

THE TIME COURSE OF ATTENTIONAL SELECTION: AN ERP INVESTIGATION

By Anthony P. Drew

The N2pc ERP component has been associated with the deployment of visual attention to regions in visual space (Luck & Hillyard, 1994a, Luck & Hillyard, 1994b). Several hypotheses have been advanced regarding what specific aspect of spatially deployed attention the N2pc reflects (Luck & Hillyard, 1994b; Kiss, Velzen, & Eimer, 2008; Tan & Wyble, 2014). One such hypothesis posits that the component reflects the localization of, or orientation to, relevant information in space in preparation of enhancement of sensory processing. In support of this hypothesis, previous research has demonstrated that the N2pc component is eliminated for a target if this target follows a second target in the same location, as a second localization process is unnecessary (Tan & Wyble, 2014). Other research provides evidence that is incongruent with the localization hypothesis. Specifically, a cue that precedes a target in the same location does not eliminate the N2pc for that target, as is predicted by the localization hypothesis (Kiss, Velzen, & Eimer, 2008). However, this study used a cue that was presented 700ms prior to the onset of target information, which may be too large of a temporal window as suggested by contemporary models of attention (Wyble, Bowman, & Nieuwenstein, 2009). The current study tested this localization hypothesis by using a cue within the time course of theoretical models of attention (Wyble, Bowman, & Nieuwenstein, 2009; Olivers & Meeter, 2008; Nakayama & Mackeben, 1989). Analyses revealed that the N2pc elicited by a single target embedded in a stream of distractors is eliminated when preceded by a cue occurring 100ms prior to the target. These results support the hypothesis that the N2pc is elicited by, or after the process of localizing relevant visual information.

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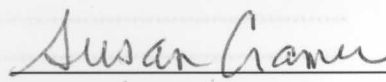
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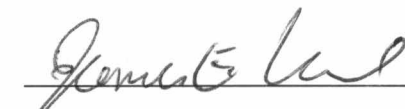
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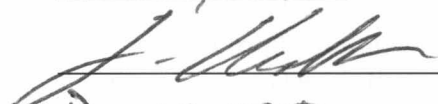
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The Time Course of Attentional Selection: An ERP Investigation

Human cognition is difficult to study, in part, because of the sheer amount of information that is constantly being processed. The construct of attention is required to build a clear understanding of what information the human cognitive system is likely to use in its computations that produce a psychological experience. This paper will discuss the conceptual role of attention, and will outline a body of electrophysiological research that examines neural responses to attending to visual information. First the paper will review a general framework for attention as a construct, then will discuss recent electrophysiological investigating an event related potential component called the N2pc. Finally it will present the results of a current experiment that examined the relationship between spatial functions of attention and the N2pc.

In order to respond to our environment, relevant sensory information must be selected and separated from the massive amount of input that strikes the sensory receptive organs. Human information processing relies on attention, a broad construct proposed to select and exclude information for processing. Attentional processes can be thought of as those selecting the sensory information that is relevant to current goal states and needed to coordinate a behavioral response within the physical constraints of the environment. Demands from the environment as well as internal drives influence these goal states and the deployment of attentional processes. In order to study attention, researchers use experimental task instructions to manipulate these goal states by pairing

the occurrence of stimuli with a behavioral response, such as when participants are asked to identify a target among a series of distracting stimuli by pressing a button. In short, attentional processes separate, prioritize, and deploy resources to extract and enhance information from the sensory environment relevant to performing behavior while excluding information that is irrelevant. This concept is known as selection-for-action (Allport, 1989).

Attention to specific sensory information can be influenced by both “bottom-up” and “top-down” factors. Bottom-up influences are stimulus-driven whereas top-down influences arise from the psychological state of the organism. Bottom-up processing, or exogenous processing, is largely reflexive and directs attention toward a demanding stimulus. An example of a bottom-up influence on attention is the “pop-out” effect. The “pop-out” effect refers to the ability to quickly attend to an item that substantially differs from a homogenous array of surrounding items or distracters (Treisman, 1988). The features of the item are so incompatible with the features of the surrounding items that the target “pops-out” to awareness effortlessly and involuntarily (See figure 1).

Attention is also influenced by “top-down” or endogenous factors. “Top-down” factors can be conceptualized as interactions between previously acquired knowledge, expectations, and currently held goals. These factors contribute to construct the attentional set, or strategy, through which sensory information is prioritized and interpreted. An example of the influence of “top-down” factors was demonstrated while studying forward-facing motion bias. Participants reported what they perceived as the direction of motion of an array of animal-like stimuli that were presented such that the

stimuli appeared to have moved but the direction of motion was ambiguous. Participants reported their perceived direction of movement as being consistent with the direction the stimuli were “facing” (McBeath, Morikawa, and Kaiser, 1992). This bias in perception represents an interaction between previously acquired knowledge about the direction that familiar objects typically move and the goal of determining the direction of movement for the current stimuli.

Conceptually Parsing Attention

Attention is commonly conceptualized as multiple cooperating systems rather than a single unified construct. Posner & Petersen (1990) proposed a model of three systems that act together to facilitate information selection, processing, and behavioral coordination. These systems are referred to as the Alerting System, Orienting System, and the Executive Control System. The following discussion on attention and its mechanisms is based largely on data from studies investigating attention in the visual and auditory modalities. Most research on attention is performed in the visual and auditory domains, such that understanding of attention is largely based on its actions in these sensory modalities.

Alerting. The Alerting system is an arousal based system that enhances or facilitates processing of target stimuli based on the occurrence of other stimuli occurring immediately prior to the target. For example, a signal that reliably indicates the onset of a target induces a preparation state and can be observed as a reduction in a participant’s reaction time in a visual discrimination task. (Posner, 1978). If a researcher measured

EEG activity from electrodes placed at frontal sites during this period between warning signal and target, then a negative shift in EEG amplitude would likely be observed occurring roughly 100ms after the onset of the warning signal (Luck, 2005). This deflection, known as the Contingent Negative Variation (CNV), is elicited when participants are required to attend to a warning signal and report the following target, but not if participants are required to ignore both the signal and a subsequently presented target. This negativity is proposed to be reflective of activation associated with preparation for the upcoming target stimulus (Posner, 1978; Petersen & Posner, 2012).

However, this facilitation of processing due to a warning signal can come at a cost in situations in which the intensity of bottom-up information is sufficiently high. Lawrence and Klein (2011) found a trade-off manifesting in improved reaction time (decreased) to targets but decreased accuracy when a warning signal of greater than baseline intensity (in this case volume of an auditory signal) reliably signaled the onset of a target in a visual discrimination task. The warning signal facilitated the behavioral response by reducing the time it took to coordinate and execute the behavior but at the cost of accurately representing the stimuli. Alerting is proposed to reduce the threshold needed to make a behavioral response such that behaviors can be executed more quickly, but is not thought to accelerate the analysis of sensory information. Even though behaviors can be executed more quickly, the information seems to be processed at the same rate (Lawrence & Klein, 2011; Posner, 1978).

Research investigating the neurological correlates of the alerting system has largely focused on neurotransmission, specifically the role of Norepinephrine in

facilitating responses to targets that are preceded by warning signals (Petersen & Posner, 2012; Posner & Petersen, 1990). Cells in the locus coeruleus that produce norepinephrine are active when participants attend to warning signals prior to targets, and facilitation effects manifested in behavior due to warning signals can be attenuated with norepinephrine antagonists.

Orienting. The Orienting System is proposed to be responsible for the localization of relevant information in space. It deploys processes to select sensory information collected from specific areas in the visuospatial environment. This system determines the spatial locus of attention at a given time and information collected from this locus is more elaborately encoded than information collected from regions falling outside this locus (Posner, 1980; Posner & Petersen, 1990, Petersen & Posner, 2012; Klein & Lawrence, 2012). The deployment of attention to a particular region in visual space may induce or require the coordination of sensory effectors to direct the sense organs to that space. For example, to visually orient to a stimulus the eyes must engage in a saccade toward the stimulus, and accommodate to place the stimulus in the field of view corresponding to the fovea. This region of the retina is densely populated with cone photoreceptors and provides the greatest visual acuity. Spatially specific information processing coupled with this direction of physical structures is called overt attention and is often studied in the context of involuntary saccadic action in response to stimuli (Klein & Lawrence, 2012).

Visual attention also facilitates extraction of information from the environment in the absence of physical movement of the eyes. That is to say that information that strikes

the retina but does not fall within the foveal region can be attended to as well. This is called covert attention and is a commonly experienced phenomenon, represented by the well-known phrase “looking out of the corner of the eye.” Covert attention is most often studied using paradigms that ask participants to maintain fixation at a particular location while attending to stimuli that fall outside of their fixation. For example, a paradigm referred to as the spatial cueing design required participants to fixate on a cross in the center of a screen while stimuli were briefly presented in the participants’ left or right visual field. These stimuli were preceded by cues that provided accurate (valid) or inaccurate (invalid) information about the possible location of the target stimulus. When cues were valid (the cue provided accurate information), faster reaction times for target identification as well as greater target accuracy was observed (Posner, 1980; Posner, Nissen & Ogden, 1978). The valid cue enabled attention to efficiently orient to the location of the target stimulus when that stimulus fell in the same region that had been cued. When cues were invalid (the cue provided inaccurate information), participants demonstrated slower reaction times to targets and decreased target accuracy (Posner, Nissen & Ogden, 1978). In these trials the cue was again a signal for attention to orient to a specific location in the visual field, but the location did not hold the target information. The interference from this cue prevented attention from efficiently orienting to the correct location of the target information. In these experimental situations the cue has oriented attention to a particular region in space to enhance the processing of information coming from that region. When orientation occurs to a region containing task relevant information, improved performance is observed, but when orientation occurs to a region

that does not contain task relevant information decreased performance is observed. In this latter example of the invalid cue, attention is not able to efficiently select the relevant information because that information does not fall within the region of enhanced processing.

The neural underpinnings of the orienting system have been primarily studied through individuals who suffered parietal lobe damage due to brain injury. This system appears to involve activity in the posterior parietal lobe, the pulvinar nucleus of the thalamus, the superior colliculus, and the frontal eye fields (Posner & Petersen, 1990; Petersen & Posner, 2012). Damage to posterior parietal areas is associated with a deficit in disengaging from a currently attended stimulus to orient to a new target stimulus that falls in the portion of the visual field contralateral to the damage. Lesions in the pulvinar are associated with a deficit in orienting to a target stimulus that is contralateral to the damage when there is distracting information that occurs ipsilateral to the damage. Damage to the superior colliculus is associated with slowed attentional shifting and the lack of any facilitation effect of cueing attention to a target location prior to target onset. Damage to this area is also associated with a tendency for attention to return to the location of recent targets as readily as to the locations of new targets (Posner & Petersen, 1990; Petersen and Posner, 2012). In most humans a phenomenon known as inhibition of return prevents this from occurring (Rafal, Calabresi, Brennan, & Sciolto, 1989). The differential functions of these brain areas seem to indicate that the Orienting System may be further parsed into sub-systems.

Executive Control. Posner & Petersen (1990) proposed a third attention system that they named Executive Control. This system provides top-down parameters that determine what sensory information is relevant and what information is irrelevant. The Executive Control System is also called a focal or conscious attention system and is conceptualized as a central detection mechanism that directs conscious awareness to selected information. Research has demonstrated that a detriment in processing occurs across many sensory domains during and immediately following the process of visual target detection (Posner & Peterson, 1990; Peterson & Posner, 2012; Posner, 1978). This has been interpreted to support the notion that executive control is not modality specific; that a central and unified mechanism is involved in the process of target detection regardless of the sensory source of the information. Experimental evidence has further supported the idea of a central detection system by demonstrating that participants' performance decreases in a visual task when completing a simultaneous auditory task (Posner, Sandson, Dhawan, & Shulman, 1989). In this experiment executive processes were committed to one task such that attempting to attend to another task resulted in decreased performance both within and across sensory modalities.

The executive control system is thought to involve the anterior cingulate cortex and medial frontal cortex. Imaging data has shown that activation in these areas are greater for target stimuli than for distracting stimuli, and for errors than for correct responses (Posner & Petersen, 1990; Petersen & Posner, 2012). These findings have been interpreted as evidence of a central attention system that is involved in making target discriminations and monitoring behavioral output.

Studies using neuroimaging techniques have provided evidence for a division in the executive control system. Specifically, short-lived activation in lateral regions in the frontal and parietal areas has been shown to be associated with participants beginning sets of similar trials and is thought to reflect an adaptive and short-lived enforcement of the task dimensions that define relevant information. An example of these task demands may be the establishment of a number as a target among a stream of letter distractors. Sustained activation in medial regions has been shown to be associated with participants completing trials across multiple trial conditions with differing target parameters and is thought to reflect more stable maintenance of global task dimensions such as sitting at a computer and making button/key press responses over an extended period of time (Dosenbach et al., 2006; Dosenbach et al., 2007). These results have been interpreted as reflecting two separable systems exerting top-down control. One system acts to enforce short term and less stable task instructions while the other acts to maintain more global behavioral routines such as sitting at a computer and engaging in multiple different kinds of tasks over an extended period of time.

Sustained and Transient Attention. Another theoretical division of attention has been proposed by Nakayama and Mackeben (1989). These researchers dichotomized spatially selective visual attention into a sustained component and a transient component based on the results of a series of conjunctive visual search experiments. Conjunctive visual search tasks involve detecting whether a target was present among a heterogeneous array of distractors that differed by two features such as color and orientation (See Figure 2). These search tasks are facilitated by deploying attention to a specific region of the

visual field containing target information (Treisman & Gelade, 1980). Participants' target detection accuracy for conjunctive search increased in a condition that used a box to outline the exact location of a target stimulus at all times during the block of trials (sustained cue), relative to a no cue condition in which no information was provided about the location of the target. The sustained cue enabled a specific region of the visual field to be attended to prior to target onset, and performance increased.

This same pattern of results was found in an experiment in which no cue occurred but participants were instructed as to the location of the target in advance and that the target would occur at that location on every trial. These sustained cue and self-direction conditions demonstrated the commonly experienced form of spatial attention that the researchers labeled sustained attention. The enhanced performance in the sustained cue and self-direction conditions were interpreted as evidence of participants voluntarily maintaining the deployment of attention at a specific location over the course of the trial. The results from these sustained cueing and voluntary self-direction conditions suggested the sustained component of attention is largely voluntary and relatively long-lived as compared to the transient component (Nakayama & Mackeben, 1989).

In further experiments the same researchers provided evidence of a second component of attention that occurs quickly and outside of the control of participants, labeled as transient attention. In another series of experiments researchers manipulated the Stimulus Onset Asynchrony (SOA) of a cue and target. That is to say they manipulated the amount of time that the cue occurred before the target stimulus. This transient cue provided valid information about the location of an imminent target at

unpredictable SOAs. Participants displayed a marked rise in target detection accuracy in a conjunctive visual search for SOAs up to 50ms. Accuracy performance plateaued at SOAs longer than 50ms up to 200ms then displayed a marked fall in detection accuracy. For cues presented at SOAs within this window (50-200ms) accuracy performance remained optimal. Furthermore, this pattern of facilitation in response to cues was present even when the participants were aware the target would occur at the same location on every trial. The authors interpreted these findings as evidence of a transient attentional component that involuntarily enhances a perceptual experience in response to a cue and is relatively short-lived (~50-200ms). This enhancement occurs above and beyond effects due to the voluntary direction of the sustained attentional component to the same region in space (Nakayama & Mackeben, 1989).

Contemporary Models of Attention

The goal of studying attention is ultimately to construct a model that represents and quantifies all the variables in a proposed attention system. The validity of the model can then be tested empirically. Attention as a construct is defined functionally. That is to say one defines the functions that attention is completing and the constraints under which it must operate. For example, a participant is presented with a single letter on a computer screen for 100ms, followed by a masking stimulus that eliminates any residual retinal processing of the letter. After the presentation the participant is able to reliably make a correct identification of the letter. In this instance attention completed the function of selecting the stimulus information, the letter, and thus allowed it to be processed to the

point at which a behavioral response could be made. This selection must have occurred in 100ms or less because the letter information was no longer physically available after this time frame. In this way researchers explicitly lay out the actions that attention as a construct is engaging in and manipulate physical constraints such as the time certain information is available to sensory processing. By tracking human performance in a variety of experimental situations researchers can begin to establish the parameters of particular variables, such as the optimal time course of attentional selection, and map these in relation to other variables such as stimulus specific factors like luminance or contrast to develop a model that explains experimental findings.

An example of a current model of attention is the Episodic Simultaneous Type/Serial Token Model (eSTST). This model is based upon the results of numerous experiments testing human performance in Rapid Serial Visual Presentation (RSVP) tasks. In RSVP tasks participants are asked to attend to streams of rapidly presented stimuli (each stimulus presented for approximately 100ms) and to make responses at the end of these streams based on the presence (or absence) of one or more target stimuli presented within the stream. For example a participant may be asked to identify a number amidst a rapid stream of letters. The eSTST model utilizes a specific paradigm using an RSVP stream with two potential targets called the Attentional Blink paradigm. The Attentional Blink (AB) design is constructed to observe and study a detriment to processing occurring in the window of roughly 200 to 500ms (blink window) following the presence of a target stimulus in a RSVP stream (Raymond, Shapiro, & Arnell, 1992). If a second target is presented in the RSVP stream after the first within this blink window

lasting roughly 300ms, that target will likely not be perceived and therefore not be reported. Another interesting characteristic of AB experiments is a phenomenon called Lag-1 sparing. Lag-1 sparing refers to the correct report of the second target in an RSVP stream of an AB experiment if it immediately follows the first target (Lag position 1). The two components that characterize the Attentional Blink are sparing in the accuracy of reporting the second target if it immediately follows the first target, coupled with the relatively poor accuracy in reporting the second target if it is presented within the blink window of approximately 200 to 500ms following the first target. Typically one will observe a U shaped pattern of results when target two accuracy is plotted by serial position relative to the first target. This U shaped pattern is characteristic of results from AB experiments (See figure 3).

A traditional interpretation of the AB posits a limited processing resource that is exhausted by the selection of the first target, in the case of Lag 1 sparing the second target is thought to occur quickly enough to take advantage of these processing resources before they are exhausted (Raymond, Shapiro & Arnell, 1992; Duncan, Ward & Shapiro, 1994). This interpretation has been challenged by more contemporary models such as the eSTST that cite results from studies in which sparing is achieved for up to four subsequent targets in an RSVP stream. In this case researchers used a modified AB experiment with four sequentially presented targets rather than two. Participants were able to accurately report the identities of subsequent targets even though several targets fell into the blink window initiated by the first target (Wyble, Potter, Bowman, & Nieuwenstein, 2011; Wyble, Bowman, & Nieuwenstein, 2009). The eSTST posits that

attention acts to enhance relevant information within a time course of approximately 150ms after the onset of this information. This enhancement mechanism, referred to as the Blaster, is triggered by the onset of relevant information (i.e. the first target) and each subsequent target excites the Blaster and maintains this state of enhanced processing for the attended information. In this way the Blaster continues to enhance sensory information and the identities of several targets can be perceived with little difficulty. If there is no relevant information to re-excite the Blaster it is then suppressed for the period of time it takes the selected information to be encoded into working memory. During this suppression the identities of any potential targets that may be presented during the blink are likely to not be perceived, and this results in the Attentional Blink.

The eSTST proposes that this suppression (blink) has an adaptive function in maintaining temporal distinctiveness for relevant information. The temporal distinctiveness of any target in an AB paradigm is threatened by the fact that lag-1 sparing is often accompanied by errors in the order that the two targets are reported (Akyurek & Hommel, 2005). This proclivity to commit temporal errors is interpreted in the eSTST as the cost of maintaining the excitation state of the Blaster. The Blaster is able to enhance processing for multiple subsequent targets but at the cost of temporal distinctiveness for the targets (Wyble, Potter, Bowman & Nieuwenstein, 2011). The blink period reflects a suppression of the Blaster to promote accurate perception of temporal order for relevant information presented in the immediate future.

The eSTST is framed through a *types and tokens* perspective. This model uses different types of nodes, or points within a conceptual system, to represent cognitive

events associated with certain stages of processing. Activation of type nodes in the model reflect earlier more sensory processes whereas activation and maintenance of token nodes in the model reflect processing in working memory. The Blaster acts to enhance specific type node activation such that the information is selected to be encoded into a token node that is then maintained in working memory (see figure 4).

Another computational model of attention, the Boost and Bounce, is similar to the eSTST in that it also posits an enhancement of relevant information, in this case by a mechanism called a Boost (Olivers & Meeter, 2008). This boost peaks approximately 100ms after the onset of relevant information and reflects the recruitment of additional attentional processing. In the case of AB experiments the boost is triggered by the first target, but the time course of this enhancement is such that it is still enhancing sensory information when subsequent stimuli occur. If this stimulus is a distractor the irrelevant information triggers another response, known as a Bounce, which provides inhibition of sensory information. This bounce reflects a reduction of available processing resources for a brief period. The interaction between the enhancement of the boost and the suppression of the bounce results in the successful processing of the first target but the failure to process any targets following the first target and at least one distractor, the results characteristic of Attentional Blink experiments.

The Boost and Bounce model is framed through a *gating* perspective. That is the boost opens the gate and allows relevant sensory information to be encoded into working memory, whereas the bounce closes the gate and prevents irrelevant information from being encoded into working memory.

Both the eSTST and Boost & Bounce models of attention propose a spatially specific enhancement mechanism that occurs within the first 150ms after target onset. This time course is remarkably similar to that of the hypothesized transient component of attention observed from experiments using spatially informative cues by Nakayama and Mackeben (1989). The current study examines this enhancement effect and its association with electrophysiological markers of spatially deployed attention.

Electrophysiology and Attention

Electrophysiological techniques have been used extensively in humans to compare conditions in which attention is differentially deployed. An EEG records voltage changes at the surface of the cortex that are thought to be associated with post-synaptic neural activity (Luck, 2005). A specific technique of EEG recording, known as the Event Related Potential (ERP) technique, records EEG activity and is time-locked to a specific stimulus presentation. By averaging waveforms from many presentations of the same stimulus type researchers can get a clear picture of the electrophysiological activity occurring during the cognitive activities associated with that stimulus. ERP waveforms are categorized by their charge and their temporal position relative to stimulus onset. For example, a waveform called the P1 is a positive change in electrical potential and occurs approximately 100ms after the onset of a stimulus and the N2 is a negative change in electrical potential that occurs approximately 200ms after the onset of a stimulus (See figure 5).

The ERP technique is well suited for studying attention because attention can be manipulated through task instructions and changes in the electrophysiological response to the same stimulus can be observed. These changes reflect an influence of attention on the processing of that stimulus. Attention and other top-down factors have variable influences on different ERP components. Early components appear to be relatively immune to the effects of attention. For example, the C1 component, a change in voltage occurring approximately 40 to 60ms after stimulus onset, is a deflection in EEG activity that can be either positive or negative and occurs at posterior electrode sites along the midline of the scalp. This component is most sensitive to the location of stimuli in the visual field and physical characteristics of the stimuli such as contrast but is not sensitive to direction of visual attention (Luck, 2005). As the time after stimulus onset increases more cognitive actions associated with that stimulus are occurring and later ERP components reflect this by being sensitive to top-down influences. For example, the P3 component has been observed to be much larger for stimuli presented to an unpredictable modality than for stimuli whose presentation was predictable (Sutton, Braren, Zubin, & John, 1965). The knowledge about what specific ERP components reflect can be used to guide the selection of an ERP component to test cognitive theories making temporal claims about information processing. The current study is designed to measure the N2pc component in an attempt to examine the time course of attentional selection of visually presented target stimuli.

The N2pc is an ERP component that has been shown to reflect spatially selective attention (Eimer, 1996). That is to say N2pc amplitude has been shown to be sensitive to

stimuli defined as targets presented in specific regions of the visual field. This component occurs approximately 250ms after the onset of a stimulus that is being attended to and can be measured as a difference between posterior sites on the scalp (see figure 6). Specifically, amplitude measured at the site contralateral to the visual field containing the target stimulus is reliably more negative than amplitude measured at the site ipsilateral to the visual field containing the target (Luck & Hillyard, 1994a; Luck & Hillyard, 1994b). The N2pc is measured by subtracting the average activity of the ipsilateral posterior site within a specified window from the average activity of the contralateral posterior site within this window. This type of ERP waveform is called a difference wave.

Theoretical Interpretation of the N2pc

Early interpretation of the N2pc posited it as reflecting simply some aspect of spatially deployed attention (Luck & Hillyard, 1994a; Luck & Hillyard, 1994b; Luck, 2005). In one experiment designed to elicit the N2pc, researchers manipulated whether a unique stimulus (pop-out stimulus) among a group of homogenous distracters was defined as a target or not. The N2pc for target pop-out stimuli was larger than for non-target pop-out stimuli (Luck & Hillyard, 1994a). The same researchers tested a more specific hypothesis that posited the N2pc as reflecting a suppression of irrelevant information during the course of encoding the sensory information associated with the target stimuli. In one experiment an N2pc was observed for a unique target among homogenous distracters, and for a unique stimulus that shared physical features with the target but was in fact a distracter. No N2pc was observed for a unique stimulus that did

not share features with a target and was easy to differentiate from a target. The authors interpreted this as the N2pc reflecting a spatially specific analysis of potentially relevant information because an N2pc was observed when participants observed relevant information or stimuli that shared features with relevant information. In a later experiment the researchers added a condition in which the target was not surrounded by distracters. No N2pc was found for targets when they were not spatially surrounded by distracters. These results further support the hypothesis that distracting information is inhibited during the process of encoding relevant information and that the N2pc reflected this inhibition (Luck & Hillyard, 1994b).

Another hypothesis posited the N2pc may reflect the deployment of attention to a specific region in space in order to select relevant information from that region. This hypothesis arose from speculation based on other ERP components that are associated with preparatory shifts of attention to spatial locations that are expected to hold target information (Eimer, Van Velzen, & Driver, 2002). It was hypothesized that the N2pc may reflect a similar mechanism involved in orienting attention to specific spatial locations based on the expected presence of a target. Specifically, the N2pc in this case may reflect the orientation to, or localization of, relevant information in the visual field (Kiss, Velzen, & Eimer, 2008; Tan & Wyble, 2015). To test this localization hypothesis, researchers used a centrally presented cue 700ms prior to target onset. On the first half of the trials the cue reliably indicated the location of target information and oriented attention to a specific location in which the target was expected to occur. The second half of the trials used a cue that occurred prior to the target but offered no information about

the location of the upcoming target such that orienting to the location of the cue was not a reliable way to complete the trial. The N2pc elicited by targets was observed to be the same for trials in which attention was validly cued to orient to a location prior to the onset of a target and for trials in which the cue did not provide information about the location of the upcoming target (Kiss et al., 2008). This finding was interpreted as evidence that the N2pc did not reflect a spatial orientation/localization process but reflected some selection process that occurred after attention had successfully located the target information.

Other researchers explored this localization hypothesis by constructing an experiment using two lateralized RSVP streams. Two targets were presented in subsequent order in these streams and could either be presented in the same stream or different streams. Participants were required to report the identity of both targets. If the N2pc reflected localization of relevant information in space, and two subsequent targets occurred in the same location a second N2pc should not be observed. The second N2pc component should not be observed because attention has already localized the specific region in space that holds the relevant information. If other relevant information falls in this space within the time frame of attentional selection, then this new information should not require its own localization process. The results demonstrated that when the two subsequent targets were presented in the same location a second N2pc did not occur for the second target. If the second target was presented at the different location than the first a second N2pc was observed for the second target (Tan & Wyble, 2015). In this case attention had to orient to, in other words localize information at, a second location in

order to select the relevant information and as such a second N2pc was elicited. These findings were interpreted as support for the hypothesis that the N2pc reflects localization of relevant information in visual space prior to processes that engage in enhancing the sensory information associated with the target. If the N2pc reflected processes involved in enhancing target information such that it could be maintained in working memory and reported, a second N2pc would be expected to occur even when two subsequent targets occurred in the same location.

The Current Study

The proposed study seeks to examine the localization hypothesis by using a cue to direct attention to orient to a specific location prior to the onset of a target. If the N2pc reflects localization of attention to relevant information for enhancement, then triggering that process prior to the occurrence of a target should eliminate the N2pc for that target. In the current study the time course of the cue will reflect the proposed time course of enhancement proposed in the eSTST, Boost & Bounce, and transient attention models. Kiss et al. (2008) found that a cue did not eliminate the N2pc for a target but used a cue with an SOA of 700ms. The time course of this cue is confounded with the time it takes for attention to localize to a region in space for selection of information. 700ms overreaches the theoretical window of enhancement proposed by contemporary models of attention. For instance, Tan and Wyble (2014) propose that by separating two targets with sufficient time a second localization process may occur for the second target. In the case of Kiss et al. (2008), the SOA between cue and target was too long to maintain the

enhanced state of sensory processing, and so attention likely deployed again to localize the target even though it was cued. A cue presented at 100ms prior to the target should act to trigger the enhanced attentional state and maintain that state until the target occurs. If the N2pc reflects localization then one crucial hypothesis can be drawn for the results of the proposed study. That is when a cue occurs shortly before a target, no N2pc should be observed for that target. Attention has already been oriented to that region to enhance the incoming information from that space, such that the occurrence of the target should not trigger another orientation process. The current study will use a valid cue 100ms prior to a target in one of two simultaneous RSVP streams. Trials in which a cue precedes a target will be compared with trials in which no cue precedes a target to determine if the N2pc is eliminated for a target if a cue occurs prior to it, within the time course of theoretical attentional enhancement. If an N2pc is observed for non-cued targets but is not observed for cued targets, then this provides support for the localization hypothesis. Given this finding a further examination of the localization hypothesis will be conducted by measuring the N2pc time locked to cues in cued trials. If the N2pc reflects localization then an N2pc should be observed for cues as they signal the onset of the localization process.

Definition of Variables. Both independent variables have two levels. The first independent variable is presence of target: (1.) Target present (2.) Target absent; and the second independent variable is presence of cue: (1.) Cue present (2.) Cue absent. There are two dependent variables. The first dependent variable is mean amplitude of the N2pc for targets and the second is mean amplitude of the N2pc for cues (See figure 7).

Hypothesis 1. If the N2pc occurs for target information then an N2pc should be elicited by the presentation of a non-cued target but should not occur in trials in which no target and no cue is presented. Specifically the mean voltage difference in the target-designated epoch for non-cued target trials should be greater (larger negative voltage) than in the target-designated epoch in the no cue and no target trials.

Hypothesis 2. If the N2pc reflects a localization process, then using a spatially informative valid cue prior to the onset of a target, within a time frame proposed as a window of involuntary attentional enhancement, should eliminate the N2pc for the cued target as compared to a non-cued target. Specifically the mean voltage difference in the target-designated epoch for non-cued targets should be greater (larger negative voltage) than in the target-designated epoch for cued targets.

Hypothesis 3. If the N2pc reflects a localization process then an N2pc should be observed when a cue is presented to signal attention to orient to a region of the visual field. Specifically the mean voltage difference in the cue-designated epoch for cued trials should be greater (larger negative voltage) than in the cue-designated epoch for non-cued trials.

Summary

The current study seeks to investigate the time course of attentional selection and to test a hypothesis regarding a common electrophysiological tool in researching spatial attention. The N2pc has been associated with the deployment of attention to regions in visual space (Luck & Hillyard, 1994a, Luck & Hillyard, 1994b). Several hypotheses have

been advanced regarding what specific aspect of spatially deployed attention the N2pc reflects (Luck & Hillyard, 1994b; Kiss, Velzen, & Eimer, 2008; Tan & Wyble, 2015).

One such hypothesis posits that the component reflects the localization of relevant information in space in preparation of enhancement of sensory processing (Tan & Wyble, 2015) and the current study seeks to test this hypothesis by using a cue within the time course of theoretical models of attention (Wyble, Bowman, & Nieuwenstein, 2009; Olivers & Meeter, 2008; Nakayama & Mackeben, 1989).

Methods

Participants

Forty three undergraduate and graduate students from the University of Wisconsin Oshkosh were recruited to participate in the study. Undergraduates were awarded course credit for their participation. Graduate students volunteered in response to email recruitment. Recruitment of undergraduates was done via the University's online subject pool. Participants were required to have normal or corrected-to-normal vision.

Paradigm

The experiment consisted of 10 practice trials followed by 300 experimental trials. Stimuli in all trials were presented in two simultaneous RSVP streams, both to the left and right of a fixation cross presented in the middle of the screen. For each trial the two streams (to the left and right of fixation) consisted of 20 stimuli per stream, and each stimulus presented for 100ms. The streams were followed by a response screen asking the participants to report whether a red target number had been presented, and if so to specify its identity. The streams were presented 3 visual degrees from center fixation and participants were approximately 25 inches from the screen resulting in an approximate viewing angle of 1.15 x .75 degrees.

In one half of trials a single colored target digit was presented in one of the two streams. The target could be presented in either the left or right stream, counterbalanced between trials. The remaining (distractor) stimuli were randomly drawn black letters and

the same letter was not allowed to occur successively. The target appeared in serial position 5, 10 or 15 within each RSVP stream, counterbalanced between trials by conditions. Each trial began with a fixation cross presented in the center of the screen at a variable length of time prior to the onset of the RSVP streams (300, 500, or 700ms counterbalanced between trials by conditions). A target was presented on one half of the trials. A cue was presented on one half of the trials in which a target was presented, and half of the trials in which no target was presented. To cue on trials in which a target was present a red box outlined the space in which the target would occur. The cue was presented 100ms prior to target onset and persisted through the presentation of the target resulting in a cue duration of 200ms. To cue on trials in which the target was absent the cue was presented in one of the streams 100ms prior to the distractor stimuli presented in serial position 5, 10, or 15 (corresponding to the serial positions of targets in target present trials) and lasted 200ms (the same duration as cues when targets occur) (see Figures 9-12 for illustrations of a trial in each condition and see figure 8 for a breakdown of the number of trials by condition).

Stimuli and Apparatus

Letter (distractor) characters were displayed in black and digit (target) characters were red in color (255, 0, 0 in RGB colorspace). The letters E, I, O, B, Z, and S were not included because they resemble digits. Stimuli were displayed on a gray background (128, 128, 128 in RGB colorspace) with Psychology Software Tools' E-Prime 2.0

Professional on Windows XP. Stimuli were presented using a 30 inch CRT monitor with a 100HZ refresh rate.

EEG Recording

Electrophysiological data was collected using a Biopac MP150 unit with EEG 100C amplifiers with a sampling rate of 500Hz, a gain setting of 10,000, a bandpass filter of 0.1-35Hz, and a 60Hz notch filter. The Acqknowledge software package was used to record, graph, and average the electrophysiological data. Electrooculographic data was recorded using an EOG100C amplifier with a gain setting of 2,000, a bandpass filter of .05-35Hz, and a notch filter of 65Hz.

Procedure

Upon arrival to the study all participants were first given informed consent and were provided the opportunity to ask any questions before commencement of the experiment. After informed consent was obtained, the researcher then measured the participants' scalp to identify proper placement of electrodes and abraded the skin with a Q-tip and NuPrep Skin Prep Gel (Weaver and Company) at sites corresponding to P3 and P4 according to the international 10-20 system (Jasper, 1958) (See figure 6), as well as a grounding site on the forehead and a reference site on the left earlobe. Gold plated single disc electrodes (Natus Neurology) were then filled with Ten20 Conductive electrode paste (Weaver and Company) and were firmly pasted to sites P3 and P4 and a grounding electrode was pasted to the center of the forehead. A gold plated electrode ear clip (Natus

Neurology) was used for the reference electrode and was filled with Signa Electro-Gel (Gel101) and attached to the left earlobe. 4mm EOG electrodes were then filled with Signa Electro-Gel (Gel101) and taped into place above and below the left eye. Electrode impedance was observed for each electrode with a Checktrode device (Checktrode UFI model 1089ES) to ensure impedance of below 5Ω . If impedance was not below 5Ω , reapplication of the compromised electrode was made until the standard was met. Once proper impedance had been reached the participant was then seated 25 inches in front of the stimulus display monitor. Once the EEG set up was complete participants completed demographics questions pertaining to their age, gender and whether their vision was normal or corrected-to-normal. Participants then completed a practice block of 10 trials that was not included in the analysis prior to completing the 300 experimental trials that was used for data analysis. For each trial, participants were instructed to maintain fixation on the cross in the middle of the screen throughout the length of the trial. They were told that they would see many trials each of which consisted of two laterally presented streams of letters. On some of the trials a single colored number would appear, and some of the time a cue would precede the location of the target. Participants were also instructed that on some trials a cue may inform them of the location of a potential upcoming target and that the target may not occur but if it did it would always occur in the location of the cue. At the end of each trial, the participant was to report the identity of a target if it occurred, or to report that no target occurred. Reporting was made by means of a button press using the right number pad on a standard computer keyboard (Keys 1-9 were used to report target identities, the 0 key was used to report a no target

trial). Participants were instructed to enter the target only if they were sure of its identity and were instructed not to respond if they were unsure of the identity of the target. (See figures 9 – 12 for illustrations of sample trials from each condition).

Averaging the N2pc

Electroencephalograph data was only analyzed from trials in which the target was correctly identified. EOG activity was removed prior to averaging with a command built into the Acqknowledge software package. Additionally, trials were removed by means of manual artifact rejection by visually identifying any trial in which EEG activity exceeded one volt above or below baseline, and/or any trial in which visible EOG activity indicated eye movement within a window defined as 500ms prior to target onset to 500ms following target onset. For each correct trial, data were extracted within a window of 1000ms (200 pre-stimulus, 800 post-stimulus) for each participant. A baseline correction was then made by subtracting the pre-stimulus baseline activity from the post-stimulus activity. Average amplitude was then obtained from epochs that were defined as 144-244ms after stimulus onset for target N2pc measurements, or 146-246ms after stimulus onset for cues N2pc measurements (or the stimuli that occurred in the corresponding serial positions for trials in which no cue or target occurred). The process of defining these epochs is described below. Voltage from the electrode site ipsilateral to the location of the presented target and cue was then subtracted from voltage from the electrode site contralateral to the location of the presented target and cue to compute the N2pc (mean amplitude difference) on a trial by trial basis and were then averaged across all trials for

each of the four conditions (Cue Absent Target Absent (NCNT), Cue Absent Target Present (NCT), Cue Present Target Present (CT), and Cue Present Target Absent (CNT)) for both cues and targets.

N2pc for Target. The grand average waveform (across all participants) for the NCT condition was used to define the epoch of measurement for targets in all conditions. This condition was used as it was designed to elicit a baseline N2pc for a solo target. To define this epoch the peak contralateral negative value was identified in a liberal window (150-300ms after stimulus onset). Then the epoch for targets was defined as occurring 50ms prior to and 50ms following this peak of contralateral negativity. This resulted in a measurement epoch of 144-244ms after stimulus onset. This epoch was used to measure the N2pc for targets in all conditions, as the NCT condition represents the only trials in which a target is designed to elicit an N2pc without influence from a cue.

To compute the N2pc for targets, average amplitude during the baseline corrected epoch at the electrode ipsilateral to target presentation was subtracted from average amplitude during the baseline corrected epoch at the electrode contralateral to target presentation to obtain difference scores. For trials in which no target occurred the same baseline corrected epoch was measured following the stimulus in the serial position corresponding to that of the target (5, 10, 15). See Figures 13-16 for the plotted waveforms for targets for each condition.

N2pc for Cue. The grand average waveform (across all participants) for the CNT condition was used to define the epoch of measurement for cues in all conditions. This condition was used as it was designed to elicit a baseline N2pc for a solo cue. To define

this epoch the peak contralateral negative value was identified in a liberal window (150-300ms after stimulus onset). Then the epoch for cues was defined as occurring 50ms prior to and 50ms following this peak of contralateral negativity. This resulted in a measurement epoch of 146-246ms after stimulus onset. This epoch was used to measure the N2pc for cues in all conditions, as the CNT condition represents the only trials in which a cue is designed to elicit an N2pc without influence from a target.

To compute the N2pc for cues, average amplitude during the baseline corrected epoch at the electrode ipsilateral to cue presentation was subtracted from average amplitude during the baseline corrected epoch at the electrode contralateral to cue presentation to obtain difference scores. For trials in which no cue occurred the same baseline corrected epoch was measured following the stimulus in the serial position corresponding to that of the cue onset (4, 9, 14). See Figures 17-20 for the plotted waveforms for cues for each condition.

Results

Behavioral Data

Descriptives. Data were analyzed from the 14 participants whose electrophysiological data was used for analysis. Behavioral accuracy was sufficiently high across conditions (all above 97%). See Table 1 for the mean accuracy and standard deviation for each condition.

Electrophysiological Data

Descriptives. Sixteen participants were removed from analysis due to a malfunction in the EOG electrodes that occurred during the electrophysiological recording sessions. Six participants were removed from analysis because they were identified as outliers in that their behavioral accuracy was substantially lower than all other participants. Three participants were removed from analysis due to excessive artifacts or other noise in their EEG signal resulting in too few trials for data analysis. Three participants were removed from analysis due to excessive movements during the experiment and one participant was removed due to impedance readings above 5Ω . In total fourteen participants were included in the analysis of electrophysiological data. See Tables 2 and 3 for mean N2pc amplitude, for targets and cues respectively, and standard deviations for each condition.

Inferential Analyses. One-Way repeated measures ANOVA was conducted to observe the pattern of differences in N2pc amplitude for targets across the four conditions

(NCNT, NCT, CT, CNT). The omnibus test indicated that there were significant differences between conditions, $F(3, 39) = 10.26, p < .01$. Pairwise comparisons indicated that the NCT condition produced a significantly larger contralateral negative response than the NCNT condition, $t(13) = 3.5, p < .01$, demonstrating that the paradigm was successful in eliciting an N2pc for target stimuli. Pairwise comparisons also revealed that the NCT condition produced significantly larger contralateral negative activity than the CT condition, $t(13) = 4.25, p < .01$, indicating that the N2pc elicited by a solo target stimuli is attenuated when the target is preceded by a cue. The N2pc for targets in the CT condition did not differ from the N2pc for targets in the NCNT condition, $t(13) = .4, p = ns$. This finding suggests that the N2pc for a target is fully eliminated when the target is preceded by a cue. See Tables 4 and 5 for results of the omnibus test and pairwise comparisons respectively.

One-Way repeated measures ANOVA was also conducted to observe the pattern of differences in N2pc amplitude for cues across the four conditions (NCNT, NCT, CT, CNT). The omnibus test indicated that there were significant differences between conditions, $F(3, 39) = 21.327, p < .01$. Pairwise comparisons indicated that the CNT condition produced a significantly larger contralateral negative response than the NCNT condition, $t(13) = 5.667, p < .01$, demonstrating that the paradigm was successful in eliciting an N2pc for cue stimuli. Pairwise comparisons also revealed that the CT condition produced significantly larger contralateral negative activity than the NCNT condition, $t(13) = 2.25, p < .05$ indicating that the N2pc elicited by a cue is still present when a target is presented immediately after the cue. Interestingly, the CNT condition did

produce more contralateral negative activity than the CT condition, $t(13) = 3.5$, $p < .01$.

See tables 6 and 7 for results to the omnibus test and pairwise comparisons respectively.

Discussion

The current study was designed to test the hypothesis that the N2pc component reflects the localization of relevant information in space, prior to the selection of that information for maintenance and coordination of behavior. This has been referred to as the localization hypothesis.

Eliciting the N2pc

Hypothesis 1 was proposed to determine whether the experimental paradigm was successful in eliciting the N2pc component. The N2pc has been demonstrated to be elicited by target information when attention has been deployed to a lateral portion of the visual field in which a target resides. (Luck, 1996). Given the manner in which the N2pc has been classically elicited, a comparison of the N2pc for targets between the NCNT and NCT conditions should reveal a difference in contralateral negativity, and demonstrate that the N2pc was elicited. The repeated measures ANOVA indicated that there was indeed significantly more contralateral negativity in the NCT condition as compared to the NCNT condition. This finding suggests that the paradigm used in the current study was successful in eliciting the N2pc for correctly identified target stimuli.

Additionally, the logic of hypothesis 1 can be applied to N2pc measurements for cues to determine if the paradigm elicited an N2pc in response to cues. A comparison of the N2pc for cues between the CNT condition and the NCNT condition should reveal a

difference in contralateral negativity, and demonstrate that the N2pc was elicited for cues. The repeated measures ANOVA indicated that there was indeed significantly more contralateral negativity in the CNT condition than in the NCNT condition. This finding suggests that the paradigm used in the current study was successful in eliciting the N2pc for cue stimuli. This finding is interesting, as the N2pc has classically been shown for stimuli that are to be attended to, and that require a behavioral response. The fact that a cue that does not require attending or a subsequent behavioral response, but still elicits an N2pc provides support for the notion that the N2pc reflects a process that is not directly linked to the selection of specific target information. This finding is the first piece of evidence in support of the localization hypothesis.

Response to Target

According to contemporary attention theory, target information triggers a rapid and short-lived enhancement of the processing of sensory information from the region in space that contains the target information. This target information is then selected over other information in visual space and maintained in working memory, and can then be used to coordinate a behavioral response (Wyble, Bowman, & Nieuwenstein, 2009). Prior to the enhancement and selection of target information, that information must be localized in visual space. That is to say that the particular region of the visual field that the relevant information falls in must be identified in order to selectively process the relevant information over other information occurring at different locations in the visual field. The current study tested the hypothesis that the N2pc component reflects a process

that engages in the localization of this relevant information. Hypothesis 2, was formed as the first critical test of the localization hypothesis. The pattern of results obtained from the repeated measures ANOVA demonstrated that the N2pc elicited by a solo target was significantly larger than the N2pc elicited by a target that was preceded by a cue. Indeed, there was no indication of contralateral negativity for trials in the CT condition as the mean difference score was positive. This suggests that the N2pc for targets was fully eliminated, rather than simply attenuated, by presenting a cue 100ms prior to the target.

The findings of the current study regarding the target elicited N2pc are consistent with that of previous work by Tan and Wyble (2015) finding support for the localization hypothesis. Previous research has shown that if two targets occur in the same location, only the first elicits an N2pc. The current study resolves a confound in this previous work by using a cue and a target presented in the same location rather than two targets. Contemporary attention theory proposes that target information begins an episode of attentional selection that lasts as long as relevant information is present (Wyble, Bowman, & Nieuwenstein, 2009). The use of two targets confounds this episode of selection with the localization processes required prior to selection. The use of a cue however does not require a selection process, but rather only localization. The use of a cue in this paradigm demonstrated that the localization process in isolation was enough to eliminate the N2pc for the subsequently presented target.

Response to Cue

Within the current experimental paradigm cues were presented 100ms prior to potential targets in order to direct attention to a particular region of space where a potential target may appear. Previous research has suggested that selection processes are most optimally engaged approximately 100-150ms after the onset of relevant information (Nakayama & McKebben, 1989). The cue, if presented, always occurred in the same location as the target and was the same color as the target. Participants were instructed that if a red box (cue) occurred it was signaling the location of a potential oncoming target. Hypothesis 3 was proposed to examine the electrophysiological response to cues. If a cue can elicit an N2pc this provides evidence supporting the localization hypothesis. Further, if a cue elicits an N2pc but a target preceded by a cue does not, this would provide stronger evidence that the N2pc does indeed reflect a localization process. The pattern of results obtained from the repeated measures ANOVA indicated that a solo cue did elicit its own N2pc. As discussed above, this is one point of evidence in favor of the localization hypothesis, as the N2pc was elicited by stimuli that do not require selection. The results also indicated that a cue presented prior to a target elicited an N2pc. As discussed above, a target that followed a cue did not elicit an N2pc. These findings converge to provide the greatest support for the localization hypothesis. An N2pc appears only to be elicited in response to a demand on attention to localize to a region of the visual field. If a region has already been localized when target information is presented in that region, then the target information does not elicit an N2pc.

It is important to note the time course of the cue-target presentations in the current study. Contemporary attention theories propose very rapid attentional mechanisms to explain findings in visual attention research (Nakayama & McKebben, 1989, Wyble, Bowman, & Nieuwenstein, 2009; Olivers & Meeter, 2008). If attention is acting rapidly to localize and select visual information, than it is likely that using longer cue-target onset asynchronies will produce different results. Specifically, with a long enough cue-target onset asynchrony one would expect the cue to initiate a localization process, and elicit an N2pc. Then, after a sufficient amount of time without onset of relevant information, this localization will end. A target presented in the same region as the cue after localization has ended would elicit its own N2pc, as it will likely require its own localization process. This sequence of events likely explains previous research that used cues to test the localization hypothesis, but found that a target elicited an N2pc even if preceded by a cue (Kiss, Velzen, & Eimer, 2008). This work used a cue-target onset asynchrony of 700ms, which may allow localization to occur, and then to end, prior to the onset of the target such that the target requires its own localization process and elicits its own N2pc.

Overview

The results from the current study indicate that an individual target embedded in an RSVP stream elicits an N2pc, and that this N2pc is eliminated when the target is preceded by a cue in the same location by 100ms. Further, the current study demonstrates that a cue itself elicits an N2pc, and that when a cue precedes a target in the same

location the N2pc occurs for the cue but not the target. Together these points of evidence converge to support the hypothesis that the N2pc reflects the localization of relevant information in visual space.

Future Directions

Several modifications to the paradigm used in the current study may allow future research to further elucidate the cognitive processes involved in eliciting the N2pc. The current study used a peripheral cue occurring in the same location as subsequent targets, to conceptually replicate the localization effects found in previous work (Tan & Wyble, 2015). A future experiment could explore whether cues presented at central fixation provide the same effect on the N2pc for targets. Trials could be manipulated to create a condition in which localization is triggered with a central cue, but there is no information in the region of the visual field to which localization has occurred. This would remove any confounding neural activity due to the selection processing of targets or inhibition processing of distractors in the periphery.

Future work could also manipulate the difficulty of the task in order to provide behavioral evidence that could support the localization hypothesis. The current study recorded behavioral accuracy and observed a marked ceiling effect. Perhaps making the cues and targets black, the same color as the distractors, would increase the difficulty such that enhanced accuracy could be observed in response to cues. Future researchers could also record more data from participants, such as reaction times and eye-movement over time to build a more complete picture of attentional responses to cues.

APPENDIX A

Figures

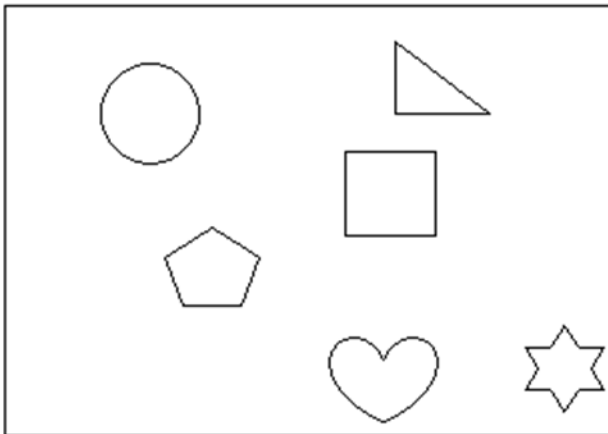
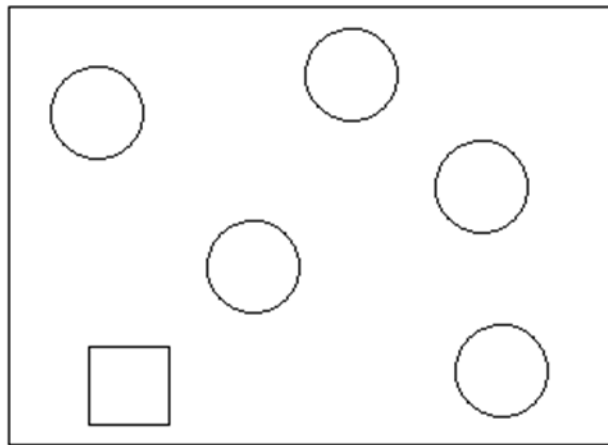


Figure 1. In a “pop-out” task participants are asked to press a button when they perceive the target, the square. In the trial represented by the upper portion of the figure the researcher would expect responses to be made with lower reaction times than in trials represented by the lower portion of the figure.

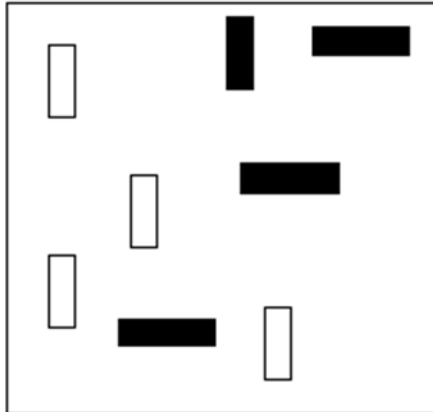


Figure 2. In conjunctive visual searches the target is defined as the stimulus that differs by two features, in this case color and orientation. White vertical bars and black horizontal bars are the distractors and the stimulus that breaks this pattern is the target. The black vertical bar.

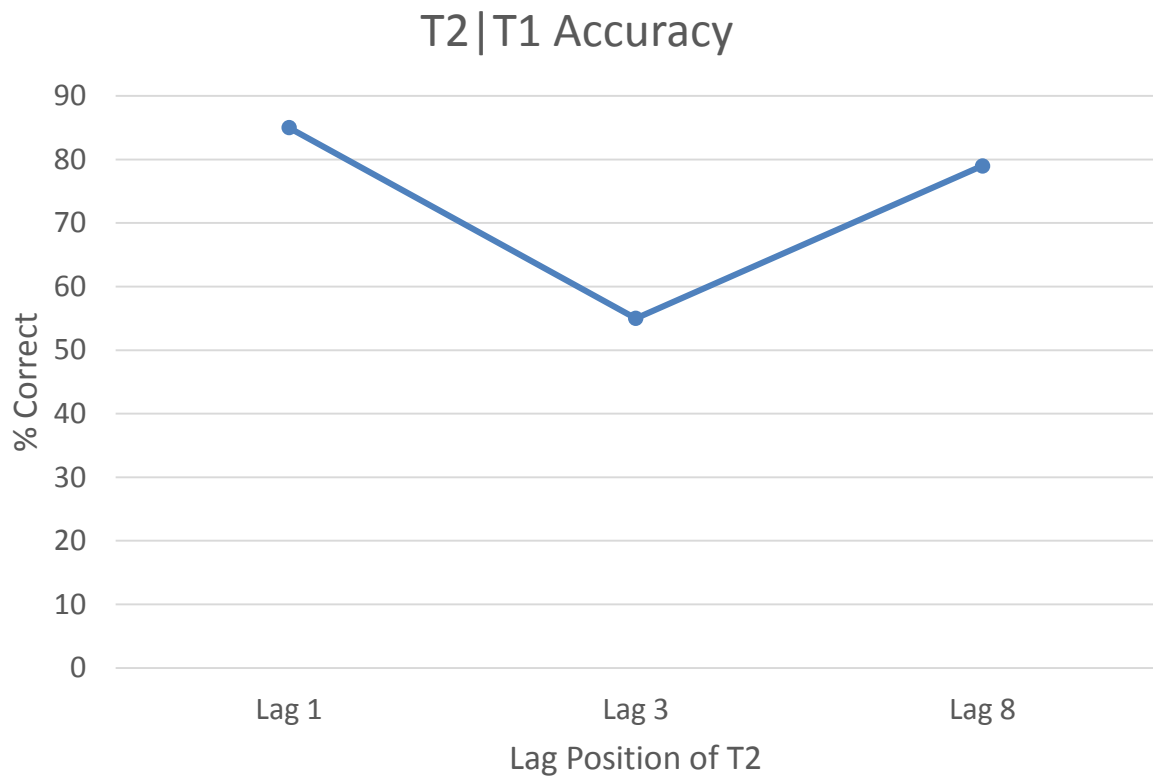


Figure 3. In typical AB experiments stimuli are presented for approximately 100ms each. Results are commonly plotted for the accuracy of target 2 identification given correct identification of target 1. The results typically demonstrate good performance for second targets falling immediately subsequent to first targets (lag 1 sparring) then a drop in performance during the next few hundred milliseconds (blink window). Performance returns to approximately baseline after a sufficient period of time between targets has passed.

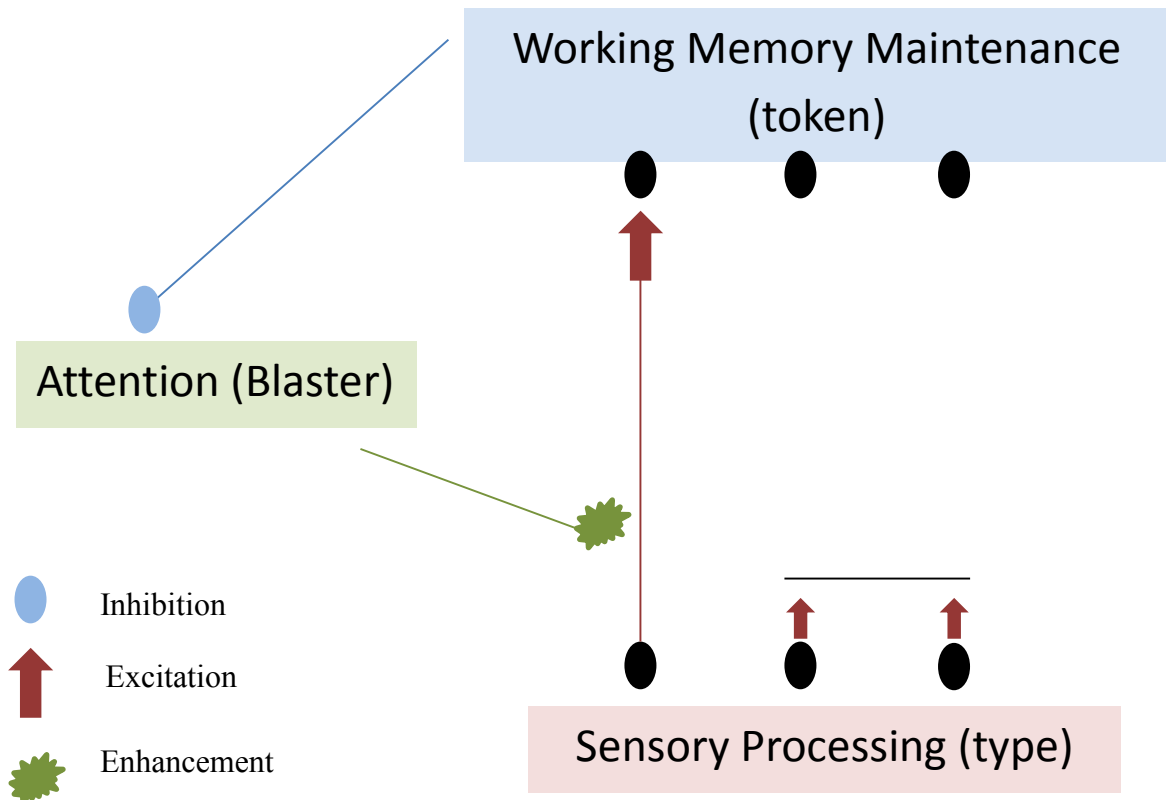


Figure 4. The eSTST posits that sensory processing is enhanced by an attentional mechanism known as the blaster to allow this information to be encoded into working memory above other information. Information that is not enhanced is not encoded, and therefore not perceived.

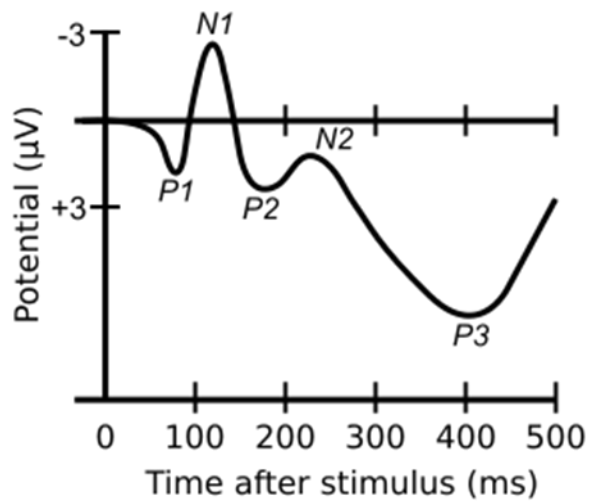


Figure 5. ERP components are named for the direction of their charge and their temporal position. For example the N2 is the negative peak of EEG activity occurring approximately 200ms after stimulus presentation. Negative voltage is often plotted as the upper portion of the figure.

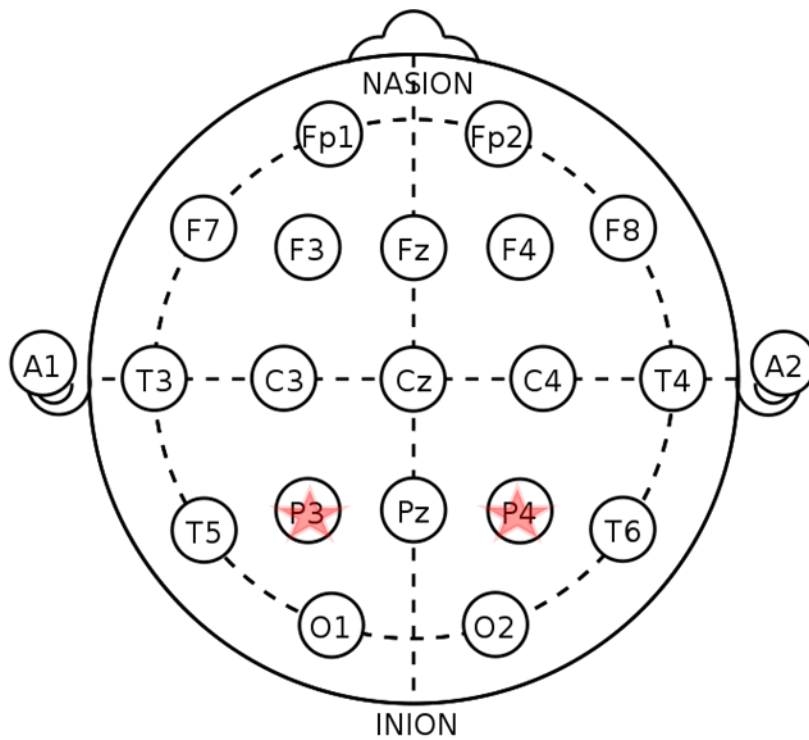


Figure 6. The international 10-20 system is an electrode configuration commonly used in research. The N2pc is recorded at posterior electrode sites, marked in this figure with red stars.

Variables		Target	
		Target Present	Target Absent
Cue	Cue Present	1.) <i>N2pc for Target</i> 2.) <i>N2pc for Cue</i>	1.) <i>N2pc for Target</i> 2.) <i>N2pc for Cue</i>
	Cue Absent	1.) <i>N2pc for Target</i> 2.) <i>N2pc for Cue</i>	1.) <i>N2pc for Target</i> 2.) <i>N2pc for Cue</i>

Figure 7. Design matrix defining independent and dependent variables.

*Independent variables are bolded, Dependent variables are italicized.

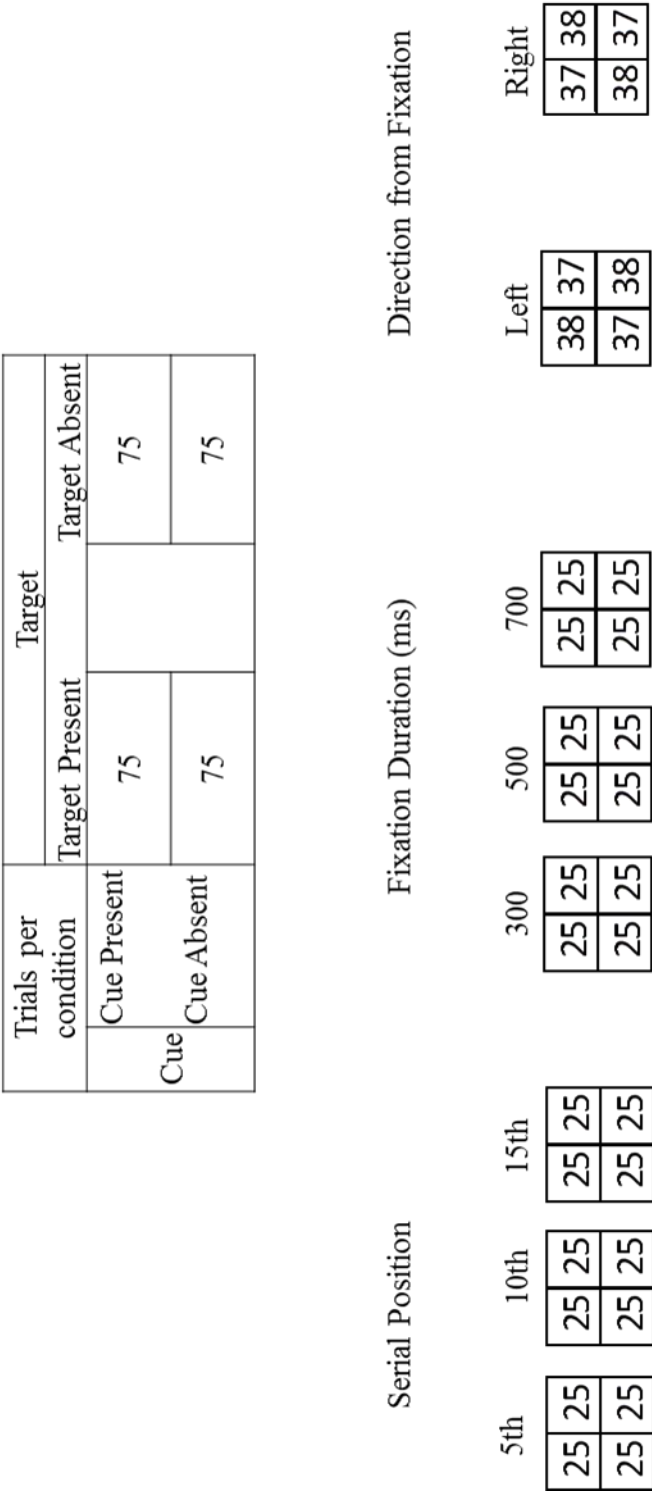
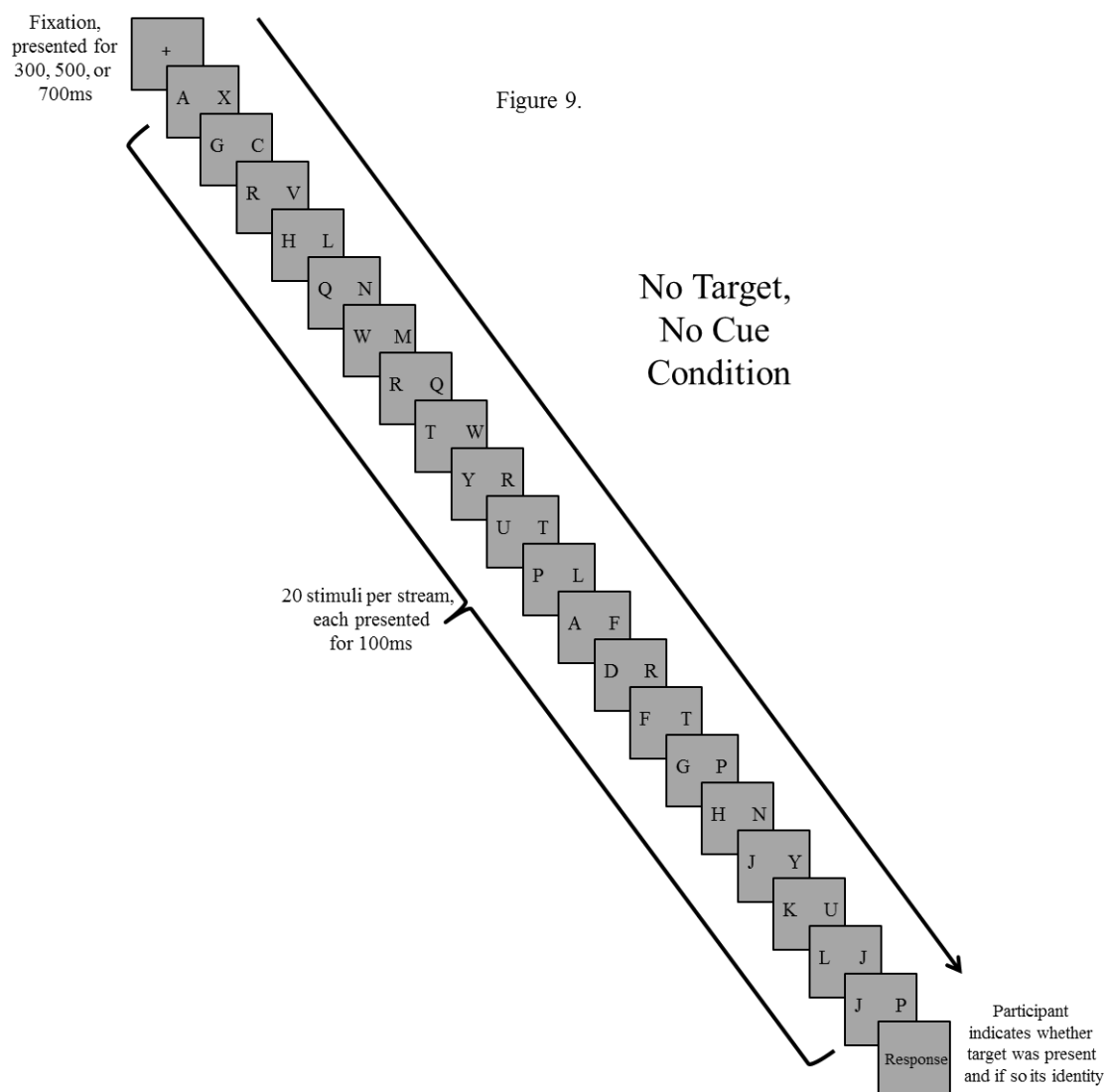
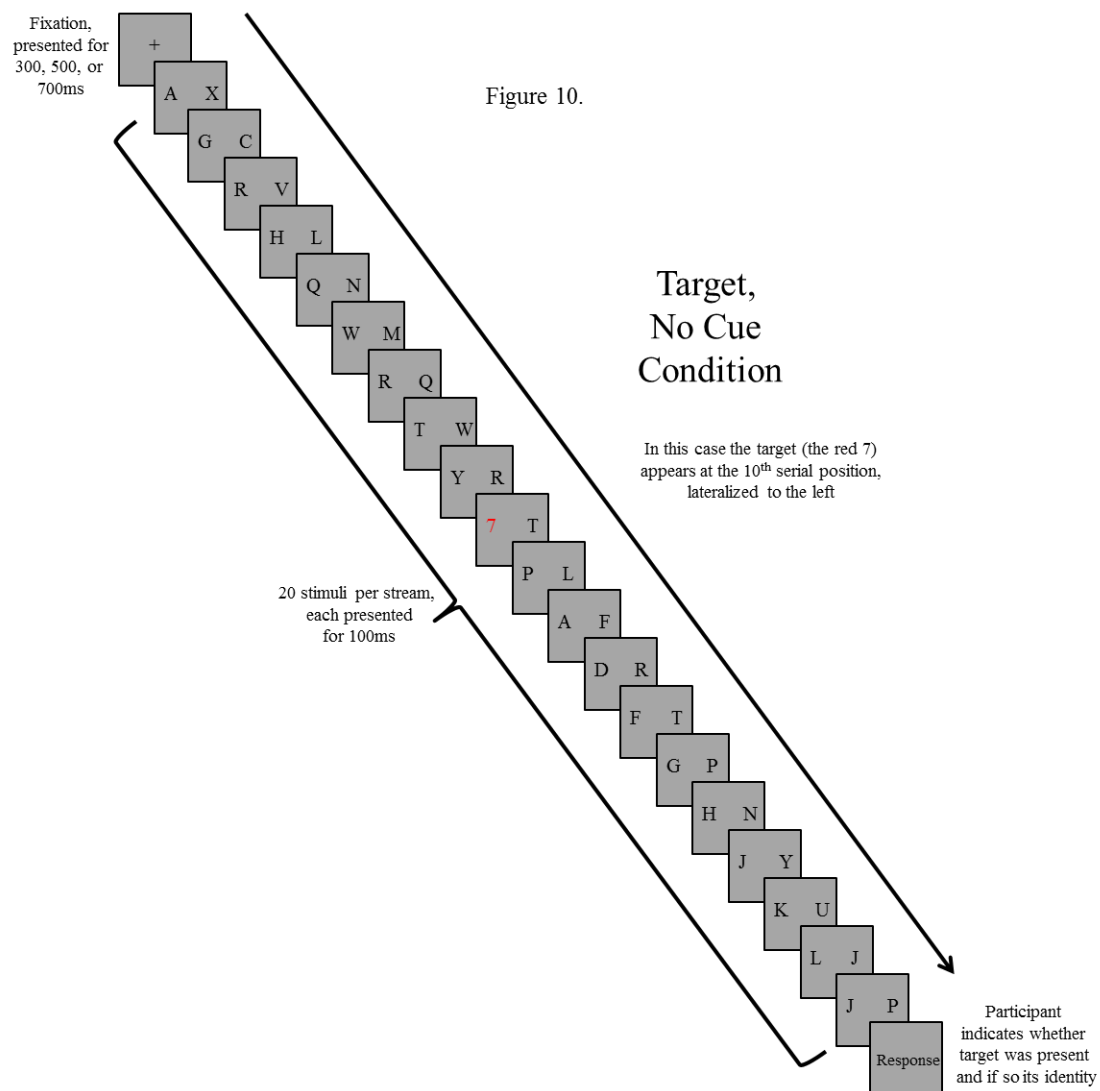
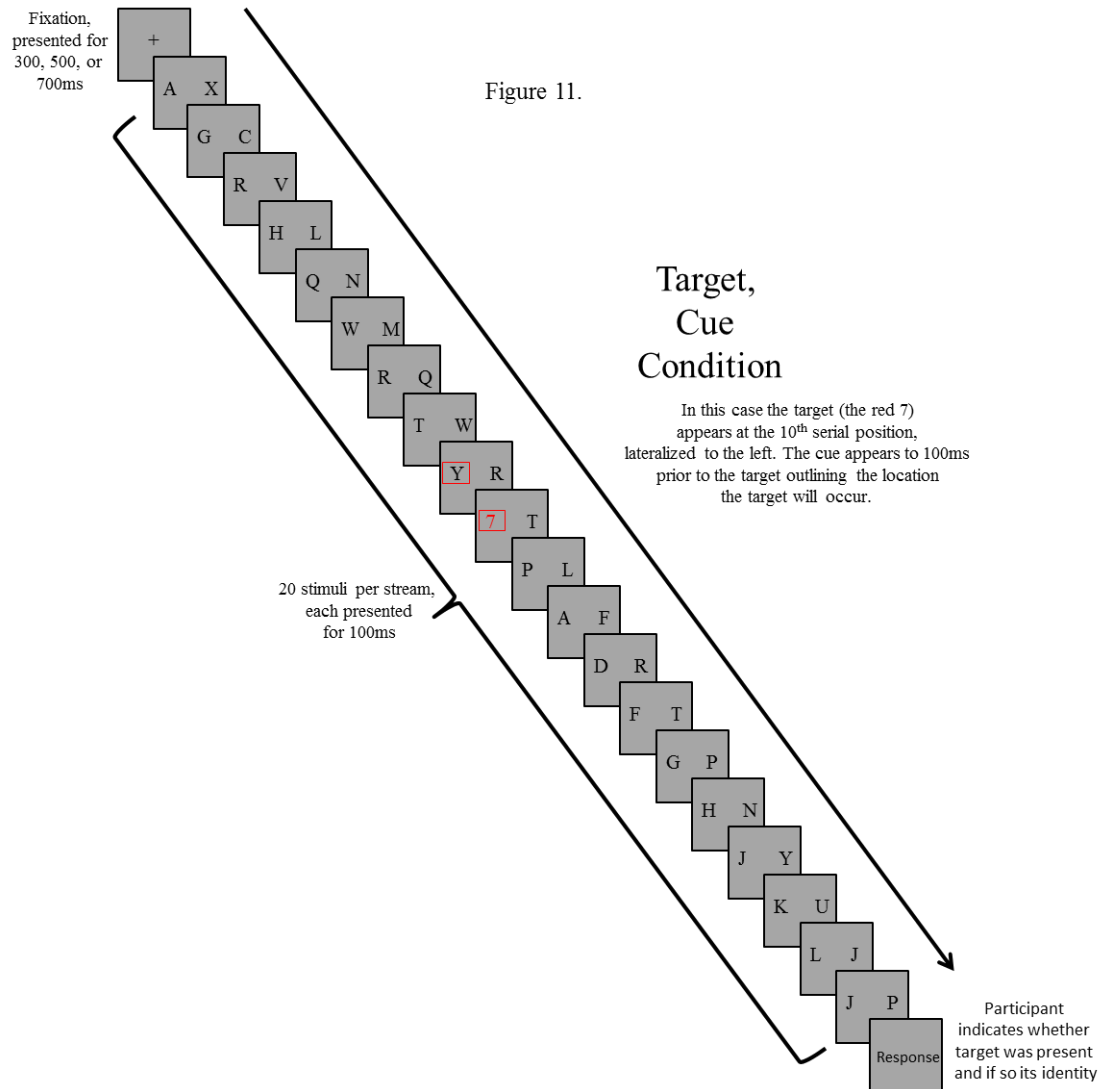


Figure 8. Trials per condition balanced between all manipulations







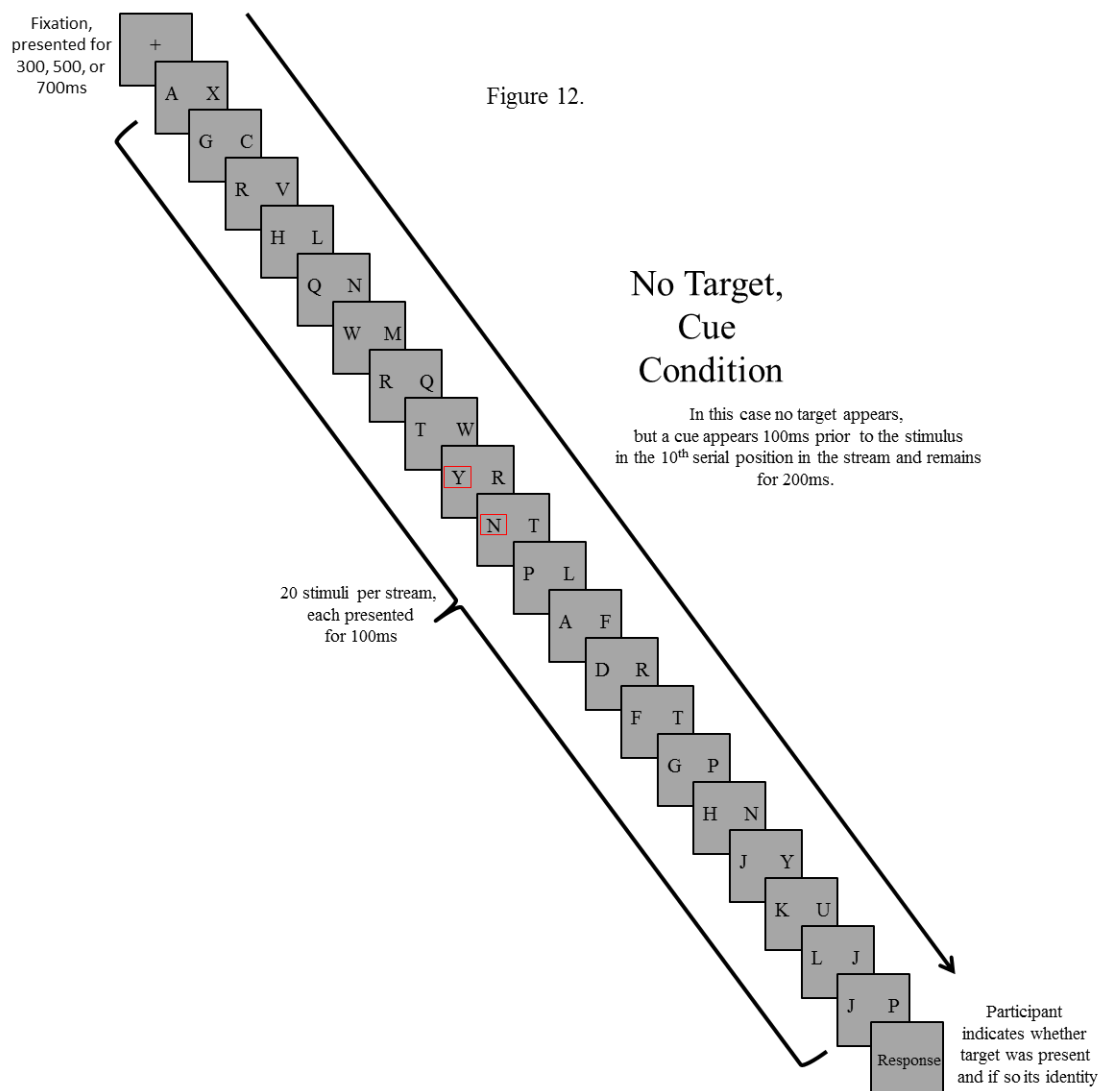
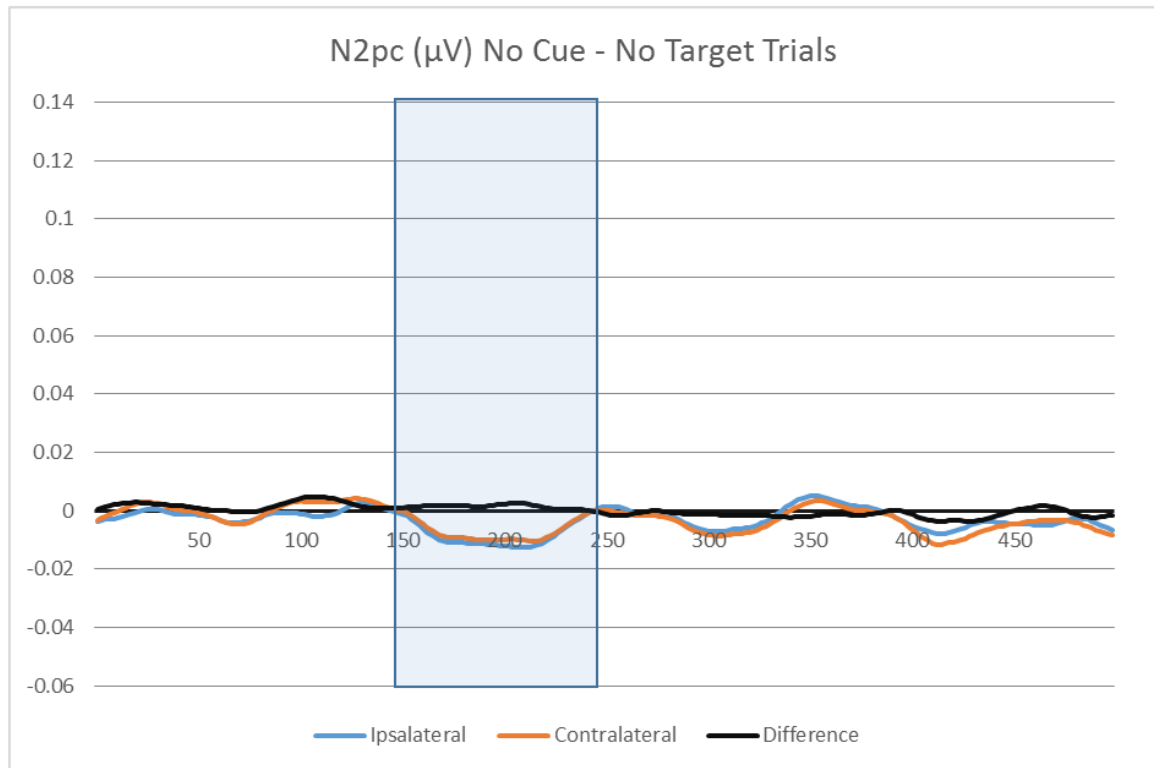
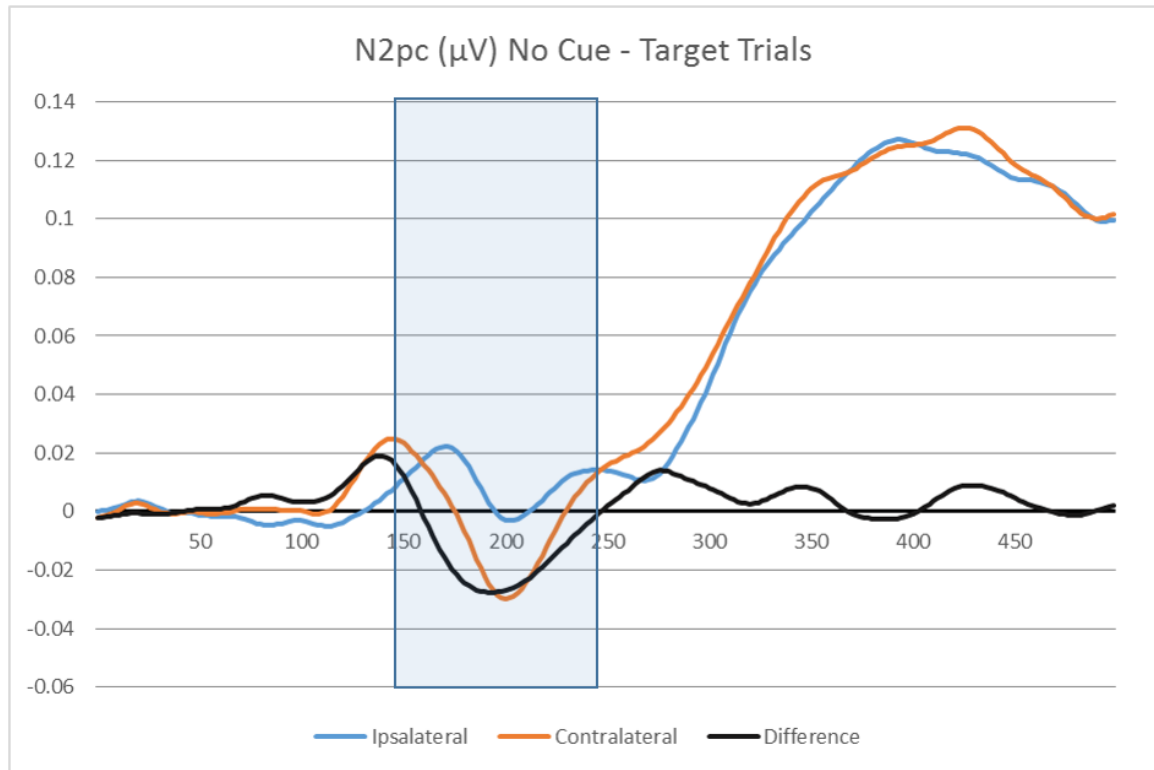


Figure 13. N2pc for Targets – NCNT Condition



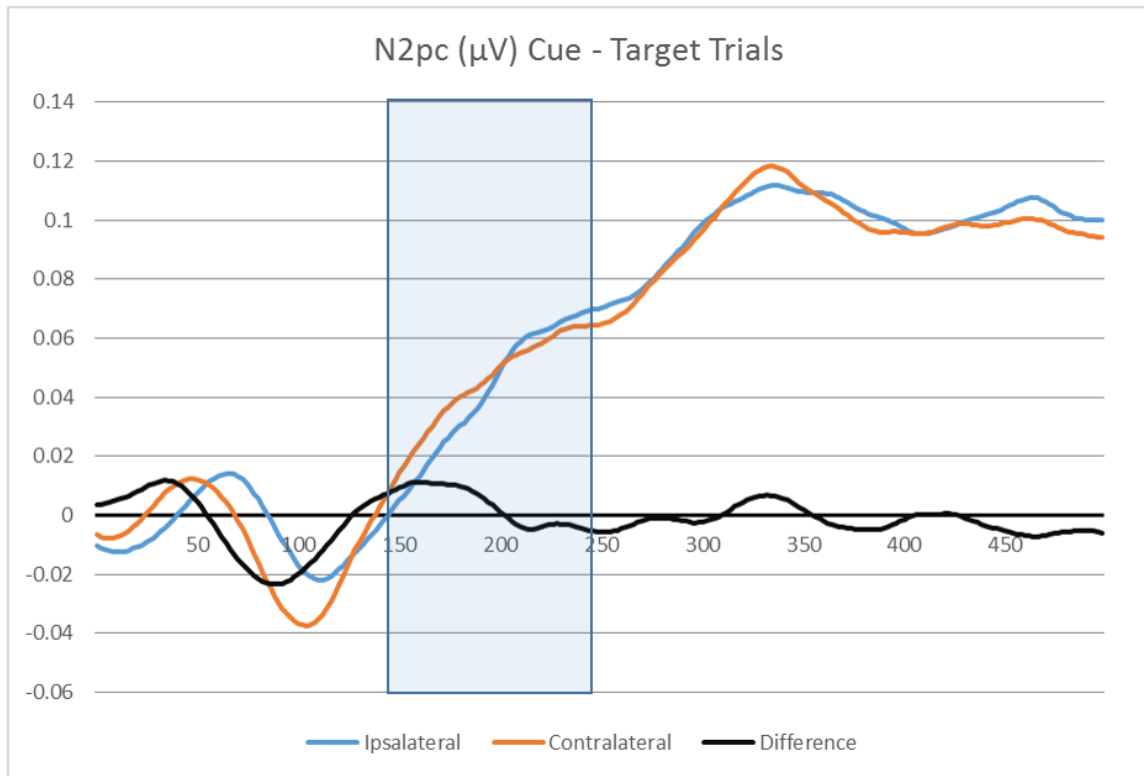
Note. Horizontal Axis represents Time in milliseconds. Zero denotes stimulus onset. Shaded area marks the epoch measured for analysis.

Figure 14. N2pc for Targets – NCT Condition



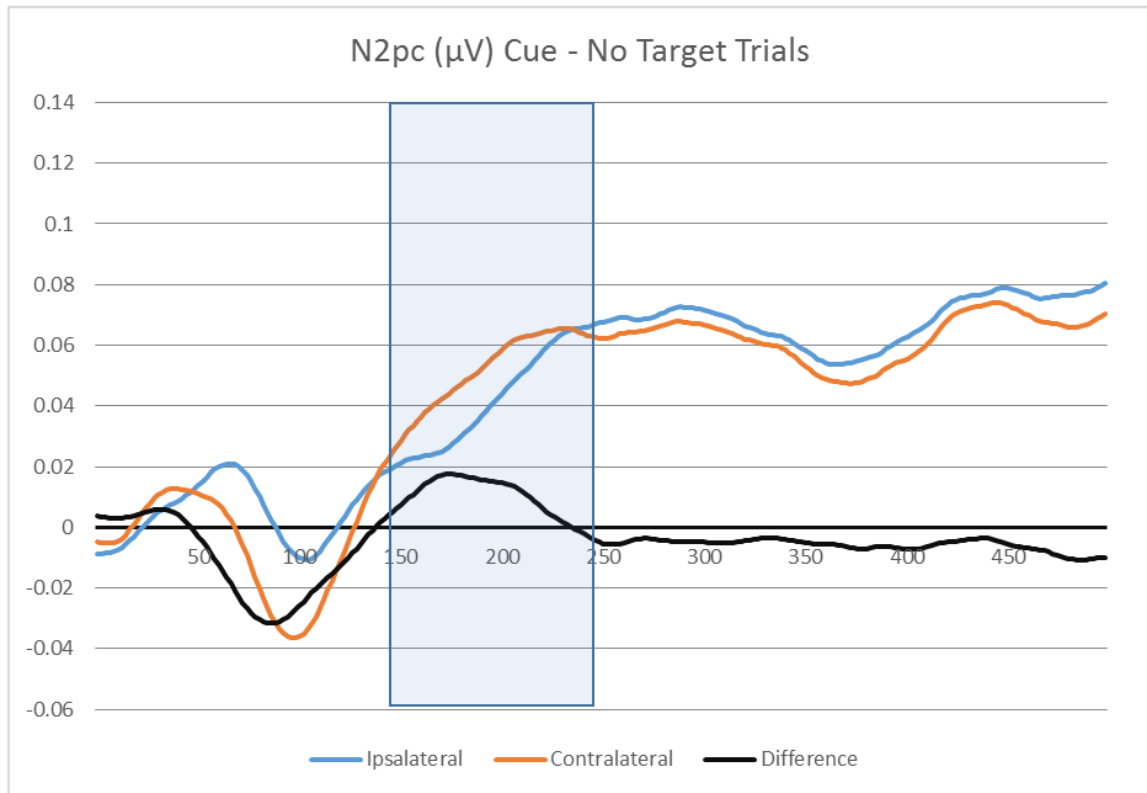
Note. Horizontal Axis represents Time in milliseconds. Zero denotes stimulus onset. Shaded area marks the epoch measured for analysis.

Figure 15. N2pc for Targets – CT Condition



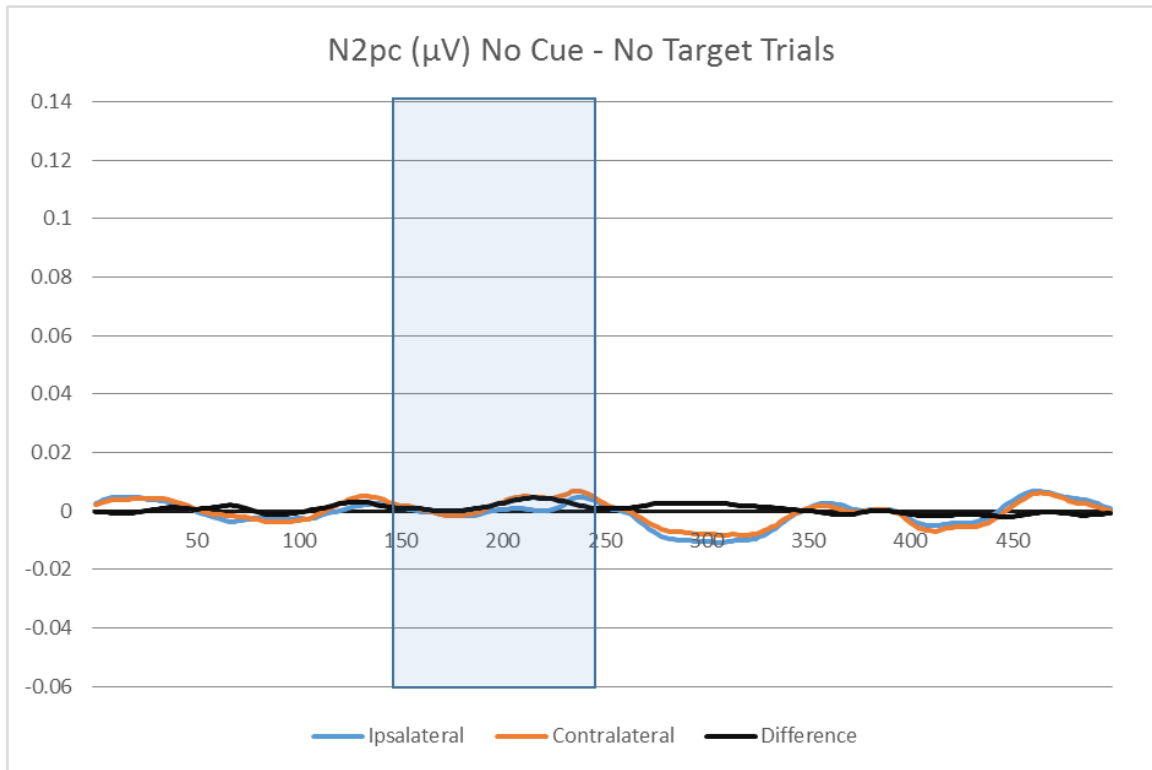
Note. Horizontal Axis represents Time in milliseconds. Zero denotes stimulus onset. Shaded area marks the epoch measured for analysis.

Figure 16. N2pc for Targets – CNT Condition



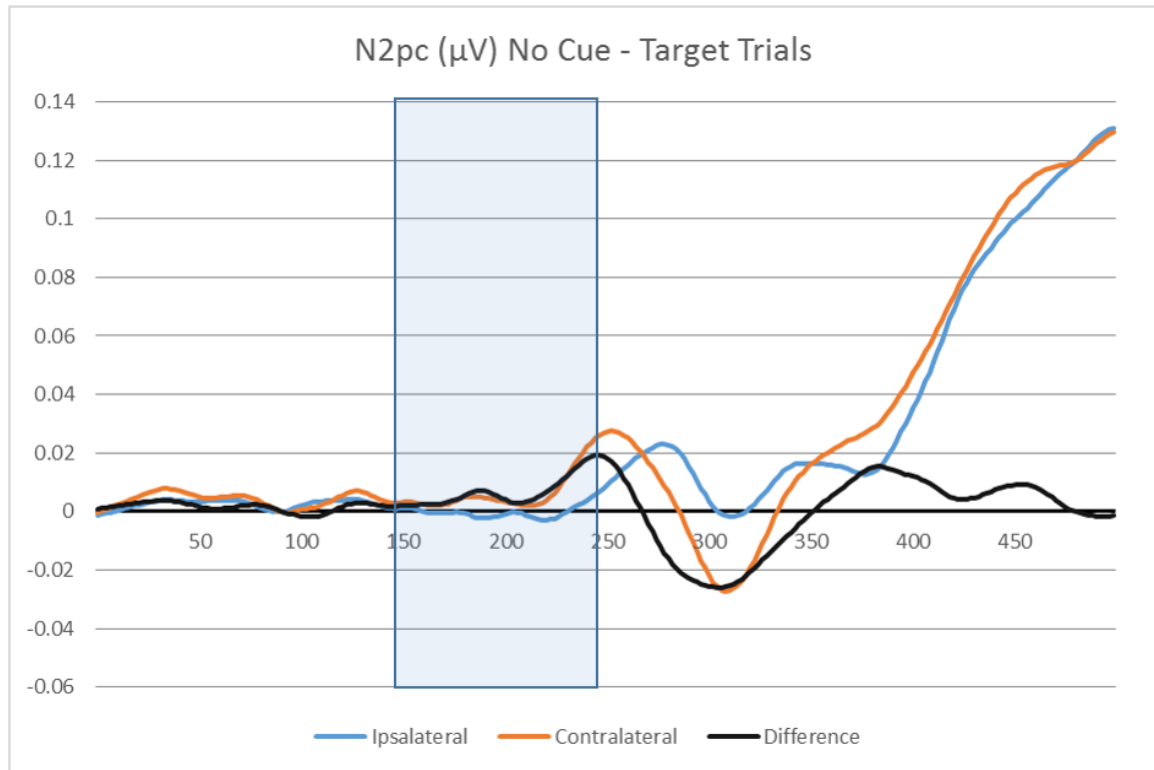
Note. Horizontal Axis represents Time in milliseconds. Zero denotes stimulus onset. Shaded area marks the epoch measured for analysis.

Figure 17. N2pc for Cues – NCNT Condition



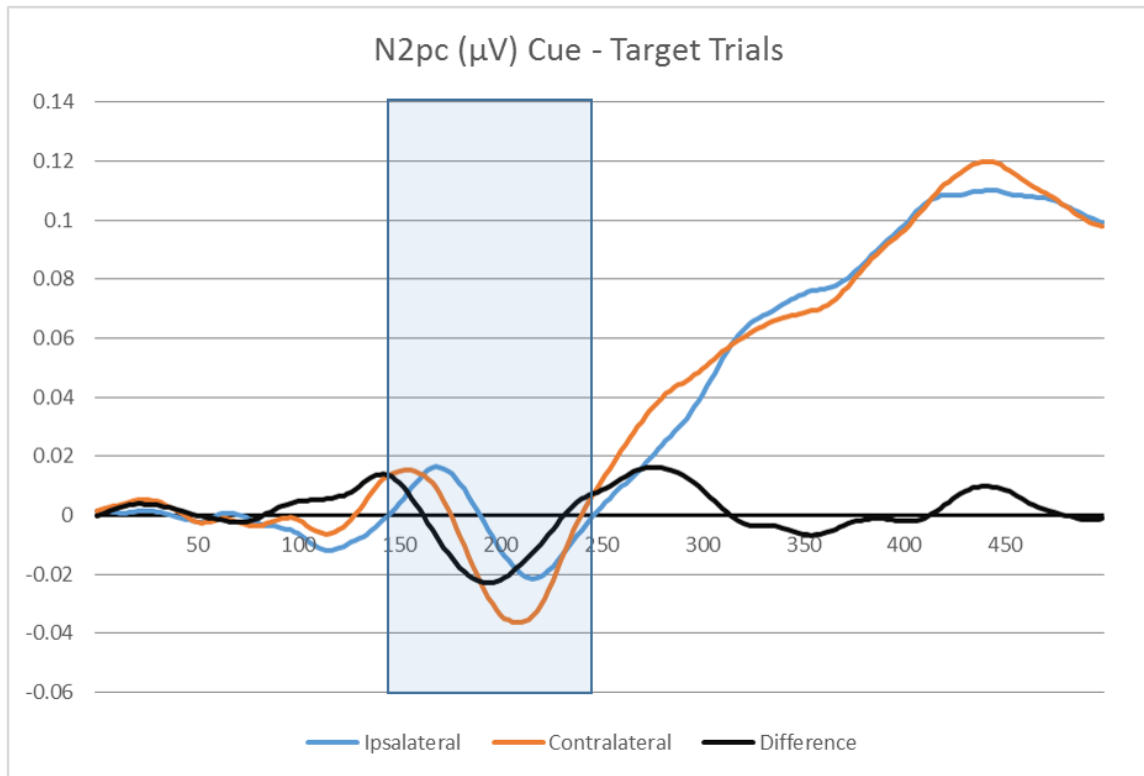
Note. Horizontal Axis represents Time in milliseconds. Zero denotes stimulus onset. Shaded area marks the epoch measured for analysis.

Figure 18. N2pc for Cues – NCT Condition



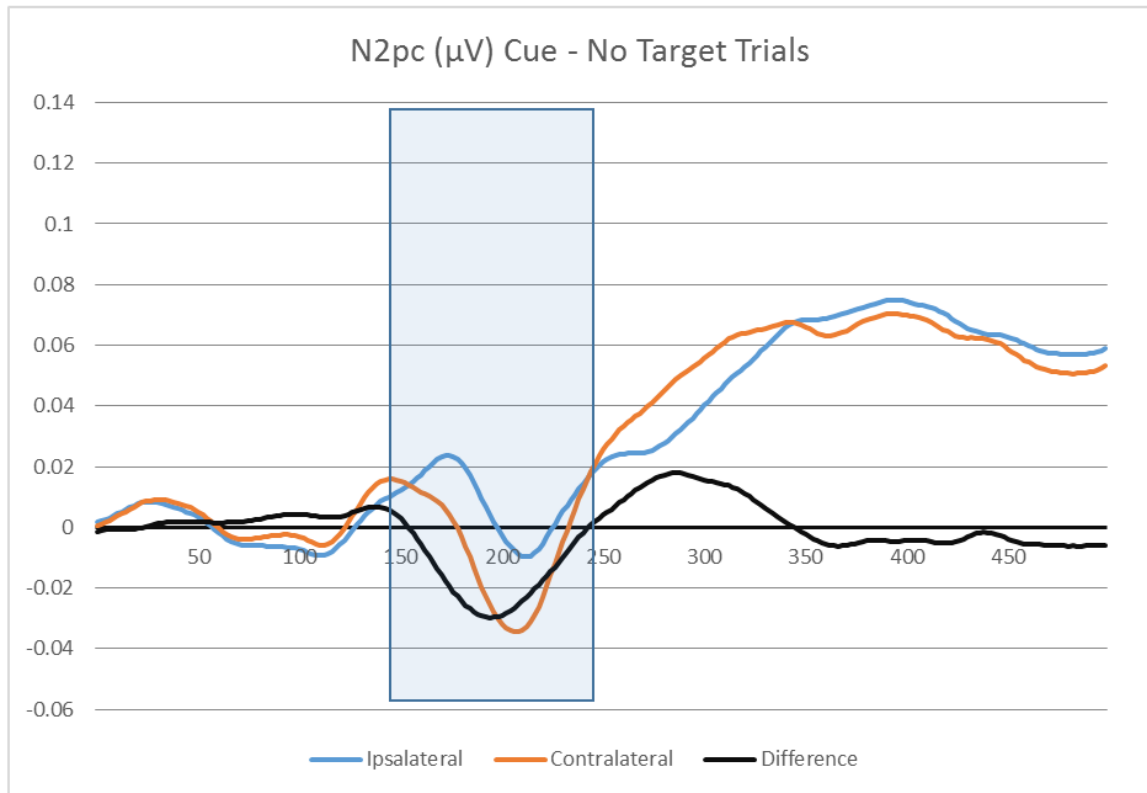
Note. Horizontal Axis represents Time in milliseconds. Zero denotes stimulus onset. Shaded area marks the epoch measured for analysis.

Figure 19. N2pc for Cues – CT Condition



Note. Horizontal Axis represents Time in milliseconds. Zero denotes stimulus onset. Shaded area marks the epoch measured for analysis.

Figure 20. N2pc for Cues – CNT Condition



Note. Horizontal Axis represents Time in milliseconds. Zero denotes stimulus onset. Shaded area marks the epoch measured for analysis.

APPENDIX B

Tables

Table 1. Target Identification Accuracy across conditions

Condition	Mean	Std. Dev.
NCNT	99.6	0.65633
NCT	98.5	2.2466
CT	97	3.26941
CNT	97.6	3.72721

Note. Accuracy in percent of trials correct

Table 2. N2pc for Targets across conditions.

Condition	Mean	Std. Dev.
NCNT	0.0014	0.00682
NCT	-0.013	0.01011
CT	0.0036	0.01707
CNT	0.0102	0.01752

Note. Mean amplitudes are difference scores representing the means of ipsilateral electrode voltage subtracted from the means of contralateral electrode voltage within each condition. A negative mean amplitude would indicate that the contralateral activity was negative relative to ipsilateral activity.

Table 3. N2pc for Cues across conditions.

Condition	Mean	Std. Dev.
NCNT	0.0019	0.00472
NCT	0.0063	0.0059
CT	-0.0076	0.01144
CNT	-0.015	0.01042

Note. Mean amplitudes are difference scores representing the means of ipsilateral electrode voltage subtracted from the means of contralateral electrode voltage within each condition. A negative mean amplitude would indicate that the contralateral activity was negative relative to ipsilateral activity.

Table 4. Repeated Measures ANOVA for Target N2pc

Source	SS	df	MS	<i>F</i>	<i>p</i>
Condition	0.004	3	0.001	10.26	<.01
Error	0.005	39	0		

Table 5. N2pc for Targets – Pairwise comparisons between conditions.

Condition		<i>t</i>	Sig.
1	2	3.5	0.002
	3	-0.4	0.682
	4	-1.5	0.138
2	3	-4.25	0.001
	4	-5.75	0.001
3	4	-3.5	0.021

Note. Adjustment for multiple comparisons: Least Significant Differences (equivalent to no adjustments)

Table 6. Repeated Measures ANOVA for Cue N2pc

Source	SS	df	MS	<i>F</i>	<i>p</i>
Condition	0.004	3	0.001	21.327	<.01
Error	0.002	39	0		

Table 7. N2pc for Cues – Pairwise comparisons between conditions.

Condition		<i>t</i>	Sig.
1	2	-2	0.039
	3	2.25	0.025
	4	5.67	0.001
2	3	4.67	0.001
	4	7	0.001
3	4	3.5	0.001

Note. Adjustment for multiple comparisons: Least Significant Differences (equivalent to no adjustments), *p* values rounded to 0.001 when lower.

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