ERP INDICES OF ATTENTIONAL DISENGAGEMENT AND FILTERING FOLLOWING REFLEXIVE ATTENTIONAL CAPTURE

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ABSTRACT

CASSIE BARASH FORD: ERP Indices of Attentional Disengagement and Filtering
Following Reflexive Attentional Capture
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The goal of this study was dissociate the mechanism of target selection when distractor suppression is required from spatial disengagement and reorienting. Specifically, we aimed to elicit and compare online event-related potential (ERP) indices of these attention mechanisms, the N2pc, IIN and P4pc. Combining the classic spatial cuing paradigm with a modified visual search design allowed the comparison of these components when attention was either reflexively oriented to the location of an upcoming target, or was reflexively captured to the opposite visual field, requiring disengagement and reorienting to the target. Reaction times and early sensory processing ERP components indicated that attention was reflexively captured by the cue, extending established reflexive attention effects from simple cuing paradigms to visual search. The ERP results suggest that the N2pc reliably indexes the direction of spatial attention, but is not an appropriate marker of the shifting of spatial attention. Significant IIN and P4pc components were found only for conditions requiring disengagement, suggesting that both may reflect the disengagement and reorienting of attention, indexing these mechanisms better than the N2pc.

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INTRODUCTION

Attention allows for the efficient and accurate selection of a subset of items from the vast array of sensory information present in the environment, enabling further processing and coordination of action. For example, imagine that you are searching for your red keychain located somewhere on the cluttered dining room table. You may look for things that are red or key-shaped. After an initial sweep eliminating all items that do not share at least one feature with your keys, you will likely find the keys by successfully inhibiting all of the distractors. Now imagine that as you approach the table to search, a bright light is shining on a small area of it, causing your attention to be captured to that area, and any illuminated objects. Your keys may be in the lit up area, in which case you will make it to work on time for once, or you may need to quickly disengage your attention and continue searching for your keys elsewhere. In all cases, attentional processes are at work. The goal of the current study is to investigate the processes of filtering out competing objects (the clutter) when selecting a target (the keys), as well as disengaging from a distractor (illuminated area) and reorienting to the target (keys) with the specific aim of identifying electrophysiological signatures of each one.

The under-specified concept of attention is understood in terms of how the system achieves the goals of control and selection. This has largely been accomplished by experimentally isolating attention's functional components and mechanisms (Posner & Petersen, 1990; Luck, 1995), in part by examining conditions in which selective impairments

to these components are found (e.g. Posner, Walker, Friedrich, & Rafal, 1984). Based on functional and anatomical evidence, Posner & Petersen (1990) proposed that attention could be divided into the subsystems of *orienting* to sensory information, *detecting* signals or conscious awareness of information, and maintaining an *alert* state. Typically studied using visual spatial attention paradigms, the orienting subsystem has been further broken down into the operations of **disengaging** from a current focus, **shifting** or moving attention to a new object, location or event, and **selecting** or processing the new information within the focus of attention (Posner & Petersen, 1990). A great deal of research has been focused on the *shift* operation, and on *orienting* in its entirety, with particular interest in how voluntarily controlled or involuntarily driven orienting result in differential effects on higher order processing of information and behavior (e.g. Briand and Klein, 1987). Less is understood about the mechanism allowing for the disengagement and reorienting of attention, and whether it is under voluntary or involuntary control, or perhaps represents some interaction between these two types of control (for a review see Corbetta, Patel & Shulman, 2008). Evidence of selective impairment to this mechanism from clinical populations, such as unilateral neglect and autism, suggests that the ability to disengage from the current focus of visual attention is a critical and separable component within selective attention and not merely a consequence of engaging attention (i.e. orienting) to a new location (Fox, Russo, Bowles & Dutton, 2001; Landry & Bryson, Posner et al., 1984; c.f. Cohen, Romero, Servan-Schreiber & Farah, 1994).

Posner and colleagues (1984) found a specific disengagement deficit in patients with parietal lobe lesions, evidenced by abnormally long reaction times (RTs) to targets appearing in their ipsilesional visual field following a cue to the contralesional field. The same long

RTs were not observed when the cue and target locations were reversed, indicating that the extreme slowing was due to the patients' difficulty disengaging from contralesional visual field stimuli and reorienting to an ipsilesional visual field event. Within the same patient population, valid target RTs showed intact orienting to both visual fields, relative to controls, providing support for the separation of orienting and reorienting with disengagement.

Landry & Bryson (2004) provided evidence of another clinical population showing a specific disengagement deficit, suggesting that the mechanism of disengagement may be a separable attention mechanism. Using a gap task in which subjects had to shift to a peripheral target when fixation either remained on screen or was removed, children with autism took significantly longer to reorient to a peripheral stimulus when the central stimulus remained on the screen, relative to both healthy control and children with Down syndrome. Interestingly, the children with autism had RTs equivalent with the other groups when the central stimulus was removed. These results suggest that the children with autism demonstrated a selective impairment with disengaging and reorienting to the peripheral stimulus (fixation remained), but intact orienting (fixation was removed).

Similarly, Fox et al. (2001) used a modified dot-probe task and found that high state-anxious individuals took longer to disengage from threatening words and faces that served as cues, as evidenced by longer RTs to targets appearing at invalidly cued locations. Again, there were no group differences for RTs to *cued* location targets, indicating no impairment to orienting as compared with non-anxious controls. A disengagement deficit was also shown in RTs in a recent peripheral cuing study of healthy college-aged individuals examining the effects of visual anchors on behavior in a discrimination task (Ford & Hopfinger, 2011). Participants responded to cued location targets equally fast when location markers were

either present or absent, but critically, were significantly slower to respond to uncued

location targets (i.e. target appeared in the opposite visual field following a peripheral cue)

when place markers were present. These results suggested that participants had trouble

disengaging and reorienting from a peripheral cue when attention was captured by a cue

coupled with an object.

Also using a dot-probe paradigm with alcohol-related words and images serving as

cues, Townshend and Duka (2001) interpreted the RT differences between cued and uncued

targets, specifically faster RTs to cued targets, as an indication that heavy social drinkers

oriented more quickly to alcohol-related cues, and *not* that these individuals took longer to

disengage from non-alcoholic images, although both interpretations would fit the results.

Similar behavioral results leading to different conclusions about what stage of selection may

or may not be impaired in a given situation highlights the challenge of studying the

functional components in attentional selection using behavioral methods alone.

Event-related potentials

The degree to which visual information is processed critically depends on where

attention is focused, as well as how it was deployed. Chronometric behavioral studies using

RT measures have revealed the performance advantages of attention (Posner & Cohen, 1984;

Posner, Rafal, Choate & Vaughan, 1985). However, many behavioral studies are unable to

determine whether improved performance is due to early perceptual facilitation (but see

Yeshurun & Carrasco, 1998), or instead later changes in decision or response criterion (e.g.

Handy, Green, Klein & Mangun, 2001; for a review see Mangun, 1995). Event-related

potentials (ERPs) are a useful online measure of ongoing neural processes with extremely

high temporal resolution, and are able to track the continuous attentional deployment that may occur between the presentation of visual stimulus and the subsequent response (Woodman & Luck, 2003; Handy et al., 2001).

ERP evidence has proven useful in testing models of attention, in particular clarifying the stage of processing upon which attention acts (Mangun & Hillyard, 1991; Handy et al., 2001). Evidence that validly cued targets resulted in larger amplitudes for ERP components beginning as early as 80ms helped lend support to a perceptual facilitation hypothesis accounting for RT advantages found for attended stimuli (Mangun & Hillyard, 1991; Mangun, 1995). Differences between the effects of central symbolic cues and peripheral cues on P1 and N1 ERP component amplitudes at long SOAs provided support for two proposed dissociable systems of attentional orienting: voluntary and involuntary (for a review see Mangun, 1995).

When participants are instructed to use predictive central symbolic cues to shift to a spatial location in advance of a target, two directing-attention potentials are found in the time interval between the cue and target, the ADAN (anterior directing-attention negativity) and the LDAP (late directing attention positivity; Praamstra, 2006). These cue-elicited lateralized components, defined as differences between contralateral and ipsilateral activity, are thought to directly index covert shifts of voluntary attention, as they are found following predictive cues, but are absent for central non-informative cues, such as overlapping arrows (⇆; e.g. Kiss, Van Velzen, & Eimer, 2008). Studies in which these directing-attention potentials are used to indicate shifts of attention typically use long SOAs (≈1sec) in order to give participants enough time to use the cues and voluntarily shift their attention in advance of the upcoming target, and also to enable the clean analysis of these components, found 400-

600ms following a cue, without fear of contamination from target-elicited activity. Critically, because of the latencies of these components and conditions under which they are found, they are associated with voluntary and *not* involuntary covert shifts of attention.

ERPs have been particularly useful in clarifying how and when attention affects cognitive processing of visual information. Early sensory-related ERP components, such as the P1 and N1 reflect modulations of attention on sensory processing, with attended stimuli receiving higher levels of processing indexed by larger amplitudes (Mangun & Hillyard, 1991; Mangun, 1995). Later components such as the P300, observed at latencies longer than 300ms following a stimulus onset are primarily driven by higher order processes related to attention such as the violation of expectancies, or memory updating (e.g. Mangun & Hillyard, 1991; Coles & Rugg, 1995). At intermediary latencies between 200-300ms, there are series of components (e.g. P2, N2, N2pc, IIN) that seem to reflect critical mechanisms serving attentional selection, but the exact nature of these mechanisms is still under investigation. The components reflecting these attentional mechanisms will be described in more detail below, as these are the focus of the present study.

An example of how ERPs can reveal the effects of attention that may be obscured by RTs alone comes from Handy and colleagues (2001), who used ERPs to evaluate a troubling contradiction to the "spotlight" model of attention. It appeared as though attention no longer facilitated behavior, and in turn sensory processing of visual information, when nonspatial expectancies about a target's identity were violated. Specifically, RTs indicated that high probability targets were facilitated by spatial pre-cuing, but low probability targets were not. The study was designed to test whether ERPs might lend support to a *postspotlight masking hypothesis*, which posits that stimuli at attended locations receive enhanced processing that is

masked at later processing stages; or would indicate that a *spotlight failure hypothesis*, in which direction of attention to a spatial location is overridden by attention to a nonspatial feature, such as form, was more appropriate. In their study, Handy et al. (2001) found that spatial cues enhanced perceptual processing for all targets, as evidenced by larger P1 amplitudes for cued versus uncued targets regardless of nonspatial expectancies. Analyses comparing the effects of expectancies on both early (P1, N1) as well later ERP component (P2, N2 and P300) also indicated that location-specific processing occurred before target form-specific processing. These ERP effects, not seen at the level of the response, provided support for the postspotlight masking hypothesis over a spotlight failure hypothesis. In this case, ERPs were able to provide strong support for one side in a previously unresolved debate, highlighting the useful nature of online measures of the effects of attention on cortical processing at multiple stages of processing.

In order to successfully use ERPs to settle theoretical debates within cognitive neuroscience, the mechanisms giving rise to the components must be identified, and the conditions modifying their amplitudes and latencies must be clarified. The following sections will review several ERP components related to attentional filtering and attentional disengagement (N2pc, IIN, P4pc) that are all found in the latency window of ≈200-300ms. The goal of the review is to highlight the ways in which these components have been used and interpreted, along with some of the controversies and questions surrounding the exact nature of the mechanisms the components are thought to index.

N2pc

The N2pc component is a lateralized component, defined as an increased negative deflection for contralateral relative to ipsilateral electrodes at posterior temporal-occipital sites (e.g. O1, O2, PO7, PO8, P7 & P8). It is typically found between 200-300ms following the onset of a search array or bilateral visual display, but has been found as early as 175ms and as late as 350ms (Luck & Hillyard, 1994b; Brisson, Robitaille & Jolicoeur, 2007). Using magnetoencephalographic (MEG) recordings as well as simultaneous ERP and event-related magnetic field (ERMF) recordings, neural generators of this component have been identified in parietal lobe regions and also anterior occipital and posterior infero-temporal cortical visual areas (Hopf et al., 2000; 2004). The N2pc has been identified as a useful index of attentional selection (Luck & Hillyard, 1994a, 1994b). It has been used extensively to resolve theoretical questions such as whether attention is captured in an automatic fashion, or depends upon top-down control settings (e.g. Hickey, McDonald & Theeuwes, 2006). Despite the wide use of the N2pc as an index of selection or attentional engagement, the mechanism giving rise to the N2pc is still not entirely agreed upon (Brisson & Jolicoeur, 2007; Kiss, Van Velzen, & Eimer, 2008; Mazza, Turatto & Caramazza, 2009).

N2pc: Index of distractor suppression?

The N2pc was initially described as an index of the filtering out (or suppression) of competitor objects during visual selection of a target or target-like object based on the findings that the N2pc was: 1) elicited by both pop-out targets and also, to a smaller degree, non-target pop-outs; 2) not found when the pop-out was defined by its contrast with the surrounding items; and 3) also not found when distractors were absent (Luck & Hillyard,

1994b). These early findings were strengthened by evidence that the magnitude of the N2pc is enhanced as additional distractors are presented in closer proximity to a target during search (Luck, Girelli, McDermott & Ford, 1997). Therefore, when participants were required to filter out additional competitors, the increased effort was directly reflected in the amplitude of the N2pc.

Contrasting the hypothesis that the N2pc reflects direct distractor suppression, other follow-up studies demonstrated that an N2pc was elicited even when a single distractor was presented in the opposite visual field (Eimer, 1996), and when the array items (distractors) had to be used in order to determine the location of the target (Mazza, Turatto & Caramazza, 2009). These findings led some to conclude that the N2pc did not reflect processing related to the *distractors*, but rather indexed the effects of attention on enhancing *target* features, enabling selection. Recent work has suggested that the N2pc may be a composite component, representing summary activity related to both target processing and the distractor suppression rather than a single process of either one or the other (Hickey, DiLillo & McDonald, 2009). Despite the lack of resolution as to whether or not the N2pc specifically reflects distractor or target processing, or possibly a combination of both, much work has demonstrated that an N2pc is reliably elicited under conditions in which selection is made more difficult due to the presence of competitor items and therefore reflects the lateralized engagement of spatial attention during a critical processing stage in target selection.

N2pc: Index of spatial shifts or reorienting?

A critical unresolved debate surrounding the mechanism(s) indexed by the N2pc, particularly relevant to the study of attentional disengagement is whether or not the

component reflects filtering and selection alone, or might also reflect spatial shifts of attention, including reorienting. Due to the component's wide use as a moment-by-moment index of the direction or locus of spatial attention (e.g. Woodman & Luck, 2003), there is confusion regarding whether the component is an index of the attentional selection processes that occur following or during a covert shift of attention (e.g. Kiss, Van Velzen & Eimer, 2008), or if it also reflects, at least to some degree, the covert shift itself (Galvano et al., 2011; Woodman, Arita & Luck, 2009).

Woodman et al. (2009) looked at how shifting to locations compares with shifting to objects in a combined cuing / visual search paradigm using central word or letter cues that always predicted the target's location. Early N2pc-like activity, occurring in the cue-target interval and found only when placeholders were present on the screen during the entire trial, was taken as evidence that anticipatory shifts only occur when there is a physical object present at the target location. The fact that the elicited activity was defined as a subtraction of contralateral minus ipsilateral activity should arguably not be enough to label it as an N2pc component, particularly as it was observed more than 800ms after the cue had onset (and more than 300ms after the cue offset). An alternate account for this activity is that participants had already covertly shifted attention to the location marker and the observed lateralized N2pc-like activity reflected the anticipatory suppression of the other competing location marker objects. The largest target-locked N2pc was found when placeholders were absent during the cue to target interval, and was interpreted by the authors as a marker of shift to the target after its onset. Again, an alternate interpretation of these findings is that a larger amount of distractor suppression was required when placeholders did not remain on

the screen in the cue-target interval because participants had not suppressed the competitor placeholders in anticipation of the target's onset.

Contrary evidence comes from a direct test of the N2pc as an index of spatial shifts. By using a central pre-cue that was either predictive or non-predictive, Kiss, Van Velzen and Eimer (2008) demonstrated that the N2pc does not reflect spatial shifts of attention. The task was a speeded two-choice discrimination in which participants had to indicate which side of a diamond (shape singleton amid squares) was cut. In all trials a central cue, consisting of two differently colored triangles facing in opposite directions ("< >" or "> <"), was presented 800ms before the target array appeared. For half of the blocks the central cue was 100% predictive (one of colored triangles preset as the instructive cue), with targets always appearing at one of the three locations on the cued side. For the other half of the blocks, participants were told that the central cue was non-predictive, and targets appeared with equal likelihood on both sides of the array. Evidence that participants used the central cue came from both faster RT's for the informative condition, as well as the presence of lateralized attention-directing ERP components associated with anticipatory shifts of attention, elicited in the cue-target interval (ADAN, LDAP) only in the informative cue condition. A clear N2pc was present within the 200-300ms window in both the informative and uninformative cue conditions, and no significant difference was detected between the two peak amplitudes for these conditions. The authors conclude that the N2pc does *not* reflect *covert attentional shifts* but rather is an index of *selection processes occurring after the shift has taken place*. However, they qualify this conclusion by pointing out that their design only tested pop-out search targets identifiable by a single feature dimension; and that

further work is needed to determine if a similar dissociation between shifts of attention and the effects mechanism indexed by the N2pc is found under more difficult search conditions.

One potential way to address this unresolved question of whether the N2pc reflects spatial shifts of attention, including reflexive orienting and reorienting, or rather is an index of distractor suppression alone, is to investigate the effects of *reflexively cuing attention* to a peripheral location before a search array is presented on the N2pc and corresponding selection behavior. Such a task would allow for the comparison of the N2pc amplitude and latency both when target discrimination requires a spatial shift of attention and when it does not. The present study used these conditions to address the nature of the N2pc directly.

Ipsilateral Invalid Negativity (IIN)

A result of the controversial use of the N2pc component as an index of covert shifts of attention (Praamstra, 2006; Woodman, Arita & Luck, 2009), is the implication that the N2pc also reflects *spatial reorienting* of attention following capture (e.g. Galvano et al., 2011). A different, more recently identified ERP component occurring in the same 200-300ms latency as the N2pc has been proposed as an index of disengagement and reorienting following reflexive capture. The ipsilateral invalid negativity (IIN) is derived by comparing the activity for invalidly-cued targets (i.e. targets appearing in the opposite visual field following a peripheral cue) with validly-cued targets (Hopfinger & Mangun, 2001, Hopfinger & Ries, 2005, Shin et al., 2010; Ford & Hopfinger 2011). As the name implies, beginning 200ms following the onset of an invalidly-cued target, an enhanced negative deflection is elicited at lateral temporal-parietal regions ipsilateral to the target's visual field. The component was originally identified in a study probing the electrophysiological effects of

reflexive attention (Hopfinger & Mangun, 2001). Using a cuing paradigm, Hopfinger & Mangun (2001) found an enhanced ipsilateral negative deflection for invalidly-cued relative to validly-cued location targets, but only when the ISI was short (34-234ms) leading to the interpretation of the IIN as an index of reorienting spatial attention. However, it is not possible to determine if the mechanism being reflected is reorienting or also includes disengagement as the two always occur in tandem in a typical cuing paradigm. The IIN interpretation was supported by the fact that the component was observed 1) for the condition in which reorienting was required (invalidly-cued location targets), 2) during the critical ERP latency after attention modulates early sensory components but before later attention-related components, and 3) was not observed at the longer ISI (566-766ms) because attention has already returned to fixation and responses were now faster for invalidly-cued targets relative to cued.

Hopfinger & Ries (2005) demonstrated that the appearance of an IIN is automatically triggered by invalid targets, but only when a cue is either a **single object onset**, or when it **matches the top-down control settings** by sharing a key target feature such as color. Specifically, the IIN was elicited by an onset cue even when the cue did not share features with the target, suggesting a special role for onset cues in reflexive attentional capture. When cues were not single onsets, however, the congruency between cue and target did affect the IIN, as the component was only found for congruent targets. This contingency effect was also observed at the level of behavior, and may suggest a stronger link between reaction times and the IIN, as compared with the link between the P1 (which always reflected capture by the cue, regardless of congruency) and behavior. In conclusion, these findings suggest a

connection between the IIN and the degree to which attention had previously been reflexively captured by a cue, indicating its potential use as an index of disengagement.

In a slightly different cuing paradigm using complex images rather than simple shapes as cues, Shin et al. (2011) similarly interpreted the finding of an IIN as evidence that attention was captured by an uninformative cue, when attention had to be subsequently disengaged and reoriented to a target appearing in the opposite visual field. In their study of attentional bias in individuals who might be at a heightened risk for developing alcoholism, Shin et al. (2011) found an enhanced ipsilateral negativity for all conditions *except* for when high-risk individuals responded to a target that appeared at the same location as a previously presented alcohol image. Importantly, a bilateral cue was used, meaning that two images were simultaneously presented, one in each visual field; and participants were informed that the target would appear at one of the cue locations with equal likelihood. The finding of an IIN for low-risk individuals for all target types was interpreted as an index of disengaging and reorienting from fixation.

A previous study within our lab examining the effect of visual anchors on the hold of reflexive attention reliably produced an IIN, with enhanced negative activity for uncued location targets peaking at 250ms following the targets' onset (Ford & Hopfinger, 2011). Critically, the IIN was significantly enhanced when placeholders were present throughout the trial, matching behavioral results suggesting that placeholders caused an increased hold at the location of the cue, and enhanced difficulty with disengagement from the cue location when the target appeared across the vertical meridian. Taken together, these studies indicate that the IIN might be useful as a measure of **disengagement and reorienting**, with amplitude enhancements reflecting the degree to which the disengagement mechanism was employed.

P4pc

Another recently described component related to disengagement is the P4pc, a positive difference derived by subtracting activity found at ipsilateral posterior electrodes from contralateral posterior electrodes occurring ≈400ms after a target appears potentially reflecting endogenous, or top-down, **disengagement** of attention (Toffanin, de Jong & Johnson, 2011). Motivated by a number of N2pc studies that reported but did not explicitly test or discuss a later "reversed N2pc" that follows the typical N2pc during selection (e.g. Eimer & Kiss, 2008), Toffanin et al. (2011) presented evidence that this component, which they labeled the P4pc due to its latency and scalp distribution, was elicited by voluntarily disengaging from a selected target and not by spatially reorienting to either a new target in the opposite visual field or back to fixation.

In their first experiment, the P4pc was elicited when participants were presented with two RSVP streams, one in each visual field, and were cued with central arrows to respond to targets in either one of the streams (< or >, focused attention condition) or both (<>, divided attention condition). Interestingly, an equivalent N2pc was elicited by targets in the focused and divided attention conditions, both of which were significantly greater than the small but significant N2pc found for targets in the ignored RSVP stream in the focused condition. Therefore, participants were clearly using the cues and also, under these conditions, the target-elicited N2pc does not seem to reflect the process of reorienting required in the divided attention condition. The later P4pc was found for all targets but was significantly larger for targets in the divided attention condition. A small but significant P4pc occurred in the focused attention condition and was interpreted as a reflection of attentional **disengagement**,

in this case from one object to another in the same spatial location, and **not reorienting**, which was not required in the focused attention condition.

In a second experiment, equivalent P4pc components were elicited by a peripheral cue that either directed participants to voluntarily *shift* to targets in the same or different visual fields or directed participants to *stay* at the cue location. The equivalent P4pc amplitudes elicited by all cues, all of which required that participants disengage from the cue and prepare for the target with or without shifting attention, further indicated that the P4pc reflects **disengagement** and not the spatial shifts of attention specifically involved in reorienting. The ISI in the second paradigm was 950ms, so these cue-locked components were observed long before the target array appeared, and were elicited by a cue array that was not masked. Critically, all conditions in which the P4pc was observed involved voluntary or endogenously controlled disengagement. This series of experiments provide compelling evidence that this later component is a reflection of endogenous disengagement, particularly given that the design is one of the few that allows for the separation of disengagement from spatial reorienting. In all conditions, the disengagement required was *endogenous*, as participants had to actively stop attending to a cue in order to prepare for an expected target in a predicted location. Further, disengagement was preceded by either sustained voluntary attention (to an RSVP stream) or by the voluntary orienting of attention elicited by a 100% valid cue. In contrast, the current study tested whether or not a P4pc would also be elicited by disengagement following *reflexive* capture by a cue.

Current Study

The primary goals of the present study were to 1) determine if previously established effects of reflexive attentional capture observed in simple cuing studies (such as faster responses to cued targets and enhancement of early sensory processing ERPs) are also evoked during visual search tasks; and 2) dissociate the mechanisms of spatial disengagement/reorienting from target selection/distractor suppression. In service of these goals we compared the hypothesized dissociable mechanisms of disengagement and distractor suppression by examining the proposed online ERP indices of each, including the N2pc, IIN, and possibly P4pc, during visual search following reflexive attentional capture. Given the argued importance of the role of disengagement and reorienting in attentional deployment, it is critical to find an ERP index that reflects the underlying mechanism. This is particularly relevant because of the potential for interpreting identical behavioral effects, such as longer reaction times to invalidly cued targets relative to cued targets, as either evidence for a disengagement deficit from a cued location (Fox et al., 2001), or as enhanced orienting to a cued location (Townshend & Duka, 2001). Additionally, due to the continued debate surrounding the mechanisms indexed by the widely studied N2pc component, it is important to dissociate the processes reflected by this component, specifically selection of relevant target features over competing distractors, from the mechanisms of spatial disengagement and reorienting.

The present study tested the hypothesis that the N2pc indexes the process of filtering out or suppressing distractors following an initial feature analysis (Luck & Hillyard, 1994a; 1994b) and does not reflect the mechanisms involved in spatial shifts of attention, including reorienting (Kiss, Van Velzen & Eimer, 2008). The experiment simultaneously investigated

whether the IIN, a proposed index of disengaging from a spatial location following reflexive attentional capture when attention must be suddenly reoriented to a target in the opposite visual field (Hopfinger & Mangun, 2001), is elicited under these conditions, and if it can be dissociated from the N2pc.

A combined cuing and visual search paradigm was employed, similar to that used by Woodman, Arita & Luck (2009) and Kiss, Van Velzen & Eimer (2008) to determine whether the attention mechanism allowing for successful target selection amidst an array of competitor objects, indexed by the N2pc, was affected by the reflexive capture of attention. Specifically we asked if N2pc amplitudes and latencies were equivalent when attention is reflexively captured to a peripheral cue that validly predicts the target's location, versus when it invalidly predicts the target's location, requiring subsequent disengagement and reorienting to the target's true location. Previous studies testing whether the N2pc was affected by spatial shifts of attention used central symbolic cues, eliciting endogenous shifts of attention (Kiss, Van Velzen & Eimer 2008; Praamstra, 2006; Woodman, Arita & Luck, 2009). Critically, if the N2pc elicited by cued location targets is **equivalent** to that elicited by uncued and neutrally-cued targets, we can conclude that the mechanism indexed by this lateralized component is not necessarily involved in covert spatial shifts of attention. If the N2pc amplitude is **attenuated** for uncued trials, relative to cued trials, we might conclude that the magnitude of the N2pc reflects the amount of attentional resources directed towards the target, available during selection/filtering. If, on the other hand, the N2pc amplitude is **enhanced** for uncued trials relative to cued trials, we might conclude that the magnitude of the N2pc reflects both the process of disengaging from the uncued location, as well as filtering distractors and selecting the relevant target. Longer N2pc onset latencies for uncued

(and/or neutrally-cued) targets may be interpreted as markers of the delay in selection due to the need to disengage and reorient spatial attention from an invalidly cued location or from fixation. Again, if there is no effect of cue condition on the observed N2pc latency, this would indicate that the N2pc does not reflect disengagement and reorienting (Kiss, Van Velzen & Eimer, 2008) either because participants have already disengaged and reoriented attention to the target by the time the mechanism of filtering is employed or because these processes occur simultaneously but are indexed by dissociable components.

The possibility that the N2pc component could be affected by peripheral cue validity despite not being affected by central cue validity (e.g. Kiss, Van Velzen & Eimer 2008) is supported by results from studies contrasting voluntary and involuntary attention mechanisms. For example, Briand and Klein (1987) found that conjunction searches resulted in a larger behavioral cuing effect than simple feature searches when peripheral cues were used. No such difference in the cuing effect size was found when symbolic central cues were used. This study thus highlighted the proposed dissociation between the mechanisms underlying voluntary and involuntary attentional orienting by demonstrating differential effects on behavior in the same task. To our knowledge, the present study is the first experiment to use ERPs to measure the electrophysiological effects of a single peripheral onset cue with a subsequent visual search task. If the behavioral cuing effect predicted for the present study (i.e. faster predicted RTs for cued location targets) is the result of a fundamentally different facilitation mechanism than that found by Kiss et al. (2008), who used central symbolic cues, then we may find a relationship between the N2pc and exogenous shifts of attention not seen when cues elicited endogenous shifts. Berger, Henik & Rafal (2005) demonstrated dissociable effects of endogenous and exogenous orienting cues

on behavior. Finding an effect of reflexive cues on the N2pc in the present study, when none was observed for endogenous cues in the Kiss et al. (2008) study, would add to the evidence for dissociations between two systems of attentional orienting; although, a follow-up within-subject comparison between the two types of cues would be needed to make any direct claims.

In addition to examining the effects of peripheral cuing on the N2pc, which is predicted for all conditions (cued, uncued and neutral), the present study will explore the effects of these conditions on the amplitude of the IIN. This will also be the first study, to our knowledge, to analyze the IIN elicited by a target presented in a complex search-type array. If the IIN is found, in addition to the N2pc, it will suggest the existence of a distinct ERP component reflecting the attentional mechanism allowing for selection when attention must be disengaged following reflexive capture. The IIN has previously been found in cuing paradigms in which a target was presented unilaterally (Hopfinger & Mangun, 2001; Hopfinger & Ries, 2005; Shin et al., 2010, Ford & Hopfinger, 2011) but it is not known whether this component will similarly reflect disengagement with a bilateral search array.

Because this is the first ERP study, to our knowledge, to combine a single peripheral cue with a subsequent target embedded in a complex search array requiring filtering out of distractors, we also analyzed the effects of cue condition on the P1 component, the earliest index of attentional modulations on perceptual processing (Mangun & Hillyard, 1991). Analysis of the contralateral P1 will aid in determining if the effects of reflexive attention on early sensory processing found in simple cuing studies (i.e. enhancement for cued location targets relative to uncued location targets, Hopfinger & Mangun, 1998), are also found during a visual search task.

Finally, we analyzed the evoked neural activity to determine if target selection following disengagement and reorienting gave rise to the P4pc component previously identified by Toffanin and colleagues (2011). This component is believed to index *endogenous* disengagement of attention, as it was elicited both by a target following disengagement from a divided attentional state, and by a cue indicating that disengagement was necessary in order to discriminate an upcoming target. In the present study, attention was reflexively captured to a peripheral location, which either did or did not contain the subsequently appearing target. Therefore, when the target stimulus appeared, participants needed to disengage attention and reorient to the target in order to make the discrimination and response. Because the location marker of the target was a predetermined pop-out feature (color), the type of disengagement involved in this task may have engaged both exogenous and endogenous attention. The finding of a P4pc component may suggest that disengagement is endogenous under these circumstances; whereas its absence leaves the question somewhat unresolved.

An exploratory aim of this study was to investigate the degree to which the behavioral and ERP measures of spatial reorienting and selection from our experiment might relate to measures of daily distractibility. Several studies have found links between the CFQ and performance on laboratory attention tasks (Tipper & Baylis, 1987; Forster & Lavie, 2007; Kanai, Dong, Bahrami & Rees, 2011). Specifically, higher CFQ scores have been correlated with the inability to successfully inhibit distractor words presented above and below a target word (Tipper & Baylis, 1987), and with increased reaction time during a search task in which a distractor letter is presented peripherally (Forster & Lavie, 2007).

Studies employing ERPs have also found links between CFQ scores and electrophysiological markers of attention (Righi, Mecacci & Viggiano, 2009; Roche, Garavan, Foxe & O'Mara, 2005). Using a sustained attention task, Righi and colleagues (2009), found an inverse relationship between CFQ scores and P3 amplitudes, with higher P3 amplitudes associated with fewer cognitive failures, even though behavior did not differ as a function of CFQ scores. Interestingly, an earlier study using a similar task found no relationship between CFQ scores and the P3 for correct trials, but found that people who reported higher levels of absentmindedness also had larger P3 amplitudes for trials in which an error was made (Roche et al., 2005). In both cases, the results were taken as evidence that lower CFQ scores correlated with higher levels of cognitive control. Taken together, these findings indicate that the CFQ can be used as a measure of individual differences in the ability to successfully ignore task-irrelevant distraction. The present study explored this relationship to determine if the behavioral and electrophysiological indices of reorienting and selection observed in this experiment predict daily distractibility.

CHAPTER 2

CUED VISUAL SEARCH EXPERIMENT

Methods

Participants

Seventeen healthy adults participated in this study after giving informed consent. One participant was excluded due to excessive eye blinks resulting in a sample of sixteen particiaptns ages 18-27 (11 female). All participants were right-handed, with 20-20 or corrected to 20-20 vision and without a history of psychiatric illness, neurological disorder or incident (such as concussion) and received paid compensation ($10/hour) for their participation.

Materials & Procedure

A within-subject experiment was conducted, using a modified cuing / visual search paradigm (e.g. Kiss, Van Velzen & Eimer, 2008; Woodman, Arita & Luck, 2009). The commercial software package, Presentation (Neurobehavioral Systems; San Francisco, CA), was used to present stimuli and record response times and accuracy levels. The experimental sessions took place in an electrically shielded room with visual stimuli presented on a CRT monitor 75cm from the subject. Following an initial training block, in which participants became familiar with the task and with maintaining fixation throughout all trials, 18 experimental blocks, each consisting of 69 trials, were completed. A central fixation dot remained on the screen throughout the entire block, including when cue and target stimuli

were on screen. Each trial sequence (Figure 1) began with a fixation screen for 1000-2000ms, and was always followed by a non-predictive cue: a black outline square (1.3˚ x 1.3˚) presented for 50 msec, either around the central fixation cross or peripherally, 5.2˚ from fixation in either the upper right or left visual field (sizes and visual angles based on Woodman, Arita & Luck, 2009). On 70% of trials, the cue was followed by the target display, at a constant ISI of 134ms. The target display consisted of 12 discrete square outlines, one target and 11 distracters, presented simultaneously, all 5.2˚ from fixation (Figure 1), which remained on screen for 167ms (similar presentation time as Kiss, Van Velzen & Eimer, 2008), before being replaced by the background fixation screen.

The target appeared after the peripheral or central onset cue with equal likelihood in either the upper right or upper left visual field (i.e. same location as the two peripheral cue locations) resulting in three equally likely target conditions: cued location, uncued location and neutrally-cued location, with 288 trials in each condition when collapsing across visual field. The target was defined as a color singleton (blue among red) and the participants were instructed to indicate whether the black line within the color singleton box was oriented vertically or horizontally. The color-singleton box containing the target only appeared at either the two o'clock or ten o'clock location, matching the two peripheral cue locations (Figure 1). The distractor shapes also contained black lines of equal sizes, at non-orthogonal rotations (e.g. 45°). Target and non-target location marker colors were equiluminant. Critically, the target's location was defined by the color of the box (i.e. blue), whereas the target attribute that needed to be discriminated for this task was the orientation of the line within the color-singleton box at that location (i.e. vertical or horizontal). This was done primarily because the N2pc component will not arise if detection of the target is able to be

completed by simply contrasting the defining feature of the target with the surrounding array (Luck & Hillyard, 1994b).

Participants were instructed to respond as quickly as possible without sacrificing accuracy. Within each block, the trial sequence was pseudo-randomized, with the constraint that a given trial type (e.g. right cue – right target) did not occur more than four times before a different trial type was presented (e.g. neutral cue – left target) in an attempt to control for idiosyncratic strategies that may arise because of trial expectancies being formed due to longer sequences of a certain trials type. Additionally, all participants were presented with the same set of 18 blocks.

The centrally presented onset cue was referred to as the "neutral cue" because it served as only a warning cue as subjects were informed that targets can never occur at the central location. This condition allowed us to control for the general alerting effects of a cue (central) vs. the attentional capture to a peripheral location. In addition, the neutral cue allowed for the comparison between recovering from capture to an erroneous location that could potentially contain the target (uncued location) from an erroneous location that would never contain the target. The cued location vs. uncued location contrast in particular allowed for the comparison of behavioral (RT and accuracy) and electrophysiological responses (P1, IIN, N2pc amplitudes and latencies, P4pc) when attention was pre-allocated to a spatial location versus when it must be disengaged and reoriented; this was a critical comparison for evaluating the hypothesis that the N2pc reflects spatial shifts of attention. Neutrally-cued location targets were included to attempt to determine whether differences in RTs and evoked neural responses found between the cued location and uncued location target conditions should be interpreted as costs or benefits of the involuntary capture of attention.

Typically, significant differences between cued and neutral conditions (or attended and divided, Mangun & Buck, 1998) are interpreted as reflecting the benefits of attention on behavior and neural responses; whereas significant differences between uncued and neutral conditions (or unattended and divided, Mangun & Buck, 1998) are interpreted as reflecting the costs of attention. Additionally, these neutrally-cued location targets allowed us to investigate whether disengaging and reorienting attention from a potential target location is more or less difficult than disengaging from central fixation.

During 30% of all experimental trials, the cue was followed only by fixation. These trials served as cue-only ("catch") trials, and required that participants respond by pressing a third "target-absent" button. These trials were included to allow for the analysis of target-elicited ERP with the sensory cue processing activity subtracted. Previous studies have shown that it is necessary to have at least 25% of trials be these catch trials, or else the lack of a stimulus will be so unusual as to evoke an additional type of activity (referred to as an omitted stimulus response, or OSR, by Busse & Woldorff, 2003). The inclusion of a third "target-absent" response was motivated by results of two behavioral pilot studies (see Appendix B). The results of these pilot experiments indicated that the three-response version of the paradigm resulted in a smaller amount of within-subject response variability across target-present conditions, and allowed for the comparison target-absent reaction time analyses.

EEG Acquisition

The EEG was recorded from 96 electrodes using the Biosemi ActiView 2 system (Amsterdam, Netherlands), amplified at a bandpass of 0.01-100 Hz, and digitized at 256

samples per second. Eye movements were monitored throughout the experiment using a

closed-circuit remote eye tracker (Applied Science Laboratories; Bedford, MA) to ensure that

participants maintain fixation on the center cross throughout the experimental block.

Additionally, lateral eye movements were recorded through the use of two electrooculogram

electrodes, one at each outer canthus. Vertical eye movements and blinks were recorded

through the use of two additional electrooculogram electrodes, located beneath each eye.

ERP analysis

EEG data was processed and analyzed using the Brain Electrical Source Imaging

analysis software (BESA 5.3.7). The EEG signal was digitally filtered with a 0.30Hz high-

pass filter to remove low-frequency drifts before averaging and was referenced to the average

of the right and left mastoids. To create the ERP waveforms, the EEG data was averaged

over a latency window starting 315ms before the onset of the cue and ending 1000ms after

the onset of the target (1185ms after the onset of the cue, as there was a 185ms cue-target

ISI) with a baseline correction period of 100ms. Artifact rejection was performed on the

latency window of 100ms prior to the cue onset to 500ms after the onset of the target (685ms

after the onset of the cue). Only trials with correct manual responses were included, and trials

with artifacts such as eye blinks, horizontal eye movements or excessive head movements

were eliminated from further analysis. All participants had trial acceptance rates of 80% or

higher. The resulting ERPs were filtered using a 40Hz low-pass filter to remove high-

frequency noise after averaging and were averaged across subjects to create a grand average

ERP. All statistical component analyses were conducted on the complex ERP wave form that

included both the cue- and target-elicited activity. There were two reasons for using this

complex wave. First, the same pattern of effects of condition and target-side on the P1 amplitudes were observed for both the complex cue *plus* target ERP, and for the derived cue *plus* target *minus* cue-only (catch) ERP (Appendix C and D), giving validity to the interpretation of the statistics performed on the complex wave. Second, because the cue-only conditions required a "target-absent" response, the catch trial ERPs resulted in visible P300 components, adversely interfering with the later target-elicited N2pc and IIN (Appendix C).

Cognitive Failures Questionnaire

All participants were given the Cognitive Failures Questionnaire (CFQ; Broadbent et al., 1982) a self-reported measure of everyday absentmindedness and distractibility (e.g., memory lapses and spatial orientation difficulties), consisting of 25 questions to be answered on a 5 point Likert scale (i.e., 0 = never, 4 = always), with higher scores indicated more self-reported cognitive failures (included as Appendix A).

Behavioral Results

Behavioral measures (reaction times and accuracy) for target present trials

For target-present trials, reaction times (RT) for correct responses and accuracy percentages were each submitted to a 3x2 repeated measures ANOVA with cue-type (cued, uncued, neutral) and target-side (right, left) as factors. Incorrect manual responses and reaction times faster than 200ms or slower than 1200ms were scored as errors. For RT, the ANOVA revealed a significant main effect of cue-type ($F(2,30)=27.89$, $p<0.001$; Figure 2). There was also an effect of target-side, significant at a more liberal level ($F(1,15)=8.46$, $p=0.01$). The interaction between cue-type x target-side was not significant ($F(2,30)=2.08$,

p=0.17), so RTs were averaged across both visual fields for the post-hoc paired t-tests exploring the main effect of cue-type. All paired t-tests were corrected for multiple comparisons using the Benjamini & Hochberg (B-H) correction procedure (Benjamini & Hochberg, 1995). Analyses revealed that participants were significantly faster responding to targets at cued locations as compared with those at uncued locations (Cued: *M*=653ms, *SE*=17ms; Uncued: *M*=670ms, *SE*=17ms; *t*(15)=-8.48, *p*<0.001; Figure 2). Participants were also significantly faster responding to targets at cued locations as compared with those at neutrally-cued locations (Cued: *M*=653ms, *SE*=17ms; Neutral: *M*=667ms, *SE*=16ms; *t*(15)=-4.56, *p*<0.001; Figure 2). There was no significant difference between RTs in the uncued and neutral conditions (*t*(15)=0.15, *p*=0.15; Figure 2). Driving the main effect of target-side was the fact that responses were significantly faster to cued targets presented in the right visual field than those in the left visual field (Right Cued: *M*=643ms, *SE*=17ms; Left Cued: *M*=662ms, *SE*=18ms; *t*(15)=-3.17, *p*=0.006). No other RT comparisons across visual field targets were significant.

The analyses of accuracy revealed that there were no significant main effects of cue-type (*F*(2,30)=0.49, *p*=0.49) or target-side (*F*(1,15)=0.50, *p*=.48), and the interaction between cue-type and target-side was not significant (*F*(2,30)=1.23, *p*=0.29), indicating speed-accuracy trade-offs do not account for the significant RT results.

Behavioral measures for target-absent trials

For target-absent trials (requiring a separate button press to indicate the subjects' awareness of this as a target-absent trial), RTs for correct trials were submitted to a repeated measures ANOVA with the single factor of cue location (right, left, or central). This

ANOVA revealed a significant main effect of cue location ($F(2,30)$=52.49, p<0.001; Figure 3). Follow-up paired t-test revealed that participants were significantly faster to respond to the absence of the target array following a peripheral cue, either in the right or left visual field, than they were to respond following a central cue (Right Cue: M=559ms, SE=15ms; Left Cue: M=559ms, SE=17ms; Central Cue: M=601ms, SE=17ms; Right Cue vs. Central Cue: $t(15)$=8.18, p<0.001; Left Cue vs. Central Cue: $t(15)$=8.03, p<0.001; Figure 3). No difference was found when comparing responses following right and left visual field cues ($t(15)$=0.14, p=0.89). As with target-present trials, there was no effect of condition on accuracy ($F(2,30)$=0.40, p=0.67).

ERP Results

Early Visual Processing

Mean amplitudes of the contralateral P1 component were measured at the lateral posterior PO7/PO8 electrodes and were submitted to a 3 x 2 ANOVA with cue-type (Cued, Uncued, Neutral) and target visual field (Right, Left) as factors. Analyses were conducted on a 25msec window surrounding the peak of the P1 component (100ms–125ms). There was a significant main effect of cue-type (Cued: M=7.64μV, SE=1.23μV; Uncued: M=4.33μV, SE=1.04μV; Neutral: M=5.14μV, SE=1.09μV; $F(2,30)$=22.90, p<0.001; Figure 4a). Because the 3x2 ANOVA did not indicate any other significant effects (main effect of target-side: $F(1,15)$=1.23, p=0.29; cue-type x target-side interaction: $F(2,30)$=0.313, p=0.58), follow-up t-tests were conducted on amplitudes averaged across both visual field. Paired t-tests indicated that P1 amplitudes for cued location targets were significantly enhanced compared to uncued location targets ($t(15)$=6.70, p<0.001; Figure 4b) and neutrally-cued location

targets ($t(15)=4.57$, $p<0.001$; Figure 4b). No difference was found in the P1 between uncued and neutral targets ($t(15)=1.67$, $p=0.11$; Figure 4b). These findings indicate that the effects of involuntary attentional capture due to a non-predictive cue affect sensory processing almost immediately, with the greatest P1 amplitudes reflecting the location of attention. This is the first evidence, to our knowledge, showing this early level of visual processing being affected by reflexive attentional capture in a visual search task.

N2pc: Amplitude

To test for the presence of a significant N2pc in each of the experimental conditions, mean amplitudes were measured from electrodes both contralateral and ipsilateral to the target (PO7/PO8), and were submitted to a 3 x 2 x 2 ANOVA with cue-type (Cued, Uncued, Neutral), target-side (Right, Left) and laterality (Contralateral, Ipsilateral) as factors. The 200-250ms latency window was used as it is typically when the N2pc is found to be maximal. Visual inspection confirmed that the N2pc component elicited by all three conditions appeared to peak within this window. A main effect of laterality (Contralateral: $M=3.68\mu V$, $SE=1.35\mu V$; Ipsilateral: $M=5.27\mu V$, $SE=1.39\mu V$; $F(1,15)=29.07$, $p<0.001$; Figure 5) indicated a significant N2pc was found when collapsing across all cue types, the contralateral site exhibiting the negative going deflection that defines the N2pc (although, similar to many previous studies, the overall waveform is positive, so a less positive potential is the N2pc). There was also a main effect of cue-type ($F(2,30)=4.53$, $p=0.037$; Figure 5) and, critically, a significant cue-type x laterality interaction ($F(2,30)=14.99$, $p=.001$; Figure 5). Similar to the P1 results, there was no evidence of a significant effect of target-side ($F(1,15)=1.98$, $p=0.18$) nor any interactions between target-side and either cue-type or

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laterality ($F(2,30)=0.94$, $p=0.40$; $F(2,30)=1.07$, $p=0.32$). Follow-up t-tests exploring the significant main effects and cue-type x laterality interaction were therefore conducted on peak amplitudes for ERPs collapsed across both visual fields.

To explore the cue-type x laterality interaction and test the effects of cue condition on the N2pc ERP component, an amplitude for each N2pc component was calculated as a contralateral minus ipsilateral difference wave in each of the three target-present conditions by subtracting the average ipsilateral ERP from the contralateral ERP at PO7/O8 during the peak latency window (Cued N2pc: $M=-2.87\mu V$, $SE=0.55\mu V$; Uncued N2pc: $M=-0.49\mu V$, $SE=0.25\mu V$; Neutral N2pc: $M=-1.42\mu V$, $SE=0.30\mu V$; Figure 6a). Paired t-tests indicated that all N2pc amplitudes were different than one another, with the largest N2pc for cued targets followed by neutrally-cued targets and finally uncued targets (Figure 6b). N2pc amplitudes for cued location targets were significantly enhanced as compared with both N2pc amplitudes for uncued location targets ($t(15)=3.93$, $p=0.001$; Figure 6b) and neutrally-cued location targets ($t(15)=4.55$, $p<0.001$; Figure 6b). These results directly conflict the theory that the N2pc component reflects the shifting of attention because such an interpretation would predict the largest amplitude for uncued or centrally-cued location targets. We found the opposite, with larger amplitudes arising during selection of cued location targets. Additionally, the N2pc amplitude elicited by neutrally-cued location targets was significantly greater than that for uncued location targets ($t(15)=2.85$, $p=0.012$; Figure 6b). The N2pc amplitude difference found between neutrally-cued and uncued location targets was not found for the P1 amplitudes nor for the RTs, and could reflect a difference in selection processing arising from differential attentional capture in the two conditions not seen at the level of behavior or early sensory processing.

N2pc: Latency

A jackknife procedure (as introduced for the study of the lateralized readiness potential, LRP, by Miller, Patterson, Ulrich, 1998 and Ulrich & Miller, 2001; and later applied to the N2pc by Kiesel, Miller, Jolicoeur, Brisson, 2008) for investigating latency shifts was used to investigate the possibility that the peripheral cue's capture of attention might cause a latency shift in the N2pc component. This technique involves first setting a criterion value for the component of interest (either an absolute value such as -0.4µV as used by Brisson, Robitaille & Jolicoeur, 2007 or a relative value such as 50% of the peak amplitude, as seen in Kiesel, Miller, Jolicoeur & Brisson, 2008), and then using this criterion to determine the onset latency for each component in the various conditions in the grand average ERP for s-1 participants, resulting in a total of N (i.e. 16) grand average ERPs, each one having eliminated one of the 16 participants to create a sample of grand average latency onset values. This jackknife method has been shown to have more power for detecting true latency differences than a method in which onsets are taken from single participants across conditions (Kiesel, Miller, Jolicoeur & Brisson, 2008).

In the current study, a relative criterion value of 50% of each condition's peak amplitude was used (Cued=-1.25µV; Uncued=-0.51µV; Neutral= -0.83µV; Figure 6a) due to the increased power afforded by this criterion (see Kiesel, Miller, Jolicoeur & Brisson, 2008 for simulation data). The resulting 16 N2pc onset latencies for each of the three critical conditions (cued, uncued and neutral) were submitted to an ANOVA with cue-type (Cued, Uncued, Neutral) as the factor (see Table 1 for latencies). The resulting F value was then corrected for inflation by dividing by $(n-1)^2$ (i.e. 225; see proof in Ulrich & Miller, 2001). The main effect of cue-type trended towards significance ($F(2,30)=4.92$, $p=0.060$), with

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mean latency values indicating the N2pc onset occurred earliest in the Cued condition (Cued N2pc: M=202ms, SE=0.5ms; Uncued N2pc: M=239ms, SE=0.8ms; Neutral N2pc: M=209ms, SD=0.5ms; Figure 6a). Although these results did not reach significance, condition means indicate that the cued location targets elicited the earliest N2pc, and the uncued location targets elicited the latest N2pc. These results seem to align with the N2pc amplitude findings, reflecting the fact that selection is occurring later for targets appearing at uncued (and neutrally-cued) locations.

IIN

Visual inspection of both the ERP waves and the topographical activity maps resulted in the selection of a peak window of 310-345ms post target-onset for the IIN component in this study (Figures 7a, 7b, 8a and 8b). This latency window is later than the one previously found for the IIN elicited during simple cuing paradigms (Hopfinger & Mangun, 2001, Hopfinger & Ries, 2005) but is similar to that reported for an ipsilateral negativity elicited by invalidly-cued targets presented in a similar search array as was used in this study (Seiss, Eimer & Kiss, 2009). Seiss et al. (2009) analyzed and reported this negativity but did not explicitly label it as an IIN (or any other established component). Mean amplitudes were measured from electrodes ipsilateral to the target (PO7/PO8), where differences were observed to be greatest, and were submitted to a 3 x 2 ANOVA with cue-type (Cued, Uncued, Neutral) and target-side (Right, Left) as factors. Again, there was no evidence of a significant effect of target-side ($F(1,15)$=1.33, p=0.27) nor an interaction between target-side and cue-type ($F(2,30)$=0.29, p=0.60). The ANOVA did reveal a main effect of cue-type (Cued: M=3.87μV, SE=1.12μV; Uncued: M=2.11μV, SE=0.98μV; Neutral: M=2.85μV,

SE=0.1.02μV; *F*(2,30)=11.85, *p*=0.001). The IIN component is identified as a *negative*

difference between conditions; therefore, although absolute amplitude values during this

latency were positive, smaller values here for uncued location targets reflect the presence of

the IIN. Critically, paired t-tests of mean amplitudes collapsed across visual field indicated

that the negative deflection was significantly enhanced to the uncued location and neutrally-

cued location targets as compared with cued location targets, respectively (Uncued-Cued:

M_{Diff}=-1.76μV, SE_{Diff}=0.40 μV; *t*(15)=-4.35, p=0.001; Figures 7a & 7b; Neutral-Cued: M_{Diff}=-

1.02μV, SE_{Diff}=0.25 μV; *t*(15)=-4.02, p=0.001; Figures 8a & 8b). There were no significant

differences between cue-type found for the ERPs at contralateral electrodes during the same

latency window (*F*(2,30)=1.87, *p*=0.17).

P4pc

       A recently identified component, labeled the P4pc has also been proposed as an index

for attentional disengagement (Toffanin, de Jong & Johnson, 2011). Toffanin et al. (2011)

found the P4pc to be maximal during the 340-430ms latency window after the onset of the

target; however they also found an N2pc maximal from 220-320ms after the target onset,

later than was found in the present study. Additionally, their study used a longer stimulus

presentation duration (200ms) followed by a 950ms mask. Therefore, in the present study, we

used an earlier time window following the offset of the N2pc in line with the Toffanin et al.

(2011) definition of the P4pc as a polarity reversal directly following the N2pc. To test for

the presence of a significant P4pc, mean amplitudes were measured from electrodes both

contralateral and ipsilateral to the target (PO7/PO8), within the 300-350ms latency window

and were submitted to a 3 x 2 x 2 ANOVA with cue-type (Cued, Uncued, Neutral), target-side (Right, Left) and laterality (Contralateral, Ipsilateral) as factors.

The results revealed a significant main effect of cue-type ($F(2,30)=7.21$, $p=0.003$), and critically, a significant cue-type x laterality interaction ($F(2,30)=10.62$, $p<0.001$). To explore the interaction, a P4pc was calculated for each condition, in a manner similar to that used for the N2pc component, by subtracting the average ipsilateral ERP from the contralateral ERP at PO7/O8 to create difference waves (Cued P4pc: $M=-0.783\mu V$, $SE=0.39\mu V$; Uncued P4pc: $M=1.43\mu V$, $SE=0.33\mu V$; Neutral P4pc: $M=0.15\mu V$, $SE=0.31\mu V$; Figure 9a). The only positive contralateral minus ipsilateral difference was elicited by uncued location targets, and was also the only significant positive difference found during this latency window ($t(15)=4.27$, $p=0.001$; Figure 9b). It seems unlikely that there is no disengagement process taking place when participants are selecting the neutrally-cued location targets, especially given the equally impaired RTs (as compared with uncued RTs). An alternate interpretation could be that unlike in the uncued location target case, disengagement from the neutral cue occurs bilaterally (not contralaterally) and is therefore not showing up in this laterally-defined component's analysis, but *is* reflected in the significant neutrally-cued location target IIN reported in the previous section.

P300

Although not the primary goal of the present study, we analyzed the target-elicited activity found 350-480ms following the target array's onset to look for evidence of a P300 component effect of cue-type, typically found to be greater for cued location targets relative to uncued location targets when peripheral reflexive cues and short SOAs are used

(Hopfinger & Mangun, 1998). Mean amplitudes were measured at the P1′/P2′ electrodes (Figure 10a) and were submitted to a 3 x 2 ANOVA with cue-type (Cued, Uncued, Neutral) and target-side (Right, Left) as factors. There was a significant main effect of cue-type (Cued=6.17μV , Uncued=5.16μV, Neutral=6.51μV; $F(2,30)=12.36$, $p=0.001$; Figure 10a). Follow-up t-tests were conducted on amplitudes averaged across both visual fields due to a non-significant main effect of target-side ($F(1,15)=0.18$, $p=0.68$) and non-significant cue-type x target-side interaction ($F(2,30)=0.13$, $p=0.88$), and revealed that P300 amplitudes for cued location targets were significantly enhanced compared to uncued location targets ($t(15)=6.70$, $p<0.001$; Figure 10b). Diverging from results found for the P1, N2pc and IIN, in the case of the P300, neutrally-cued location targets were significantly enhanced as compared with uncued location targets ($t(15)=4.29$, $p=0.001$; Figure 10b); and no difference was found in the P300 for cued and neutral targets ($t(15)=0.99$, $p=0.34$; Figure 10b).

CFQ

Analysis of sum scores from the self-reported CFQ (Broadbent, et al., 1982) revealed that individual scores on this self-reported measure of daily distractibility were positively correlated with both RT to cued location targets ($r=0.54$, $p=0.03$), and with RTs for uncued location targets ($r=0.53$, $p=0.03$), indicating that individuals who are more distractible were slower overall in this task regardless of the cuing condition. There was also a non-significant trend for these CFQ scores to be positively correlated with RTs to neutrally-cued location targets ($r=0.48$, $p=0.06$). These results match a previous behavioral study in which higher CFQ scores were correlated with increased reaction time during a search task (Forster & Lavie, 2007).

Although CFQ scores have also been correlated with the ERP components, specifically, the P300 (Roche et al., 2005; Righi, Mecacci & Viggiano, 2009), the present study did not find any significant correlations between CFQ scores and ERP component amplitudes. A possible explanation for the present study's null findings is the clearly restricted range seen in the CFQ scores for our participants, limiting our power to detect any additional correlations that may exist in the population. The CFQ scale has a range of 0-100, however the range of scores for the current sample was 10-53. Roche and colleagues (2005) suffered from a similar range attenuation problem in their small sample (28-59) but used a median split to explore the relationship between CFQ scores and the P300. This method would not be appropriate in the current sample as the median CFQ score was a 38, and a split would results in one participant with a score of 38 being labeled as "low CFQ" and two different participants with scores of 39 being labeled as "high CFQ".

CHAPTER 3

DISCUSSION

The aim of this study was to determine if the mechanism of target selection when

distractor suppression is required could be dissociated from spatial disengagement and

reorienting by investigating whether distinct ERP components reflected each process. In

service of this aim, this study sought to resolve the debate surrounding the use of the N2pc as

an index of spatial shifts of attention including reorienting, and determine if other ERP

components, such as the IIN and P4pc might be more appropriate indices of attentional

reorienting. Additionally, the present study aimed to extend the previously established effects

of reflexive attention during cuing studies to a visual search task. These goals were

accomplished through an ERP experiment using a cued visual search paradigm, in which

non-predictive onset cues were presented either peripherally or at fixation. Broadly, the

results indicate that reflexive attention resulted in a benefit to both behavioral and neural

responses for targets appearing at the cued location during visual search; and that the N2pc

component reflects target selection but not attentional shifts, whereas the IIN and P4pc

components may be more direct indices of attentional disengement.

Reflexive attention effects during visual search

Extending previously established effects of reflexive attention in simple cuing

paradigms (e.g. Hopfinger & Mangun, 1998; 2001), we found that reflexive capture of spatial

attention in advance of a visual search resulted in faster reaction times for cued location

targets as compared with both neutrally-cued location and uncued location targets. The RT results suggest reflexive attentional capture by the cue resulted in an attentional benefit as there was a difference between the attended (cued) and neutral conditions (Mangun & Buck, 1998), but no cost, as there was no difference found between the unattended (uncued) and neutral conditions (Figure 2). At first glance, these results seem surprising as they imply equivalent disengagement and reorienting processes both when attention is captured to a possible target location (uncued condition) and when attention is captured to a location in which a target will never appear (neutral condition). However, RTs from the target-absent trials revealed that participants were significantly slower to respond to the absence of a target when the cue was presented centrally versus peripherally (Figure 3), indicating a disengagement cost associated with capture at fixation when making a target-absent decision. It could be the case that attentional costs associated with capture to the uncued location (as would be evidenced if these RTs were significantly slower than the neutral RTs) were obscured by the added cost associated with disengagement from capture to an object presented at the fovea (i.e. centrally).

ERP results revealed an enhancement of the contralateral P1 amplitude for cued location targets relative to both uncued and neutrally-cued location targets, reflecting the heightened processing for attended targets as compared with unattended targets at early stages of visual processing (Figures 4a and 4b). The effects of attention on this component indicate that reflexive attentional capture by a peripheral cue affect processing of a target in a complex array at the earliest sensory processing stages, and in a manner similar to that seen for target discrimination in a simple cuing paradigm (Hopfinger & Mangun, 1998). These

findings provide novel evidence for early sensory processing modulation by reflexive attentional capture in a visual search task.

The P300 component, which is associated with higher order processes related to attention such as the violation of expectancies, or memory updating (e.g. Mangun & Hillyard, 1991; Coles & Rugg, 1995), also exhibited a pattern of results similar to those found in reflexive attentional cueing studies utilizing a short SOA (Hopfinger & Mangun, 1998) in which attended targets produced the largest P300 amplitudes. In the present study, the P300 was significantly enhanced for cued location targets relative to uncued location targets (Figures 10a). The neutrally-cued targets also elicited a P300 significantly greater than that found for uncued targets, and equivalent to that found for cued targets (Figure 10a). In accordance with previous interpretations of the effects of cuing on the P300, these results suggest that the cued and neutrally-cued targets received higher priority in terms of relevance, than the uncued targets, despite the non-predictive nature of the cues (Hopfinger & Mangun, 1998). Critically, the effects of non-predictive cues on reaction times and on the amplitudes of both the P1 and P300 replicate and extend previous findings on the neural effects of reflexive attention.

N2pc as an index of spatial reorienting

One of the central goals of this study was to clarify the use of the N2pc as a direct index of spatial shifts of attention. To that end, we compared the N2pc amplitude elicited during target selection after attention was reflexively captured to the location of the target (cued), with the N2pc elicited when attention was captured to a different location and had to be disengaged and reoriented upon the appearance of the target array (uncued and neutrally-

cued). If the N2pc amplitude tracks spatial shifts of attention we would have expected to find the largest amplitudes following uncued and neutrally-cued targets, as these were the conditions in which attention had to be disengaged and reoriented after the onset of the target array. However, the results directly contradict this hypothesis. N2pc amplitudes were significantly attenuated for neutrally-cued location targets, relative to cued targets, and even more so for uncued location targets (Figure 6a). There are two related interpretations of the observed N2pc attenuation in these conditions. First, the diminished N2pc components could reflect reduced attentional resources directed at the target location in these conditions due to the fact that attention was previously captured elsewhere (either in the opposite visual field or at fixation). Second, the enhanced N2pc found in the cued condition could reflect a greater amount of active distractor suppression occurring in this condition, which results in faster RTs. Critically, the results do not support an interpretation of the N2pc component as an index of attentional reorienting.

In their recent study investigating disengagement from a distractor following reflexive capture, Sawaki and Luck (2013) refer to the N2pc broadly as an index of attentional deployment and specifically as index of attentional capture (to the cue) and reorienting (from the cue to the target), highlighting the continued ambiguity about precisely which attentional process are reflected by the N2pc component. As previously stated, the results from the present study contradict the use of the N2pc as an index of reorienting. Our results do corroborate the use of the component in its broadest use as an index of attentional deployment, as we observed enhanced amplitudes in the condition in which attention was directed to the location of the target. However, the N2pc is only observed when visual stimuli are presented in both visual fields (Luck & Hillyard, 1994b), and for tasks that are more

complex than simple pop-out detection (i.e. involve a discrimination of a feature which is not defined as pop-out). Given these constraints, it seems crucial to refine the use of the N2pc as an index of attentional deployment with the caveat that some form of attentional selection during distractor suppression must also be ongoing to observe the component. The use of single onset cues in the present study precluded the analysis of an N2pc to the cue (as was done by Sawaki and Luck (2013), who employed a balanced array of cues in both visual fields), but, critically allowed us to reveal the effects of reflexive attentional capture on visual search.

We also analyzed whether or not the cue manipulation resulted in a change in the N2pc onset latencies. Although the analyses of the N2pc amplitudes did not support the use of the N2pc as an index of spatial shifts of attention, it could have been the case that the onset latency and not the amplitude reflected reorienting. Brisson, Robitaille & Jolicoeur (2007) found effects of stimulus intensity (specifically line thickness) on early sensory components and on the onset latency, but not amplitude, of the N2pc. Using the jackknife method to compare ERP latencies across conditions (Kiesel, Miller, Jolicoeur, Brisson, 2008; Miller, Patterson, Ulrich, 1998; Ulrich & Miller, 2001) we found marginally significant evidence that cued targets resulted in the shortest N2pc latency onset, followed closely by the neutrally-cued targets and then, later by uncued targets (Figure 6a). The latency results support the observed N2pc amplitude difference across conditions, indicating that selection occurred later for targets appearing at uncued (and neutrally-cued) locations. Our results also echo those reported by Sawaki and Luck (2013), in which they found (non-significant but trending) results suggesting that the earliest N2pc onset latency was elicited by trials in which the target appeared in the same visual quadrant as the cue. This set of results suggest

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that the onset latency of the N2pc may reflect the fact that attentional selection was delayed in conditions for which disengagement and reorienting was required, but do not directly support the use of the timing of this component as an index of when reorienting is taking place. Future studies are needed to explore the relationship between reorienting and the differential effects on both N2pc amplitudes and latencies in order to determine if the onset latency of this component closely tracks when selection occurs.

The finding in this study that reflexive attentional capture resulted in a modulation of the N2pc conflicts with evidence that centrally presented predictive and, critically, non-predictive cues resulted in equivalent N2pc components (Kiss, Van Velzen & Eimer, 2008). However, in their study, Kiss, Van Velzen & Eimer (2008) used centrally-presented cues, an extremely long SOA of 900ms, and designed the study to examine the effects of endogenously directed attention on the resulting N2pc component during target selection. The present study's finding of an effect of reflexive attention on selection during search, and its associated ERP indices, adds to the established dissociation between endogenous and exogenous attention (e.g. Berger, Henik & Rafal, 2005).

IIN and P4pc as indices of attentional disengagement

The N2pc analyses indicate that it is not an index of spatial reorienting. Two other components, the IIN and P4pc, have been associated with spatial disengagement following exogenous and endogenous orienting, respectively. The IIN is a derived component, which has been found in reflexive cuing studies by comparing the activity for uncued location targets with cued location targets (Hopfinger & Mangun, 2001, Hopfinger & Ries, 2005, Shin et al., 2010; Ford & Hopfinger 2011). The present study tested whether or not the IIN

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would be similarly observed when comparing activity arising from uncued and cued location targets in a visual search task. The results suggest that an IIN was elicited for both uncued and neutrally-cued location targets when comparing ipsilateral activity to that arising from cued location targets (Figures 7a and 8a). The IIN found using the present search paradigm was observed at a later latency than previously recorded in cuing study (≈325ms vs. ≈250ms). This is not entirely surprising as the present study's target array was more visually complex, and presented for a longer duration than that used in previous cuing studies (e.g. 167ms in present study vs. 50ms in Hopfinger & Mangun, 2001). Critically, the IIN was observed *after* the N2pc component. Given the N2pc results of attenuated amplitudes in the uncued and neutrally-cued conditions, it seems consistent with previous IIN interpretations to interpret the present study's IIN as a reflection of the disengagement and reorienting process occurring in the uncued and neutrally-cued conditions. It is interesting to note that for neutrally-cued targets, visual inspection of the topographical maps indicated that the negative activity at lateral temporal-occipital electrodes during the IIN peak latency window was more bilaterally distributed than that found for uncued targets (Figure 11). Analyses of target-elicited activity at the contralateral electrodes did not produce evidence of a significant negative difference when comparing neutrally-cued and cued conditions; however the evidence from the P4pc analyses was able to test this contralateral vs. ipsilateral activity difference more directly.

The P4pc is a recently described component, suggested as an index of endogenous disengagement of attention. Similar to the derivation of the N2pc, the P4pc is defined as a positive difference calculated by subtracting activity found at ipsilateral electrodes from contralateral electrodes (PO7/PO8) occurring ≈400ms after a target array appears (Toffanin,

de Jong & Johnson, 2011). In the present study, we found evidence of a significant contralateral minus ipsilateral positivity *only* in the uncued location target condition, and occurring at ≈350ms: after the N2pc but before the previously reported P4pc (Figure 10a). There was no difference between the contralateral and ipsilateral activity for neutrally-cued targets, and there was a negative difference for cued targets (Figure 10b). The RT (and P1) results both indicate that following a neutral (central) cue, participants were slower to respond and showed attenuated sensory processing of the target, suggesting that disengagement and reorienting was indeed required for successful target discrimination in this condition. The fact we found a significant neutrally-cued IIN but no significant neutrally-cued P4pc along with the observed bilateral negativity in the same 300-350ms latency window supports the fact that disengagement in this condition may have been bilateral. Critically, these results suggest that the IIN and P4pc may indeed be indexing the same mechanism of disengagement and reorienting, but are able to show a more complete picture of the disengagement process due to the different ways in which the two components are derived.

In conclusion, the present study suggests that there are distinct ERP components reflecting the processes of attentional selection during search and attentional disengagement and reorienting, respectively. Specifically, the results suggest that the N2pc reliably indexes the spatial direction of attentional focus and is elicited during visual search following reflexive capture, but is not an appropriate marker of the shifting of spatial attention. Further, the results suggest that both the IIN and P4pc may reflect the disengagement and reorienting of attention, and given their differential derivations, both may be useful when evaluating neural activity generated by these processes.

Future directions

The present study addresses the debate surrounding the interpretation of the N2pc as an index of spatial attentional shifts, and suggests that this component should not be used as an index of reorienting. It remains unresolved, however, whether or not the enhancement of the N2pc for cued targets found in the current study reflects additional resources involved in target discrimination or if the enhancement reflects boosted distractor suppression taking place in this condition. Additional conditions in a cued visual search paradigm, which increase and decrease the need for distractor suppression (e.g. more or less distractors present) and target discrimination (e.g. dim vs. bright targets), respectively, may help clarify which interpretation of the N2pc is more appropriate.

One of the most interesting and unexpected results in the present study was the evidence that disengagement following the central cue (neutral condition) was bilateral. These results may indicate that the Ipsilateral Invalid Negativity may need to be more appropriately named (e.g. Contralateral Disengagement Negativity). Future studies could directly test the nature of this component by including multiple distractor eccentricities and evaluating the topographic distributions of the elicited IIN component for each. Additionally, a study in which the target appears not only peripherally, but also at fixation, could cause disengagement from the central cue to be more difficult, and therefore show the bilateral disengagement, not found to be significant using the present design, more distinctly.

Under the Posner & Peterson (1990) model, there are dissociable subcomponents of disengaging and shifting within visiospatial attention. So far, studies in which an IIN has been detected have not been able to conclusively determine if this component reflects only

one or both of these subsystems (i.e. disengagement and/or reorienting). A follow-up study might determine which of the two processes is being indexed by creating a condition in which disengagement, but not shifting, is required and compare the ERP elicited in this condition with one in which both disengagement and shifting take place, as was done in the study of the P4pc (Toffanin, de Jong & Johnson, 2011).

Finally, the present study found evidence that participants who were more distracted during daily tasks (as self-reported using the CFQ; Broadbent et al., 1982) were slower overall when responding to the targets. We did not find evidence linking these traits with any of the observed ERP effects, possibly due to our homogeneous and highly functioning, sample. Future studies would benefit from recruiting a sample in which a more diverse set of CFQ scores could be correlated with behavioral and neural measures of attentional capture and disengagement. A more variable sample might help determine whether differences in daily distractibility are reflected in changes to all stages of processing associated with attentional modulations (i.e. beginning at the P1 and continuing through the later occurring P300, IIN and P4pc), or if such differences only manifest at later stages in the processing stream.

Table 1: N2pc onset latencies used in jackknife procedure.

N2pc latency onsets (msec)			
Omitted Sub	Cued	Uncued	Neutral
1	204	239	208
2	204	235	209
3	204	239	208
4	204	238	208
5	200	239	208
6	200	243	212
7	200	237	212
8	204	239	208
9	200	237	208
10	200	243	208
11	204	231	212
12	200	237	208
13	204	241	208
14	204	240	212
15	204	242	207
16	200	237	208
Mean:	202	239	209
SE:	0.5	0.8	0.5

Figure 1. Cued Visual Search Paradigm: Example target-present and target-absent trial sequences. A cue appeared every trial, and was followed by the target array on 70% trials or by fixation on 30% of trials. The target only appeared in the 2'oclock and 10'oclock position and was defined as the blue singleton box. Participants were instructed to push "1" when the bar inside the blue box was vertical (as it is here) and "2" when horizontal. For cue-only trials, the cue appeared with equal likelihood in either the right or left upper visual field, or at fixation. For these trials, participants were instructed to push "3" to indicate the absence of the target.
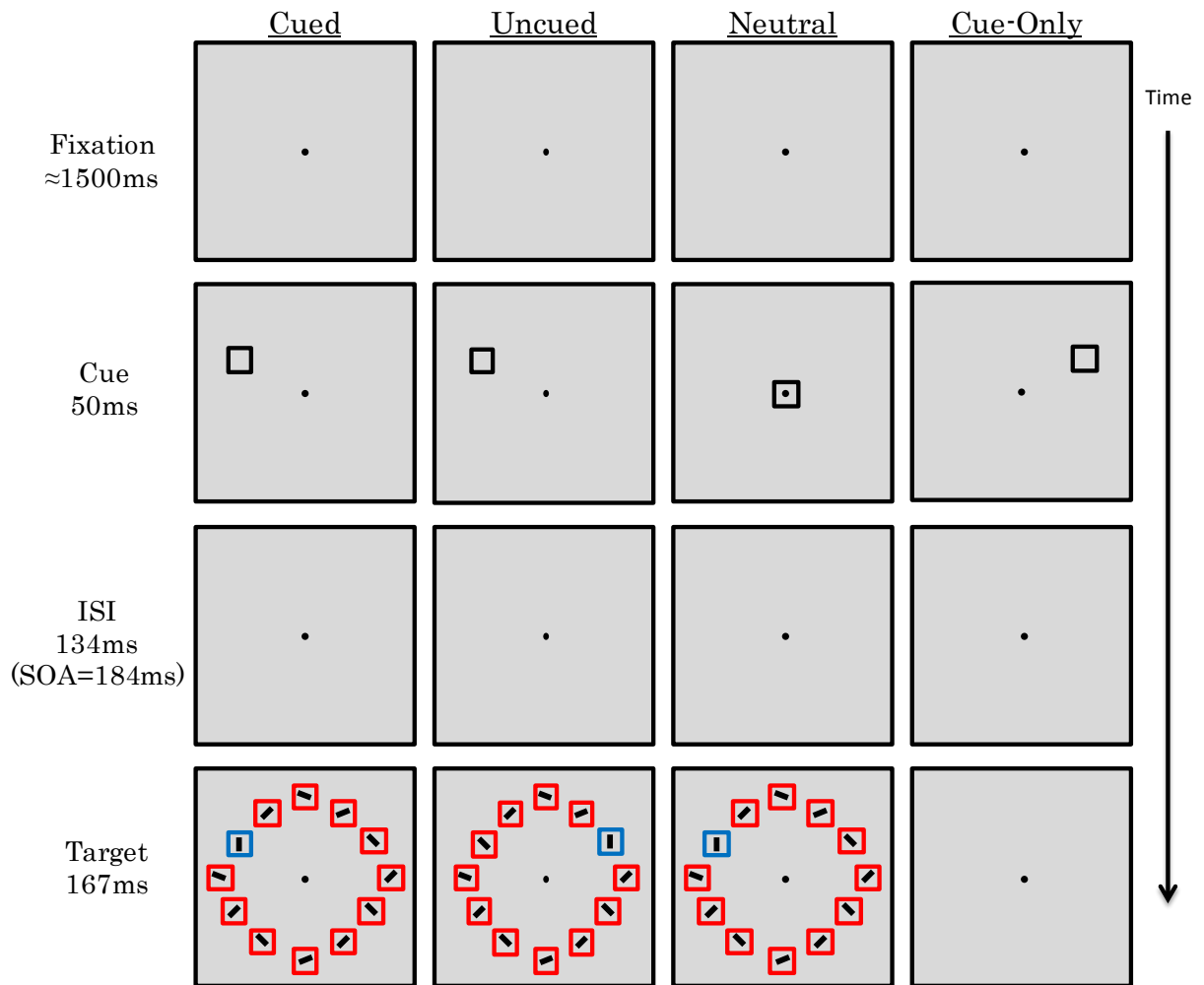
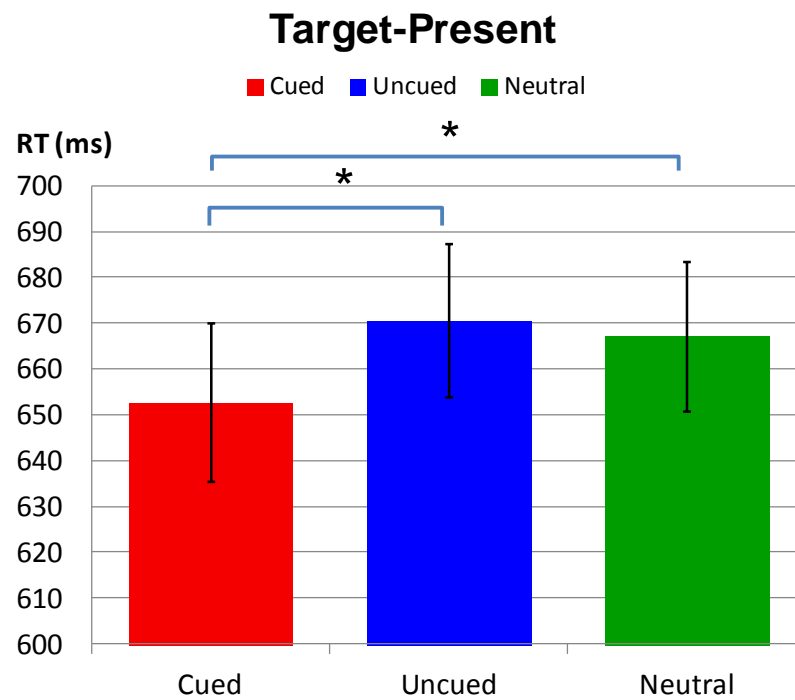Figure 2. Reaction times for target-present trials.
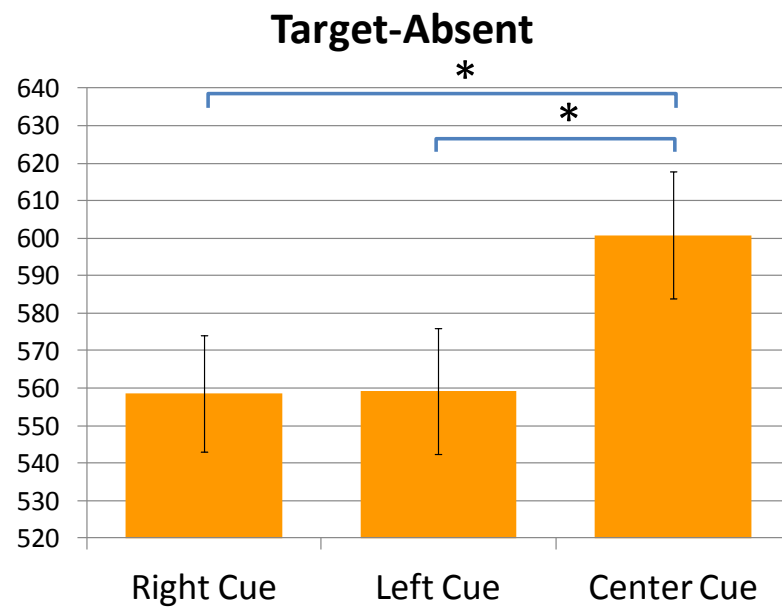
Figure 3. Reaction times for target-absent trials.

Figure 4a**.** ERP plot of lateral parietal electrode (PO7/PO8) showing contralateral P1 effects collapsed across visual field.
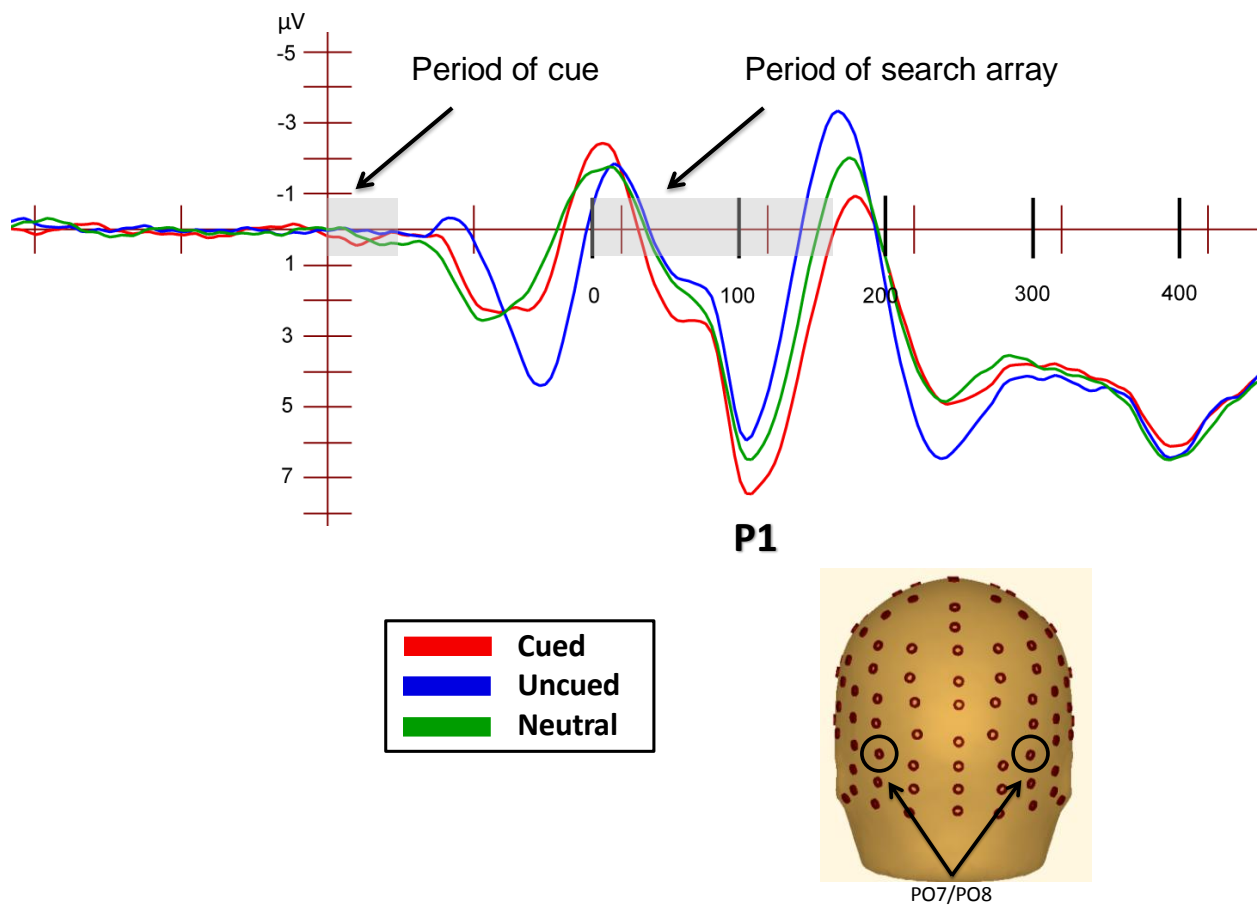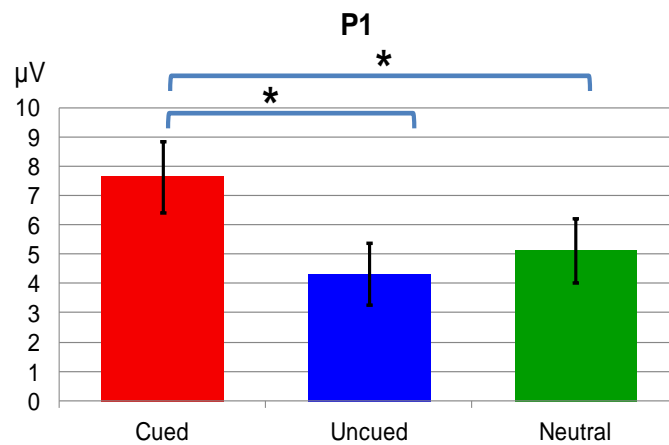

P1

Figure 4b. Contralateral P1 amplitudes measured at PO7/PO8.

* indicates significant t-test at 0.05 level after B-H correction.

Figure 5. ERP plot of N2pc component at lateral parietal electrode (PO7/PO8) showing main effects of laterality and cue-type, and laterality x cue-type interaction, collapsed across visual field.
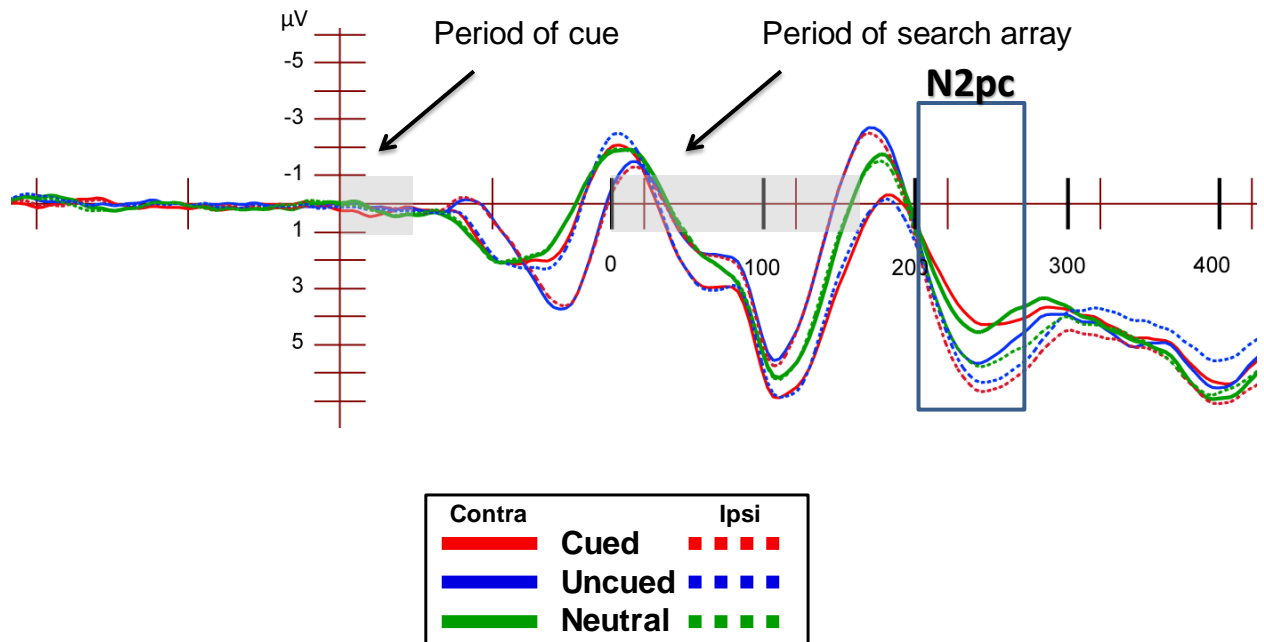
Figure 6a**.** ERP plot of N2pc difference waves (contralateral minus ipsilateral) at lateral parietal electrode (PO7/PO8) collapsed across visual field. Dotted lines indicate the average onset latency for each conditions' N2pc, evaluated using the jackknife method.
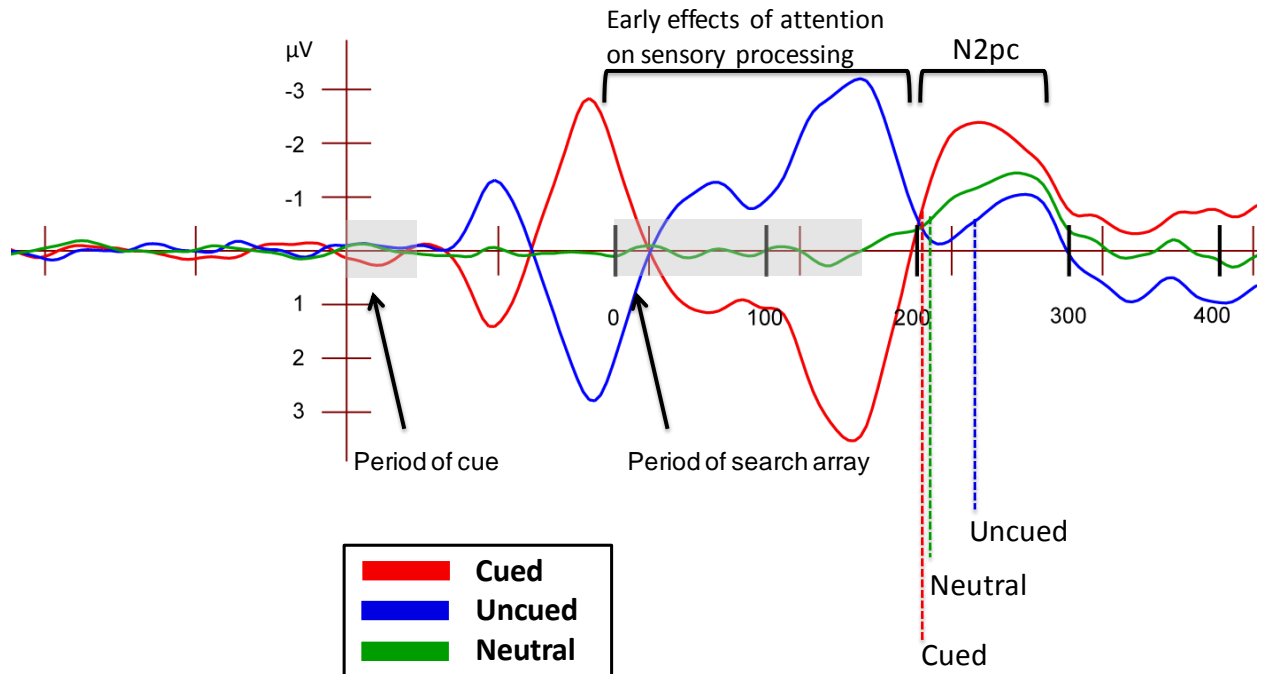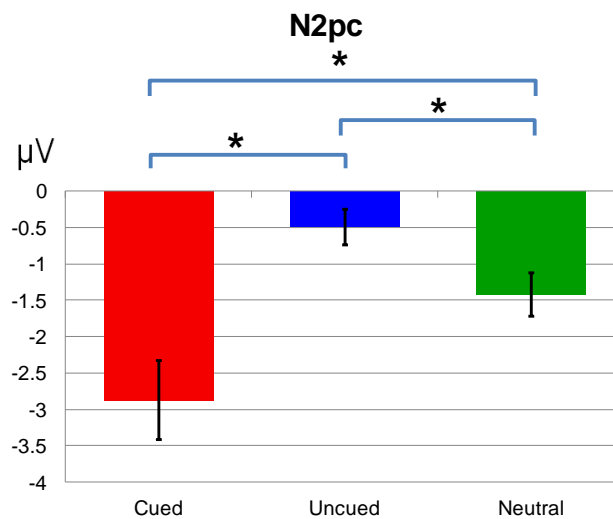

Figure 6b. N2pc difference wave amplitudes (contralateral minus ipsilateral) for the three conditions, collapsed across visual field.

* indicates significant t-test at 0.05 level after B-H correction.

Figure 7a. ERP plot of Uncued-Cued IIN difference wave at a lateral parietal electrode (PO7/PO8) collapsed across visual field, ipsilateral to the target's visual field (i.e. PO7 for left visual field targets and PO8 for right visual field targets).

Figure 7b. Topography of ipsilateral activity for both uncued and cued targets during the peak window of the IIN.

Figure 8a. ERP plot of Neutral-Cued IIN difference wave at a lateral parietal electrode (PO7/PO8) collapsed across visual field, ipsilateral to the target's visual field (i.e. PO7 for left visual field targets and PO8 for right visual field targets).
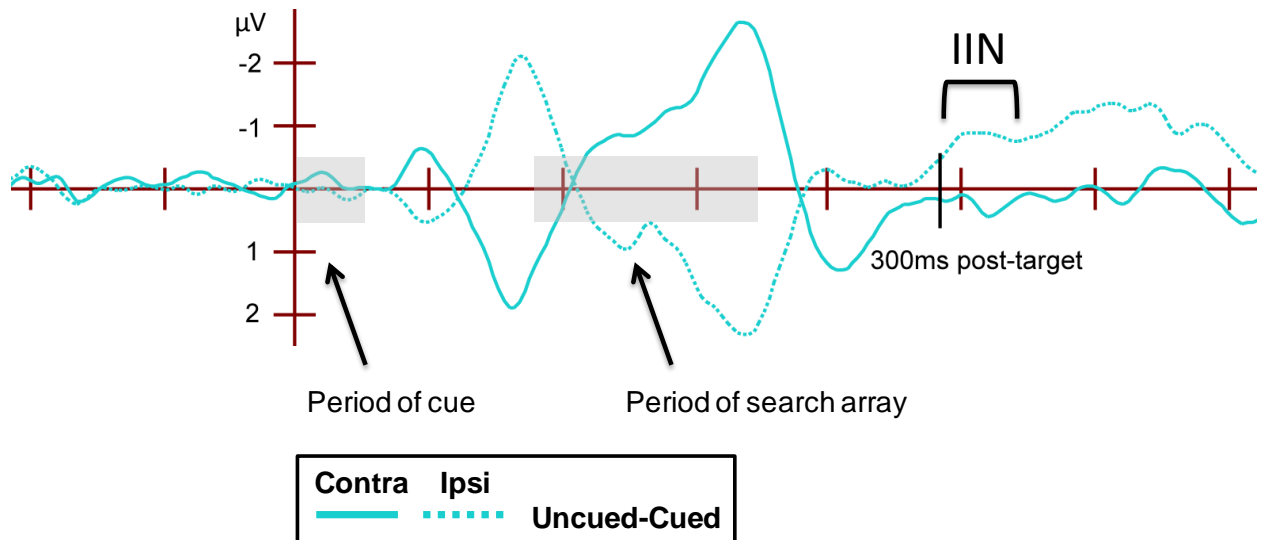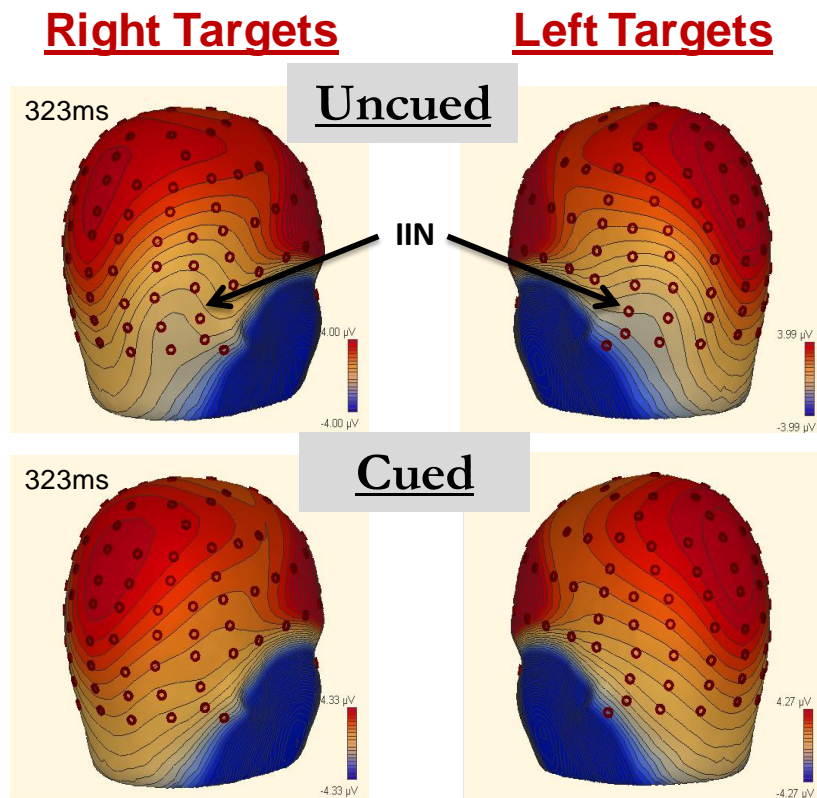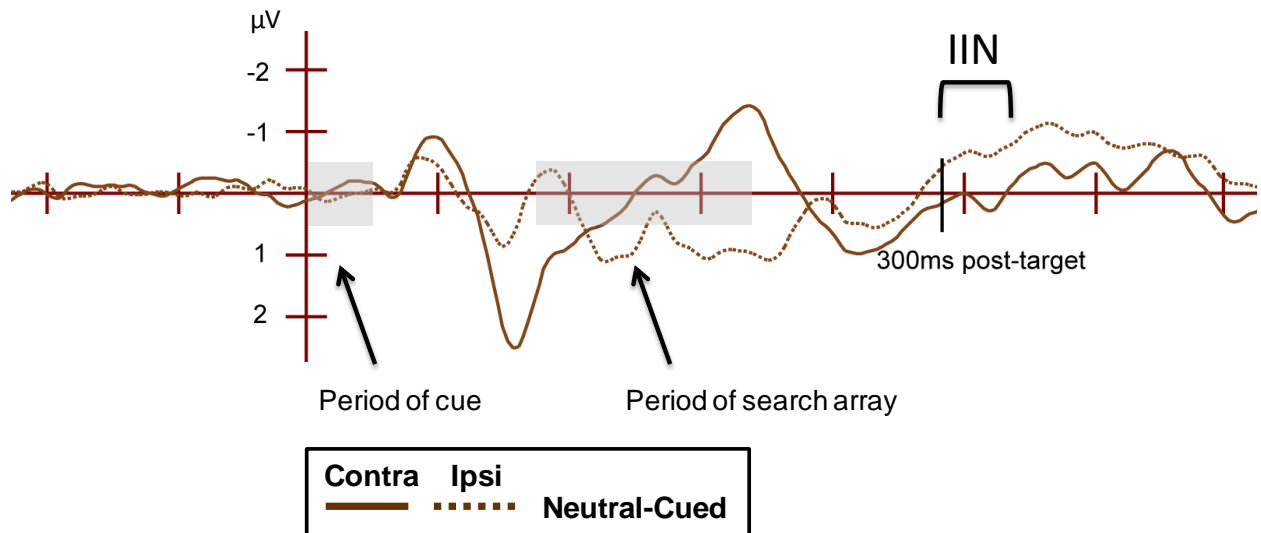

Figure 8b. Topography of ipsilateral activity for both neutral and cued targets during the peak window of the IIN.

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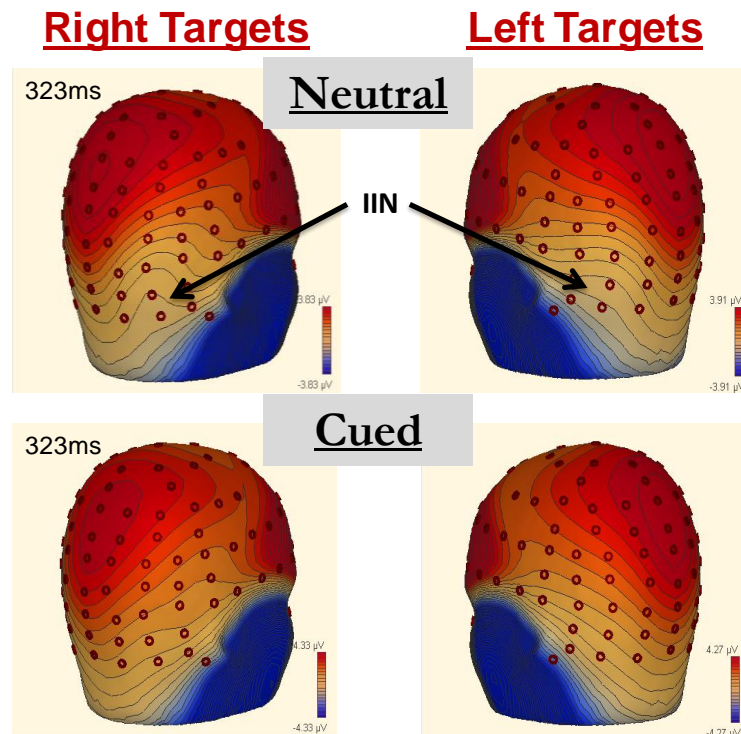
Figure 9a. ERP plot of P4pc difference waves (contralateral minus ipsilateral) at lateral parietal electrode (PO7/PO8) collapsed across visual field.
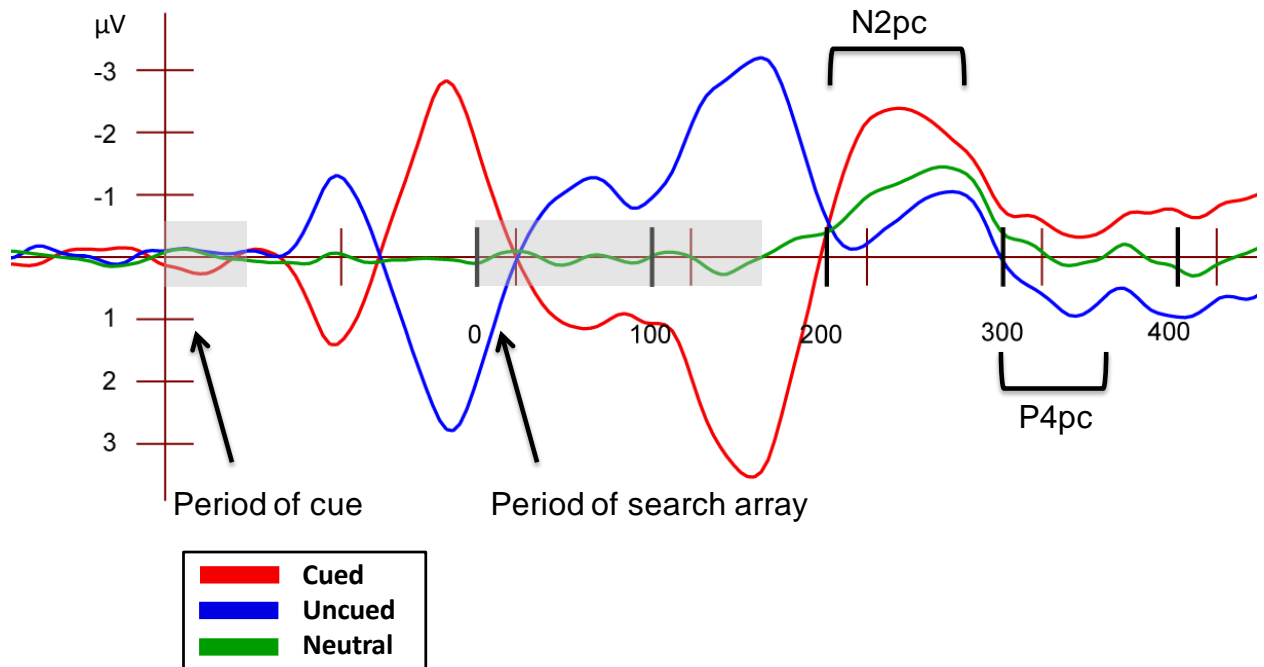
Figure 9b. P4pc difference wave amplitudes (contralateral minus ipsilateral) for the three conditions, collapsed across visual field. A significant positive difference (P4pc) was only observed in the uncued condition.
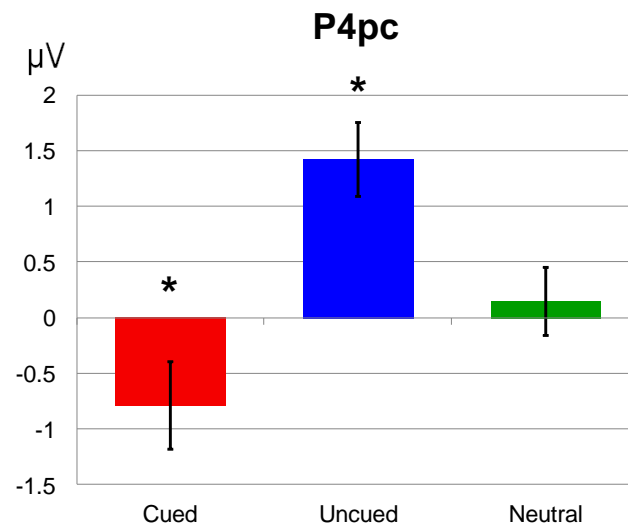
* indicates significant t-test at 0.05 level after B-H correction.

Figure 10a. ERP plot of anterior parietal electrode (P1′/P2′) showing P300 effects collapsed across visual field.
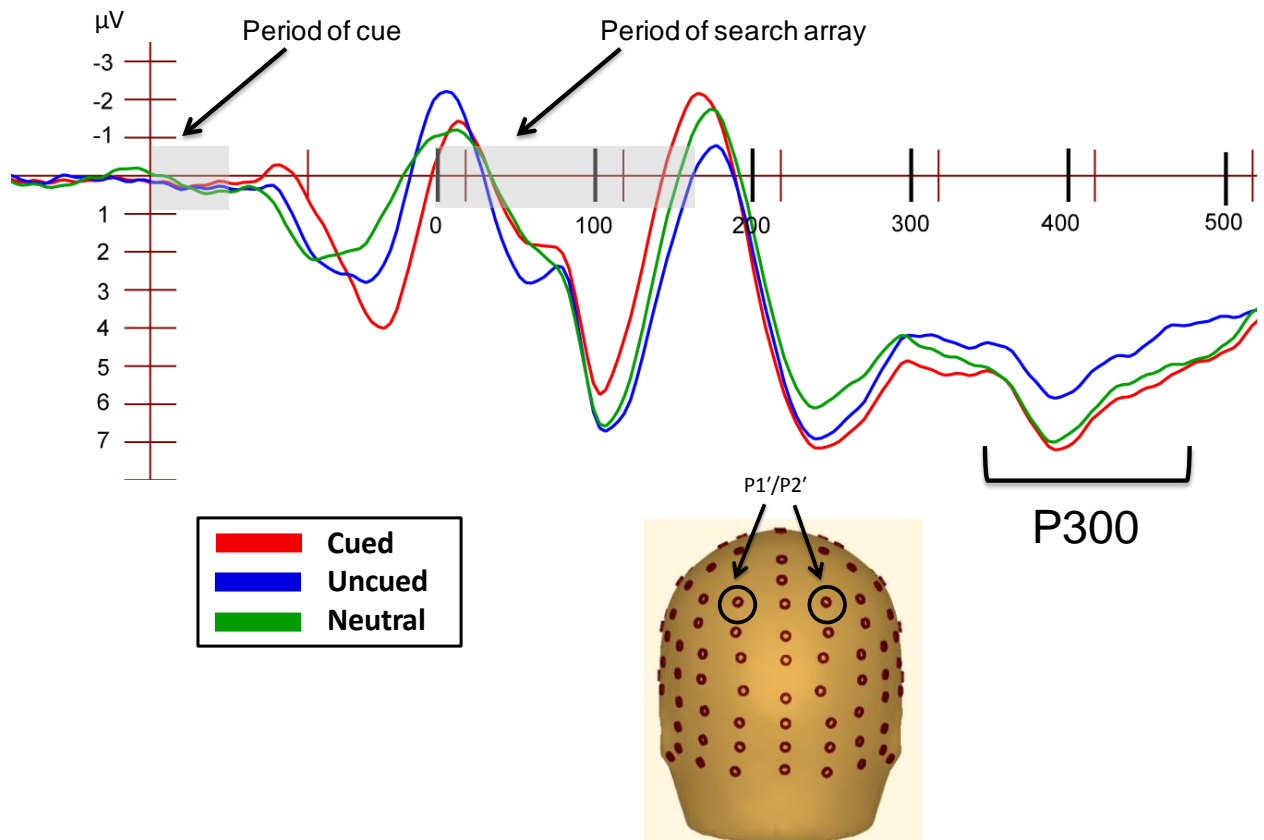
Figure 10b. P300 amplitudes collapsed across visual field.
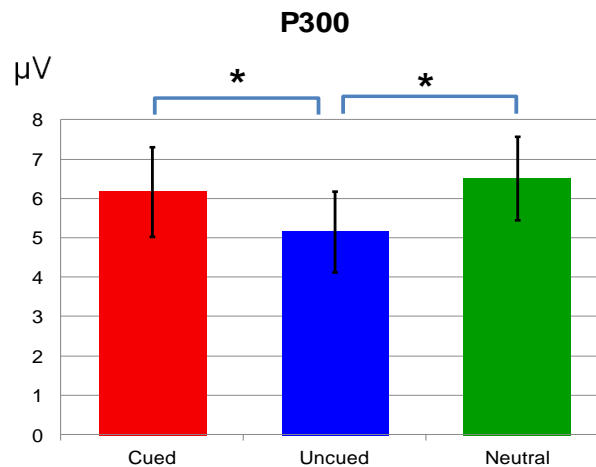
* indicates significant t-test at 0.05 level after B-H correction

Figure 11. Topographic maps during peak IIN latency showing bilateral activity in the neutral condition only.

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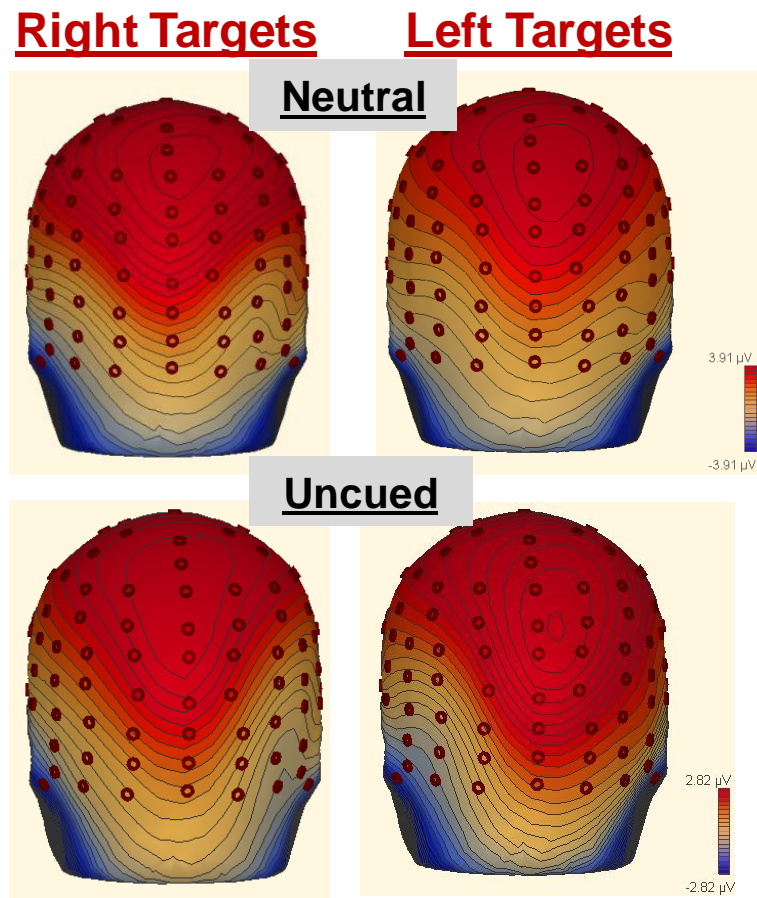
APPENDIX A: Cognitive Failures Questionnaire

The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to your in the past 6 months. Please circle the appropriate number.

		Very often	Quite often	Occasionally	Very rarely	Never
1.	Do you read something and find you haven't been thinking about it and must read it again?	4	3	2	1	0
2.	Do you find you forget why you went from one part of the house to the other?	4	3	2	1	0
3.	Do you fail to notice signposts on the road?	4	3	2	1	0
4.	Do you find you confuse right and left when giving directions?	4	3	2	1	0
5.	Do you bump into people?	4	3	2	1	0
6.	Do you find you forget whether you've turned off a light or a fire or locked the door?	4	3	2	1	0
7.	Do you fail to listen to people's names when you are meeting them?	4	3	2	1	0

		Very often	Quite often	Occasionally	Very rarely	Never
8.	Do you say something and realize afterwards that it might be taken as insulting?	4	3	2	1	0
9.	Do you fail to hear people speaking to you when you are doing something else?	4	3	2	1	0
10.	Do you lose your temper and regret it?	4	3	2	1	0
11.	Do you leave important letters unanswered for days?	4	3	2	1	0
12.	Do you find you forget which way to turn on a road you know well but rarely use?	4	3	2	1	0
13.	Do you fail to see what you want in a supermarket (although it's there)?	4	3	2	1	0
14.	Do you find yourself suddenly wondering whether you've used a word correctly?	4	3	2	1	0
15.	Do you have trouble making up your mind?	4	3	2	1	0
16.	Do you find you forget appointments?	4	3	2	1	0

		Very often	Quite often	Occasionally	Very rarely	Never
17.	Do you forget where you put something like a newspaper or a book?	4	3	2	1	0
18.	Do you find you accidentally throw away the thing you want and keep what you meant to throw away – as in the example of throwing away the matchbox and putting the used match in your pocket?	4	3	2	1	0
19.	Do you daydream when you ought to be listening to something?	4	3	2	1	0
20.	Do you find you forget people's names?	4	3	2	1	0
21.	Do you start doing one thing at home and get distracted into doing something else (unintentionally)?	4	3	2	1	0
22.	Do you find you can't quite remember something although it's "on the tip of your tongue"?	4	3	2	1	0
23.	Do you find you forget what you came to the shops to buy?	4	3	2	1	0

		Very often	Quite often	Occasionally	Very rarely	Never
24.	Do you drop things?	4	3	2	1	0
25.	Do you find you can't think of anything to say?	4	3	2	1	0

APPENDIX B: Pilot experiments

We conducted two behavioral studies prior to conducting the above ERP study in order to test the cued visual search paradigm design to first, see if the expected behavioral cuing effect would indeed occur in this novel design, and second, determine whether or not the presence of so many cue-only trials (30%) that did not require a manual response might increase reaction time variability within the responses of the participants. The only difference between the two experiments was whether or not participants were required to make a "target-absent" decision response.

Participants

Seventeen healthy adults participated in both pilot studies after giving informed consent. In the three-response version (pilot A), 2 participants were excluded due to extremely low accuracy (i.e. less than 50% accuracy for at least one condition within a block), indicating a lack of participation. In the two-response version (pilot B), one participant was excluded due to experimenter error (ran the same block twice), and one was excluded due to extremely low accuracy rates, resulting in a total of fifteen participants in each of the experiments. All participants were right-handed, with 20-20 or corrected to 20-20 vision and without a history of psychiatric illness, neurological disorder or incident (such as concussion) and received course credit as compensation for their participation.

Materials and Procedures

The experimental stimuli, conditions, task and timing of stimuli presentation were identical to those used in the main ERP study described previously with the following exceptions. Just as in the ERP study, in pilot A, participants were instructed to make a third

"target-absent" response for trials in which the cue was not followed by the target array. In pilot B, participants were not instructed to make this third response, but were told to withhold from making any button pushes, and simply wait for the next trial to begin. In both pilot experiments, 8 blocks of trials were conducted following a practice block, for a total of 96 trials in each of three target-present conditions (cued, uncued and neutral) and 96 target-absent trials, with 32 trials for each cue-type (right, left and central). As the pilot studies were conducted to collect behavioral measures only (reaction times and accuracies), no EEG data was collected or analyzed.

Results

Pilot A (3 responses): Behavioral results (Reaction times and accuracies)

For target-present trials, reaction times (RT) for correct responses and accuracy percentages were each submitted to a 3x2 repeated measures ANOVA with cue-type (cued, uncued, neutral) and target-side (right, left) as factors. For RT, the ANOVA revealed a significant main effect of cue-type ($F(2,28)=9.08$, $p=0.002$). There was no main effect of target-side ($F(1,14)=3.14$, $p=0.10$) nor any interaction between cue-type x target-side ($F(2,28)=0.32$, $p=0.73$). Post-hoc paired t-tests exploring the main effect of cue-type, with RTs were averaged across both visual fields revealed that, identical to the results later found in the ERP version of the experiment, participants were significantly faster responding to targets at cued locations as compared with those at uncued locations (Cued: $M=662$ms, $SE=15$ms; Uncued: $M=680$ms, $SE=16$ms; $t(14)=3.42$, $p=0.004$). Differing from the later ERP experiment results was evidence showing that participants were also significantly faster responding to targets at neutrally-cued locations as compared with those at uncued locations

(Neutral: M=668ms, SE=16ms; Uncued: M=680ms, SE=16ms; t(14)=3.35, p=0.005), and there was no significant difference between RTs in the cued and neutral conditions (t(14)=1.46, p=0.17). There were no significant effects of cue-type or target-side, nor any interactions on accuracy (cue-type: F(2,28)=1.38, p=0.27; target-side: F(1,14)=2.14, p=0.17; cue-type x target-side: F(2,28)=1.63, p=0.21).
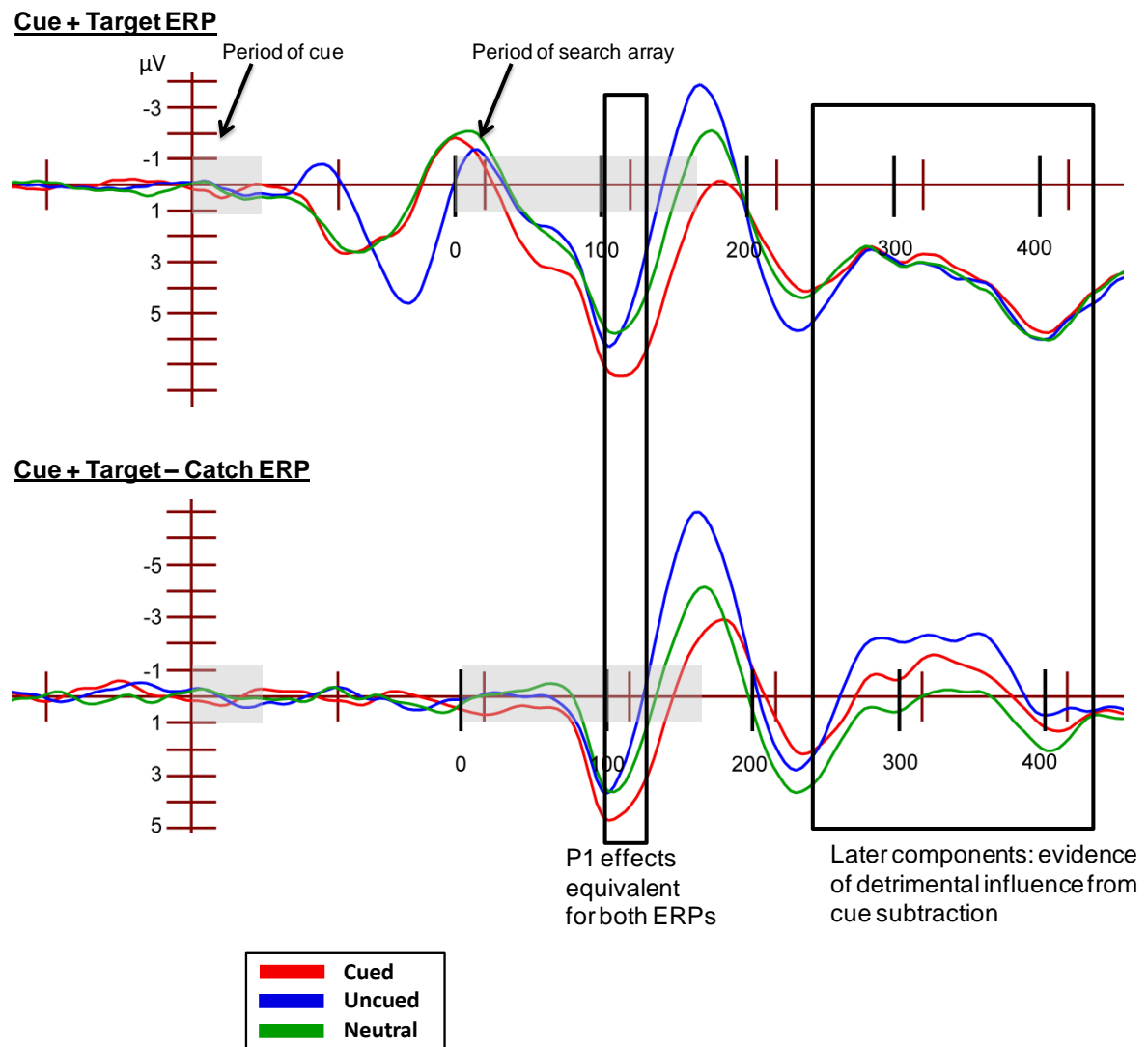
Pilot B (2 responses): Behavioral results (Reaction times and accuracies)

Unlike the results found in pilot A, those found in pilot B were identical to those later found in the ERP experiment. For RT, the 3x2 repeated measures ANOVA with cue-type (cued, uncued, neutral) and target-side (right, left) as factors revealed a significant main effect of cue-type (F(2,28)=9.25, p=0.002), no main effect of target-side (F(1,14)=0.08, p=0.78) nor any interaction between cue-type x target-side (F(2,28)=1.46, p=0.25). Post-hoc paired t-tests again indicated that participants were significantly faster responding to targets at cued locations as compared with those at uncued locations (Cued: M=608ms, SE=17ms; Uncued: M=626ms, SE=19ms; t(14)=4.75, p<0.001). Participants were also significantly faster responding to targets at cued locations as compared with those at neutrally-cued locations (Cued: M=608ms, SE=17ms; Neutral: M=627ms, SE=16ms; t(14)=3.62, p=0.003), and there was no significant difference between RTs in the uncued and neutral conditions (t(14)=0.24, p=0.81). There were no significant effects of cue-type or target-side, nor any interactions on accuracy (cue-type: F(2,28)=0.46, p=0.64; target-side: F(1,14)=4.00, p=0.07; cue-type x target-side: F(2,28)=1.37, p=0.27).

Discussion

    In both pilot experiments, we found behavioral evidence that reflexive attentional

capture by an onset cue can cause either improvement or impairment of target selection

during visual search. The results from the three-response version (pilot A) suggest the cue

resulted in an attentional cost (i.e. significant difference between unattended and neutral

conditions; Mangun & Buck, 1998), but no benefits. These results conflict with those found

in the later the ERP version of the experiment, in which the results suggest that the cue

provides an attentional benefit (i.e. a difference between attended and neutral) but no cost.

The results from the two-response version (pilot B), however, were identical to those later

found in the ERP experiment. Given that both versions revealed that the paradigm

successfully reveals effects of reflexive attentional capture on visual search, the three-

response version was chosen due to the fact that it resulted in smaller standard errors, and

allowed for the comparison of reaction times in cue-only trials.

APPENDIX C: Comparison of cue-locked ERPs with and without catch trials subtracted out.

Cue + Target ERP

Cue + Target – Catch ERP

P1 effects
equivalent
for both ERPs

Later components: evidence
of detrimental influence from
cue subtraction

Cued
Uncued
Neutral

APPENDIX D: ANOVA tables for ERP component statistics

P1 (with cue activity)

Source	SS	df	MS	F	p	Partial η2
TarSide	70.93	1	70.93	1.23	0.285	0.08
Condition	190.18	2	95.09	22.90	0.000*	0.60
TarSide x Condition	1.44	2	0.72	0.31	0.735	0.02

P1 (without cue activity)

Source	SS	df	MS	F	p	Partial η2
TarSide	126.01	1	126.01	3.19	0.094	0.18
Condition	73.11	2	36.55	12.88	0.000*	0.46
TarSide x Condition	3.72	2	1.86	1.01	0.376	0.06

IIN (ipsilateral electrodes)

Source	SS	df	MS	F	p	Partial η2
TarSide	27.21	1	27.21	3.63	0.076	0.19
Condition	20.29	2	10.15	5.64	0.008*	0.27
TarSide x Condition	0.12	2	0.06	0.06	0.941	0.00

IIN (contralateral electrodes)

Source	SS	df	MS	F	p	Partial η2
TarSide	70.57	1	70.57	4.97	0.041*	0.25
Condition	5.81	2	2.90	1.87	0.172	0.11
TarSide x Condition	0.16	2	0.08	0.05	0.948	0.00

N2pc

Source	SS	df	MS	F	p	Partial η2
TarSide	9.62	1	9.62	1.98	0.180	0.12
Laterality	121.17	1	121.17	29.07	0.000*	0.66
Condition	38.07	2	19.03	4.53	0.019*	0.23
TarSide x Laterality	27.13	1	27.13	1.07	0.318	0.07
TarSide x Condition	2.56	2	1.28	0.94	0.403	0.06
Laterality x Condition	46.01	2	23.00	14.99	0.000*	0.50
TarSide x Laterality * Condition	9.96	2	4.98	12.89	0.000*	0.46

P4pc

Source	SS	df	MS	F	p	Partial η2
TarSide	81.78	1	81.78	4.43	0.053	0.23
Laterality	5.74	1	5.74	1.25	0.281	0.08
Condition	45.73	2	22.86	7.21	0.003*	0.32
TarSide x Laterality	5.74	1	5.74	1.25	0.281	0.08
TarSide x Condition	16.39	2	8.19	3.39	0.047*	0.18
Laterality x Condition	10.08	2	5.04	10.62	0.000*	0.41
TarSide x Laterality * Condition	10.08	2	5.04	10.62	0.000*	0.41

ANOVA tables for ERP component statistics (continued)

P300

Source	SS	df	MS	F	p	Partial η2
TarSide	2.14	1	2.14	0.18	0.677	0.01
Condition	31.91	2	15.95	12.36	0.000*	0.45
TarSide x Condition	0.25	2	0.13	0.13	0.880	0.01

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