorrect responses.

The ERPs presented in the figures were digitally low-pass filtered in order to remove high-frequency noise produced by muscle activity and external electrical sources (~30 dB attenuation at 20 Hz). Statistical analysis of the data was conducted prior to digital filtering. ERP baselines for both statistical and display purposes were computed with respect to a 100-msec pre-stimulus period.

3.3.2 Results

3.3.2.1 Behavioural Results

The mean average of grey shades created by the twelve participants in the colour matching procedure had a luminance of 2.45 cd/m^2 ± 2.09 cd/m^2 s.d., reasonably close to the 3.92 cd/m^2 measured luminance of the red line stimulus. The inter-participant mean correct RT was 555 ms, and mean error rate was 3.1%.

3.3.2.2 Electrophysiological Results

Figure 1 shows ERPs observed at the lateral occipital electrode sites PO7 and PO8 for the three stimulus configurations possible in Experiment 1: lateral line with contralateral square (Figure 1a), non-lateral line with lateral square (Figure 1b), and lateral line with non-lateral square (Figure 1c). The waveforms consist of a series of positive and negative peaks oscillating at approximately 10 Hz, including P1 (120 ms) and N1 (180 ms), P2 (250 ms) and N2 (280 ms) components. When the bright green stimulus was presented at a lateral search display location, the contralateral and ipsilateral waveforms diverge soon after stimulus presentation (Figures 1a, 1b). This is likely a product of imbalances in sensory energy resulting from the lateral presentation of the bright square stimulus with no equally bright stimulus in the contralateral visual hemifield. When stimulus energy was balanced across the visual field, the ERP showed no evidence of early sensory laterality (Figure 1c).

When sensory energy was balanced across the visual field the first evidence of divergence between the ipsilateral and contralateral waveforms began at approximately 200 ms, at which point the contralateral waveform became more positive than the ipsilateral (Figure 1c). This amplitude difference had a mean magnitude of 1.37 μV in the 220 – 260 ms post-stimulus interval and was statistically assessed in a repeated measures analysis of variance (RANOVA) with within-participant factors for Distractor Side (left vs. right) and Electrode Laterality (ipsilateral vs. contralateral). This test revealed a main effect of Electrode Laterality [$F(1,11) = 6.483$, p = 0.027], indicating that the difference between ipsilateral and contralateral waveforms was significant. All other effects were non-significant [Fs < 1].

An additional RANOVA was conducted in order to examine the effect of stimulus elevation on the divergence. This test had factors for Target Elevation (upper visual hemifield vs. lower visual hemifield) and Distractor Elevation (upper visual hemifield vs. lower visual hemifield), and was conducted on mean amplitude of the contralateral-minus-ipsilateral difference waveforms in the 200 – 260 ms latency interval. A main effect of Distractor Elevation was observed, with a larger difference between ipsilateral and contralateral waveforms elicited when the distractor was in the upper visual hemifield (1.67 μV) than when it was in the lower (0.87 μV) [$F(1,11) = 5.145, p = 0.044$]. Target Elevation was found to have no effect on the magnitude of the difference

[$F < 1$]. Proximity of target and distractor, expressed as the interaction of Target Elevation and Distractor Elevation factors, also had no significant effect [$F(1,11) = 2.346, p = 0.154$].

3.3.3 Discussion

The central finding of Experiment 1 was that an ignored lateral distractor stimulus resulted in a divergence in ipsilateral and contralateral ERP waveforms that occurred in the latency of the N2pc, but was of opposite polarity (see Figure 1c). This divergence had two interesting characteristics. First, it varied as a function of the elevation of the line distractor, but was unaffected by the elevation of the square target. Second, it was expressed at electrode sites contralateral to the line distractor. These characteristics link the component to processing of the distractor. In the pages below we refer to this component as the distractor positivity, or $P_{D.}$

Experiment 1 was designed to allow for the identification of lateralized ERP activity associated with distractor processing in the absence of lateralized activity associated with target processing. One potential problem was that participants could have correctly performed the task by selecting only half of the target stimulus. Recent data suggests that attending to one half of a centrally displayed stimulus, such as a symbolic cue, may elicit an N2pc (van Velzen & Eimer, 2003). The P_D could thus reflect an N2pc associated with selection of the half of the target farthest removed from the distractor, not an ERP positivity contralateral to the distractor itself. To investigate this possibility we conducted a follow-up experiment where correct target discrimination could not occur if attention was oriented to only half of the stimulus. The follow-up experiment was identical to Experiment 1 except that the target stimulus was a vertical line rather than a square, and participants were required to discriminate its length rather than its orientation. As in Experiment 1, we observed an ERP positivity contralateral to the distractor when the target was on the vertical meridian [0.47 μV; 240 – 280 ms post-stimulus; Electrode Laterality: $F(1,7) = 8.71, p = 0.021$]. This P_D demonstrates that this lateralized component is not an N2pc tied to the target stimulus.

We conducted an additional experiment to further characterize the P_D and to isolate ERP activity associated with target processing. In Experiment 2 the same visual search arrays from Experiment 1 were used, but participants were instructed to attend to the square on half of all trials and to the line on the remaining trials.

3.4 Experiment 2

3.4.1 Methods

3.4.1.1 Participants

Fifteen healthy students of Simon Fraser University gave informed consent before beginning Experiment 2. None of the participants had taken part in Experiment 1. All participants reported normal or corrected-to-normal vision and normal colour vision, and received course credit for their participation. Data from two participants were discarded due to excessive eye movement artefacts in the EEG, and data from one participant were discarded due to participant error in the equiluminance matching procedure that preceded experimental participation. All of the remaining twelve participants (five men; mean age = 22.8 years ± 3.1 years s.d.) were right handed.

3.4.1.2 Procedure

As in Experiment 1, participants completed a luminance matching procedure before beginning the experiment. This procedure was identical to that in Experiment 1 with the following exception. In Experiment 1, matches began with the grey box differing from the exemplar by ~2.5 cd/m^2; in Experiment 2 this initial difference was ~0.5 cd/m^2.

Stimuli displays in Experiment 2 were identical to those used in Experiment 1. Each participant took part in two experimental conditions with order of conditions counterbalanced across participants. In the *attend-square* condition response was based on the form of the bright green square, as was the case in Experiment 1. In the *attend-line* condition response was based on the length of the equiluminant red line; half of participants pressed the left button when the line was long and the right when the line was short, with the remainder using the opposite map. All participants responded with their right hand. All other design parameters were as in Experiment 1.

3.4.1.3 Recording and Analysis

EEG recording and analysis procedures were as in Experiment 1.

3.4.2 Results

3.4.2.1 Behavioural Results

The mean average of grey shades created by the twelve analysed participants in Experiment 2 had a luminance of 3.84 cd/m^2 ± 0.18 cd/m^2 s.d., closely matching the 3.92 cd/m^2 luminance of the red exemplar.

Table 1 presents the RT and error data observed in each of the experimental conditions. The inter-participant mean correct RT was 585 ms for the attend-line condition and 558 ms for the attend-square condition. This 27-ms difference was found significant in a RANOVA with a within-participant factor for Condition (attend-line vs.

attend-square) and a between-participant factor for Condition Order (attend-line first vs. attend-square first) [Condition: $F(1,11) = 9.36$, $p = 0.012$, Condition Order: $F < 1$, Condition x Condition Order: $F(1,11) = 1.90$, $p = 0.198$]. A similar analysis of errors found that mean participant error rate in the attend-line condition, at 5.4%, was significantly greater than that observed in the attend-square condition, at 2.8% [Condition: $F(1,11) = 12.20$, $p = 0.006$, Condition Order: $F(1,11) = 1.76$, $p = 0.214$, Condition x Condition Order: $F < 1$].

3.4.2.2 Electrophysiological Results

Figures 2 and 3 present the ERPs observed at lateral occipital electrode sites PO7 and PO8 for each of the three possible stimulus configurations in the attend-square (Figures 2a, 2b, 2c) and attend-line conditions (Figures 3a, 3b, 3c). Lateralized ERP differences were observed in the latency of the posterior P1 and N1 components when displays contained a lateralized bright green square, regardless of whether this stimulus was a target or distractor (Figures 2a, 2b, 3a, 3b). These differences were not apparent when the square was presented on the vertical meridian of the search display (Figures 2c, 3c).

To isolate activity associated with target and distractor processing, we examined ERP waveforms elicited by displays containing a lateralized equiluminant line and a non-lateralized square (Figures 2c, 3c). As in Experiment 1, when participants were instructed to attend to the square and ignore the line the P_D was observed at posterior electrode locations contralateral to the line (Figure 2c). The P_D began at ~230 ms, returned to baseline at ~280 ms and had a mean magnitude of 0.99 μV through this time period. In contrast, when participants were instructed to attend to the line and ignore the square, the same visual search display elicited a posterior ERP negativity contralateral to the attended line. This negative component began at ~175 ms, returned to baseline at ~325 ms and had a mean magnitude of -1.48 μV through this time period. We refer to this isolated ERP component as the target negativity, or N_T.

The P_D and N_T were statistically assessed at lateral occipital electrode sites PO7 and PO8. Mean ERP amplitudes were measured in a 175 – 325 ms post-stimulus interval in the attend-line condition and in a 230 – 280 ms post-stimulus interval in the attend-square condition (corresponding to latencies of the observed N_T and P_D components, respectively). An initial RANOVA had within-participant factors for Condition (attend-line vs. attend-square), Stimulus Side (left visual hemifield vs. right visual hemifield), and Electrode Laterality (ipsilateral vs. contralateral) and a between-participant factor for Condition Order (attend-line first vs. attend-square first). The Condition x Electrode Laterality interaction was significant [$F(1,10) = 25.74$, $p < 0.001$], owing to the fact that a posterior contralateral positivity was observed in the attend-square condition and a posterior contralateral negativity was observed in the attend-line condition (see Figure 4). No other effect approached significance [$Fs < 1$]. Two further RANOVAs were conducted to test the P_D and N_T components in isolation. These tests had within-participant factors for Stimulus Side (left visual hemifield vs. right visual hemifield) and Electrode Laterality (ipsilateral vs. contralateral) and a between-participant factors for Condition Order (attend-line first vs. attend-square first). Significant main effects of Electrode Laterality were observed for both the N_T [$F(1,10) = 16.14$, $p = 0.002$] and P_D [$F(1,10) = 9.93$, $p = 0.010$], which provides evidence that both components were reliably evoked. Only one other effect reached significance in these analyses, a Stimulus Side x

Electrode Laterality x Condition Order interaction in analysis of the P_D [$F(1,10 = 5.23$, $p = 0.045$]. This interaction may reflect a change in neural mechanisms employed in order to ignore a stimulus when that stimulus has previously been a target.

As in Experiment 1, additional RANOVAs were conducted in order to examine the influence of stimulus elevation on component amplitudes. These tests had within-participant factors for Target Elevation (upper visual hemifield vs. lower visual hemifield) and Distractor Elevation (upper visual hemifield vs. lower visual hemifield) and were conducted on mean P_D or N_T amplitude computed over the 200 – 260 ms post-stimulus interval (see figures 2c and 3c). A main effect of Target Elevation was found in analysis of the N_T, with this component larger in magnitude when the target line was presented in the lower visual hemifield (-2.21 μV) than when it was presented in the upper visual hemifield (-1.23 μV) [$F(1,11) = 7.822, p = 0.017$]. Distractor Elevation and the interaction of Target Elevation and Distractor Elevation were found to have no significant effect on the N_T [Fs < 1]. A main effect of Distractor Elevation approached significance in analysis of the P_D, with this component larger when the distractor line was presented in the upper visual hemifield (1.31 μV) then when it was presented in the lower visual hemifield (0.48 μV) [$F(1,11) = 2.868, p = 0.119$]. Target Elevation [$F < 1$] and the interaction of Target Elevation and Distractor Elevation factors [$F(1,11) = 1.532, p = 0.242$] were found to have no significant effect on the P_D.

Figure 4 presents the contralateral-minus-ipsilateral difference waves based on the ERPs presented in Figures 2c and 3c. These difference waves show that the N_T peaked before the P_D (250 ms vs. 289 ms, respectively). This latency difference was statistically assessed in a RANOVA with a within-participant factor Condition (attend-line vs. attend-square) and a between-participant factor for Condition Order (attend-line first vs. attend-square first) [Condition: $F(1,11) = 5.110$, $p = 0.045$; Condition Order: $F < 1$, Condition x Condition Order: $F(1,11) = 1.048$, $p = 0.328$].

Spherical-spline-interpolated scalp maps of both the P_D and N_T are presented in Figure 5 (Perrin et al. 1989). These half-head scalp maps were created from the contralateral-ipsilateral difference waves by mirroring the data across the midline and artificially setting the values on the midline to zero. Figures 5a and 5b present mean voltage topography across a 250 – 280 ms interval for each of the P_D and N_T, while Figures 5c and 5d present interpolations of t-statistic values associated with the difference between contralateral and ipsilateral waveforms in the same latency interval. The topographical t-statistic maps in figures 5c and 5d were thresholded such that only spline gradients corresponding to a p value of less than approximately 0.05 are displayed. The t-statistic was employed as a descriptive measure that describes both effect size and inter-participant variability, and these maps are not intended to provide inferential statistical content.

Both the P_D and N_T were distributed over the occipital scalp. Voltage and t-statistic maps show that the N_T was focused more ventrally than the P_D (Figure 5). In an effort to assess the reliability of this topographical difference a RANOVA was conducted based on mean P_D and N_T amplitude recorded from a subset of electrodes, with factors for Component (N_T vs. P_D), Laterality (medial vs lateral), and Posteriority (anterior vs. mid vs. posterior). The electrode locations used in this analysis are identified in Figures 5c and 5d, with medial electrodes noted by circles and lateral electrodes by squares. The effects of interest were the Condition x Laterality interaction, which was highly significant [*F*(2, 22) = 13.64, $p < 0.001$], and Condition x Posteriority interaction, which approached significance [*F*(2, 22) = 3.18, $p = 0.061$]. These results provide some support for the idea that the P_D and N_T differ in terms of topography.

3.4.3 Discussion

As in Experiment 1, the critical stimulus configuration in Experiment 2 was that in which the bright green square was presented on the vertical meridian while the red line was presented to a lateral location. When the bright square was attended and the lateral line was ignored, the experimental procedure was identical to that in Experiment 1 and the results are accordingly similar (cf. Figure 1c and Figure 2c). When the line was attended, however, the elicited ERP differed dramatically from those observed when the line was ignored, with a negativity observed at electrode sites contralateral to the attended stimulus (Figure 3c). As was the case with the P_D, this negative component was found to vary as a function of stimulus location. However, while in Experiment 1 the P_D was found to be larger when the distractor was in the upper visual hemifield but was unaffected by the location of the target, the negative component observed in Experiment 2 was found to be larger when the target was in the lower visual hemifield but was unaffected by the location of the distractor. This, coupled with the fact that this negative component was expressed at electrode locations contralateral to an attended target, suggests that it is tied to target processing. With this in mind we refer to this component as the target negativity, or N_T.

Because both the P_D and N_T were elicited in Experiment 2 we were able to make comparisons between these components. In comparison of scalp topography the N_T was found to occur over ventral lateral visual cortex, while the P_D was found to occur over dorsal medial visual cortex. Visual processing is thought to be roughly divided into dorsal and ventral processing streams, with the dorsal stream involved in processing of spatial features and the ventral stream involved in processing of nonspatial object features (Ungerleider & Mishkin, 1982). The dorsal topography of the P_D thus suggests that this component is highly spatial in nature, while the ventral topography of the N_T suggests that this component is related to the processing of object features.

In comparison of component latency, the N_T was observed to peak earlier than the P_D. This suggests that selection in visual search begins with target processing and progresses through the suppression of distractor stimuli. A similar sequence of events has been suggested in the animal electrophysiology literature, with the attention-related enhancement of neural activity preceding distractor processing (Treue, 2001).

3.5 General Discussion

This study was conducted in order to isolate electrophysiological correlates of target and distractor processing in visual search. We conducted two experiments in which we recorded ERPs while participants were presented with sparse search arrays containing a square, which was brighter than the display background, and a line, which was of equal brightness with the display background. These stimuli could be presented to positions located directly above or below fixation, and thus on the vertical meridian of the display, or at lateral positions in the upper or lower visual hemifields (see Figures for examples). The critical experimental condition was that in which participants were presented with a line at a lateral display position and a square at a position on the vertical meridian. This display allowed for the identification of lateralized ERP components tied to processing of the line, as stimuli presented on the vertical meridian of the display do not elicit lateralized ERP activity (Woodman & Luck, 2003; Hickey, McDonald, & Theeuwes, 2006). Furthermore, lateralized ERP activity elicited by the line in this display could be attributed to attention, because the line was equiluminant with the display background and was thus unlikely to elicit lateral sensory activity. This critical display was found to elicit an ERP negativity at electrode sites contralateral to the line when this stimulus was the target, and to elicit an ERP positivity at electrode sites contralateral to the line when this stimulus was ignored. We named these two components the target negativity (N_T) and distractor positivity (P_D).

The P_D and N_T were found to have a number of differing characteristics other than polarity. While both were focused over posterior scalp, the P_D was found to occur over more medial and dorsal visual areas while the N_T was found to occur over more lateral and ventral visual areas. In addition, amplitude of the P_D was found to vary as a function of the location of the distractor stimulus, larger when the distractor was presented in the upper visual field and smaller when it was presented in the lower visual field. Amplitude of the N_T, in contrast, was found to vary as a function of the location of the target stimulus, larger when the target was in the lower visual field and smaller when it was presented in the upper visual field. These characteristics suggest that the components reflect two types of processes involved in visual search, one tied to distractors and the other to targets.

We believe that the P_D indexes suppression of distractor stimuli. Characteristics of the component, however, make it unlikely that this distractor suppression is involved in the extraction of featural information from attended stimuli. That type of distractor suppression is thought to be spatially circumscribed, extending no farther than a few degrees of visual angle beyond the location of a target (Hopf et al. 2006; Müller & Kleinschmidt, 2005; Müller, Mollenhauer, Rösler, & Kleinschmidt, 2004; Mounts, 2000). In contrast, the distractor suppression indexed by the P_D appears to be unaffected by target and distractor proximity, and occurred even when target and distractor were separated by ~8.5° of visual angle.

An alternative is that the P_D reflects distractor suppression involved in the orientation of attention to the target. Such a mechanism has been suggested necessary to the control of spatial attention, and is thought to possibly result from thalamo-cortical interactions (LaBerge, 1995). This type of suppression would presumably be unrelated to target location, as is found with the $P_{D,}$ and highly spatial in nature, consistent with the dorsal topography of the P_D. Some evidence for a suppressive mechanism that acts on distractor locations has been provided in the behavioural literature, where response to probes presented at distractor locations was slower than response to probes presented at any other location (Cepede, Cave, Bichot, & Kim, 1998).

In contrast to the distractor-related role of the $P_{D,}$ the N_T appears to index processing that is tied to the target stimulus. The present results do not, however, provide clear evidence that links the N_T to any particular attentional process. It may be that this component reflects increased neural activity associated with enhanced target processing, as reported in the animal literature (Spitzer, Desimone, & Moran, 1988; Roelfsema, Lamme, & Spekreisje, 1998; Treue & Maunsell, 1999). Alternatively, it is possible that the N_T reflects a higher level mechanism such as perceptual hypothesis testing (DiLollo, Enns, & Rensink, 2000; Shedden & Nordgaard, 2001).

In previous electrophysiological examinations of visual search researchers did not isolate activity associated with target and distractor processing. Target selection in these studies was associated with a single component, the N2pc. We believe that under certain circumstances the N2pc may in fact reflect a summation of the N_T and P_D components, thus representing the aggregate potential of neurons involved in both the suppression of distractors and processing of the target. This could have occurred in previous studies because target and salient distractor stimuli were often presented to contralateral visual hemifields. For example, in one study a single target was presented to one field and a single distractor was presented to the other (Eimer, 1996). The N2pc was measured as the total difference between the waveform contralateral to the target (and thus ipsilateral to the non-target) and the waveform ipsilateral to the non-target (and thus contralateral to the target). This difference may have reflected both an N_T in the waveform contralateral to the target and a P_D in the waveform contralateral to the non-target. Both target-elicited negativity and nontarget-elicited positivity would have increased the relative difference between the waveforms ipsilateral and contralateral to the target, thus confounding the N_T and P_D in total N2pc amplitude.

The potential to confound the N_T and P_D is not limited to two-stimulus displays. The N2pc is most commonly elicited by visual search displays that are balanced across the left and right visual hemifield in terms of sensory energy. This is often achieved through the use of displays in which each visual field contains an equal number of low-salience distractor stimuli, and one salient *pop-out* stimulus (defined by a featural difference from the distractors such as a unique colour). One pop-out is the target, and the other is a non-target (e.g. Luck & Ford, 1998). As in the example above, the subtractive procedure used to identify the N2pc elicited by this type of display would confound negativity related to the pop-out target with positivity related to the pop-out non-target, with activity associated with the suppression of the low-salience distractors equal across left and right visual cortices, and thus cancelled out.

The current study was motivated by the presence of contradictory results in the N2pc literature. We conclude by suggesting that an aggregate role for the N2pc, in which this component reflects both target and distractor processing, may allow for the resolution of this conflict. For example, the N2pc has been tied to distractor suppression, larger in amplitude when distractors are similar in nature to the target stimulus (Luck, Girelli, et al., 1997), yet is observed at electrode locations contralateral to a target even when distractor stimuli are far from the target location (Eimer, 1996). So long as the N2pc is thought of as a pure correlate of either target or distractor processing, these characteristics seem directly at odds. However, if we consider the N2pc a summation of the N_T and P_D components, apparently target-related variance of the N2pc can be attributed to the N_T, while apparently distractor-related variance of the N2pc can be attributed to the P_D.

3.6 Tables

Table 1 **Behavioural Results.** Mean correct response times (in milliseconds) and error rates (in percentage) for Experiment 2 by experimental condition.
(1.) Attend line condition. (2.) Attend shape condition.

Experimental Condition	Mean RT (s.d.)	Error Rate (s.d.)
1 – Attend to shape	558 (73)	2.8 (2.1)
A: Lateral Target, Contralateral Distractor	562 (75)	3.1 (2.4)
b: Lateral Target, Vertical Distractor	551 (72)	2.6 (2.3)
c: Vertical Target, Lateral Distractor	561 (73)	2.3 (2.0)
2 – Attend to line	585 (74)	5.4 (2.9)
a: Lateral Target, Contralateral Distractor	582 (73)	5.3 (3.1)
b: Lateral Target, Vertical Distractor	587 (78)	4.8 (2.8)
c: Vertical Target, Lateral Distractor	586 (73)	6.1 (4.5)

3.7 Figures

Figure 1 **Experiment 1, Attend to square ERPs.** Grand averaged ERPs elicited in Experiment 1. As with all ERPs presented in this paper, these ERPs were recorded at posterior lateral electrode sites PO7 and PO8. Note that negative is plotted upwards, and that stimulus onset occurred at 0 ms and is indexed by the y-axis.

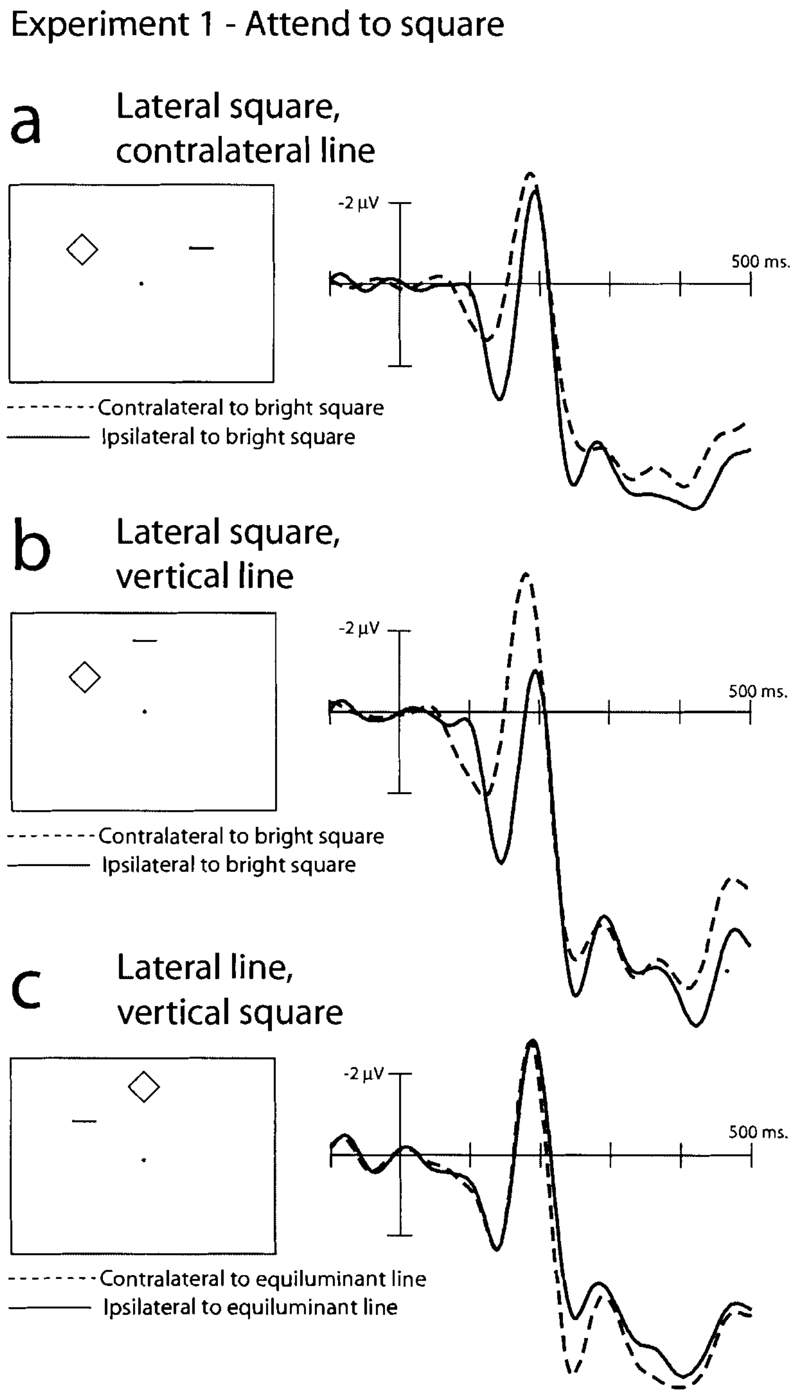


Figure 2 **Experiment 2, Attend to square ERPs.** Grand averaged ERPs elicited in Experiment 2 when participants attended to the square stimulus.

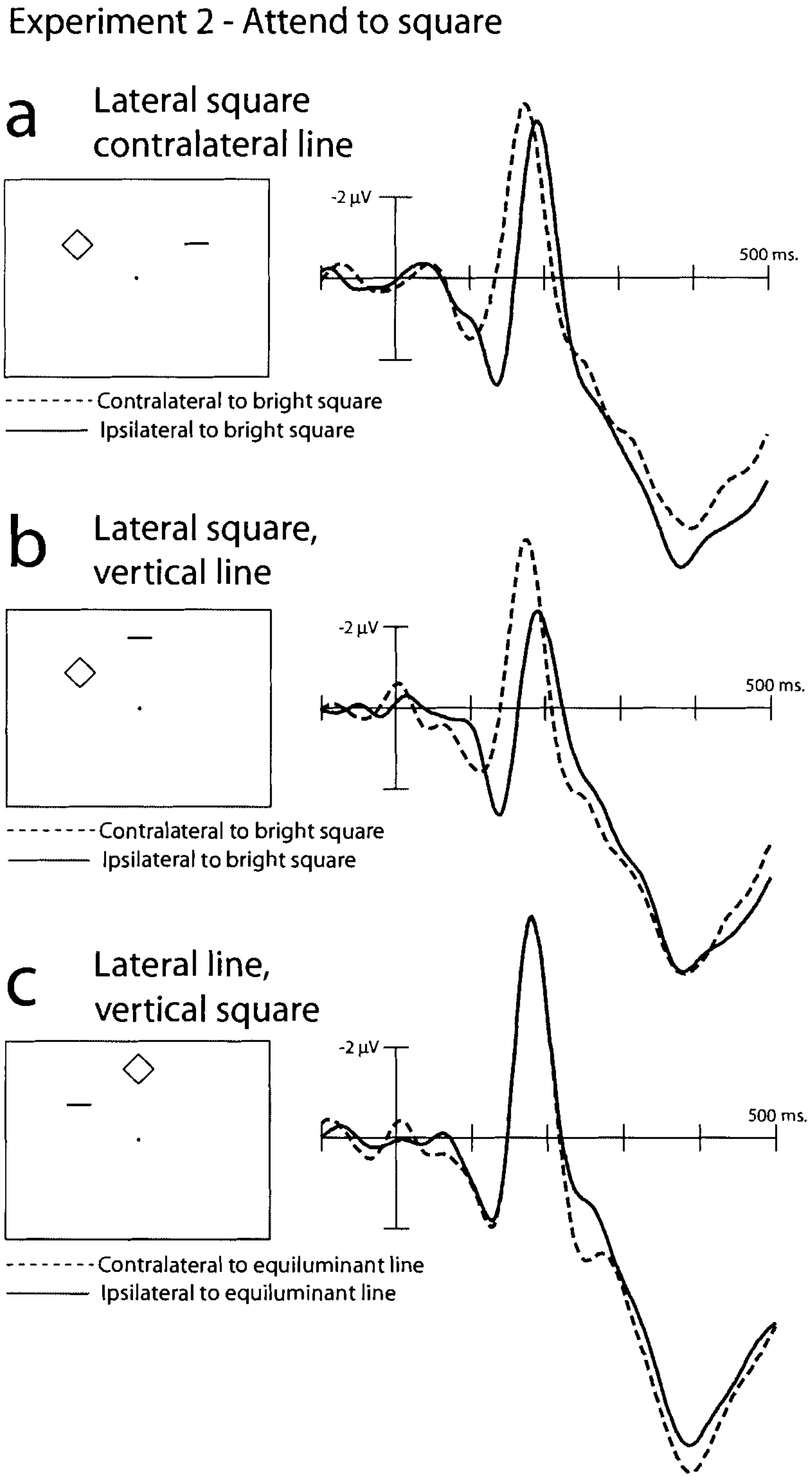


Figure 3 **Experiment 2, Attend to line ERPs.** Grand averaged ERPs elicited in Experiment 2 when participants attended to the line stimulus.

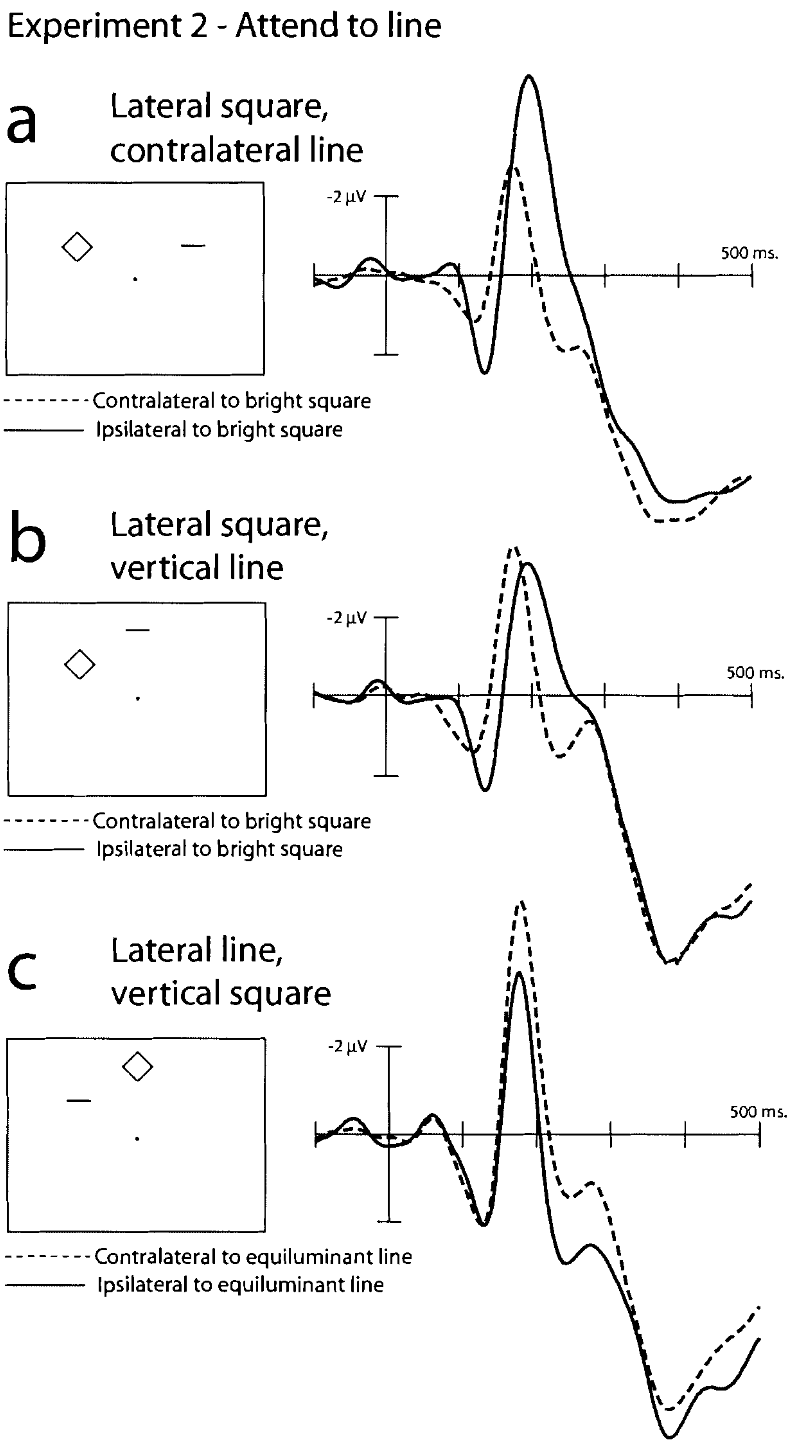


Figure 4 **Experiment 2, Difference Waves.** Contralateral-minus-ipsilateral difference waves based on the data from Experiment 2 presented in Figures 2c and 3c. The target negativity and distractor positivity are identified.

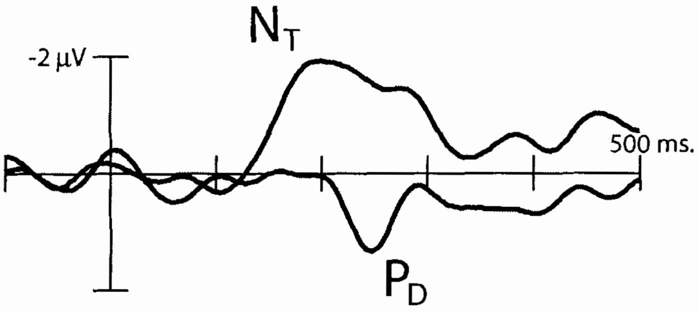
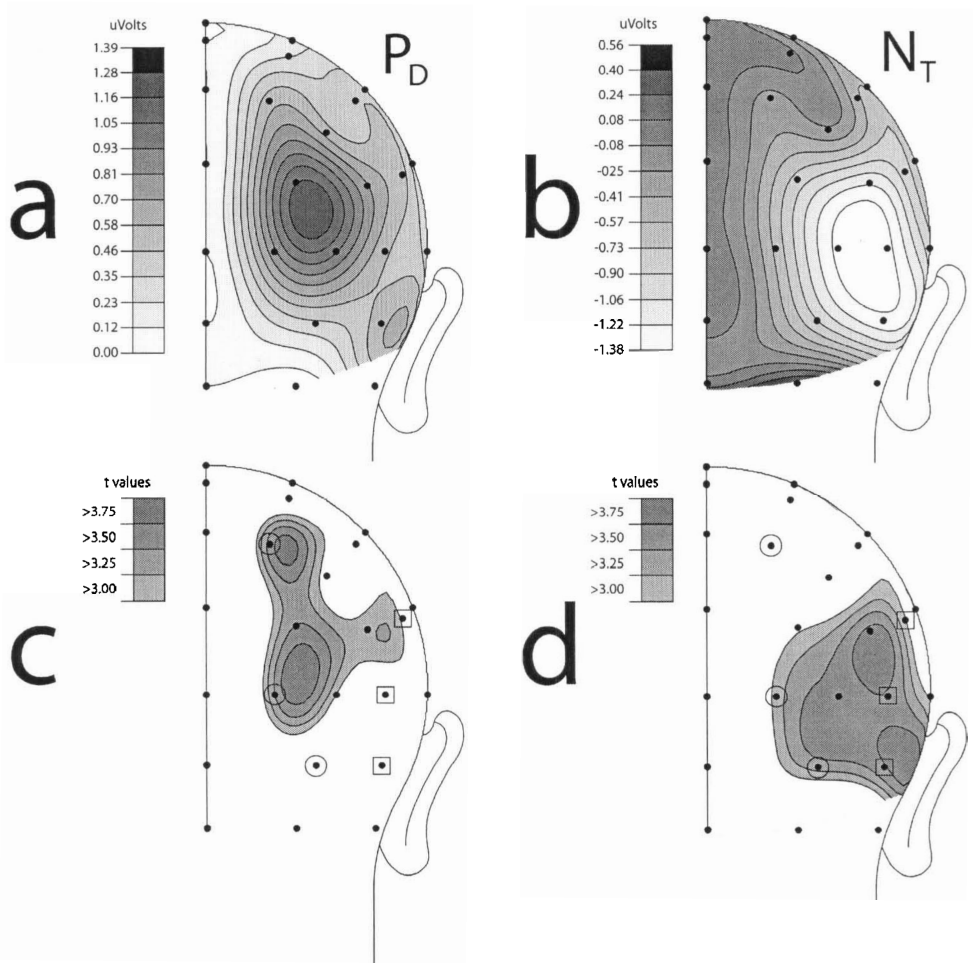


Figure 5 **Experiment 2, Topographical Maps.** Spherical-spline-interpolated scalp maps of the distractor positivity and target negativity. Figures 5a and 5b present voltage topography. Figures 5c and 5d present t-statistic topography.



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CHAPTER 4 GENERAL CONCLUSIONS

Two research questions are addressed in the studies reported above. In chapter 2, the ability of salient non-target stimuli to capture attention was investigated. The N2pc, a component of the visual ERP, was used to chronicle the orientation of attention stimuli in a visual search display. The results showed that attention was oriented to the location of a salient non-target before being reoriented to the target. In this study, the N2pc was used as a tool. In chapter 3 the fundamental nature of this component was examined. The N2pc has been thought to reflect the suppression of distractor stimuli; the results reported in chapter 3 suggest that the component rather reflects both target and distractor related processes.

These two studies stand somewhat independent of one another. In future experimentation I have plans to integrate these results. For example, examining the isolated ERP activity associated with target and distractor processing that is elicited when participants are presented with displays containing salient non-target stimuli should allow insight into the precise mechanisms that are influenced by salience. This may even allow for a distinction to be made between attentional mechanism that are under the control of cognitive strategy and those that act as a function of environmental stimuli. Alongside the research reported above, this further experimentation will certainly allow for a clearer understanding of the interplay of target and distractor processing in selective attention.