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AN ERP INVESTIGATION OF HAND-BASED BIAS ON VISUAL ATTENTION

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Doctor of Philosophy

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by

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ABSTRACT

Recent behavioral studies have investigated the importance of hand and arm position in visual attentional processes. Reed et al. (2006) found facilitated (faster) detection for targets that appear in the space near the hand, relative to targets appearing on the opposite side of a monitor display. The current study aimed to explore the potential bottom-up and top-down neural sources underlying this hand-bias effect on attention with ERP. Using a standard, non-predictive visual cuing paradigm, we examined early (N1, P1) and later (P3) ERP components in response target presentations in three conditions: with the non-responding hand resting on the table (Resting), with the hand held up near the screen and target location (Up), and with the hand held up but away from the screen (Away). An effect of hand-position was found for the P3 in a central electrode group, in which validity effects that were present in the Resting and Away conditions, were not present in the Up condition. This result suggests that top-down sources of attentional bias from positioning a hand near the screen can alter the occurrence of validity effects in this ERP component. However, significant effects were not found in the earlier P1 and N1 components, nor did the behavioral results completely replicate the original findings of Reed et al. (2006). The limited findings from these other aspects of the study may be explained by a number of limitations discussed in the paper.

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Chapter 1: Introduction

Overview

As people go about their daily lives, they are faced with a constant stream of stimuli and inputs from multiple sensory modalities. Because it is impossible to process all of this information, the most relevant stimuli must be selected for further processing. Selective attention is the cognitive process by which we select, from among the myriad of inputs and stimuli we are constantly faced with, particular objects or spatial locations for further processing (Pashler, 1998). However, attention does not work at random. It is not only directed by the properties of stimuli in the environment, but also is directed in accord with our goals to select the most important stimuli to facilitate our ongoing actions (Tipper, 2004).

Consider the archetypal example of reaching for a mug of coffee. In order to accomplish this successfully, we may first need to visually scan the table on which the mug rests in order to identify it, localize its location, and distinguish it from any other nearby objects. These initial steps in the task are primarily visual, but ultimately the goal is to reach out, grasp the mug's handle, and successfully lift it. Accomplishing this requires the coordination of visual, somatosensory, and proprioceptive inputs, in addition to information about general body position – the relation among its parts and the other objects in the environment. Thus, the goal of the task, to reach and grasp, implicates the body in a central way such that it should be expected to have an important role in the allocation of spatial attention. This study aims to better understand how the body, in particular hand position, can influence spatial attention by exploring the electrophysiological signatures of a previously demonstrated behavioral effect of hand position on attention.

Attention and The Body

Many current theories of visual attention focus on explaining how attention knows what to select from the environment, i.e. attentional control (Luck & Vecera, 2002). Control of attention is typically considered to be determined by factors coming from two general directions: bottom-up features and top-down control parameters. Bottom-up factors are also termed *stimulus driven*, as they are comprised of features from or aspects of the environment that change attention in significant ways. For example, a red item in an array of green items (i.e., color singleton) that *pops out* as salient and automatically draw attention constitutes a bottom-up effect on attention (e.g., Theeuwes, 1992). Other examples of bottom-up influences include the abrupt onset of a stimulus (Yantis & Jonides, 1984), or the onset of apparent motion (Abrams & Christ, 2003). Alternatively, top-down factors of attentional control are more closely related to an individual's task set, goal, or strategy. For example, being instructed to look for red targets might lead one to strategically look for these specific targets in a directed manner affecting overall performance (e.g., Folk, Remington & Johnston, 1992). Both bottom-up and top-down factors compete for control to govern the allocation of attention (Desimone & Duncan, 1995), but little is known about how the body and its effectors might control attention or how it might fit into this dichotomy.

Although many theories address the visuospatial aspects of selective attention, some researchers have reasoned that human perceptual and attention systems operate to help us perform functional and adaptive actions (Previc, 1990; Berthoz, 1991; Tipper, 2004). This latter point of view constitutes an embodied perspective of cognition and attention. The embodied perspective acknowledges that we are physical beings with physical goals in the real world that are mediated by our bodies. Berthoz (1991) argued that the co-evolution of perception and action mechanisms led to the development of *functional* neural representations of space that exist to aid our actions, and thus that these mechanisms generally should be studied in an integrated manner. In other words, our brains evolved and they develop in the physical world, learning through experience and interactions with it. It follows from our phylogeny and ontogeny that a fair degree of our brain organization would reflect specialization in spatial processing specifically as it relates to navigation and interaction with the world.

Previc (1990) formalized what is meant by a functional representation of space by dividing visual space into distinct regions that he theorized would be represented by different neural regions and thus unique systems. In particular, he noted that the upper and lower visual fields present different types of information that would have unique functional importance for an organism. The upper visual field is typically reserved for viewing scenes or objects at a distance, and accordingly maps more readily on to the dorsal visual stream where object recognition processes are predominant. The lower visual field, however, usually encompasses space that more nearby an upright standing primate or human. It is within this space that we can reach out for, grasp, and manipulate objects. Thus spatial representations, especially as they relate to the body, will be more important here, and accordingly correspond to the dorsal visual processing stream where these processes occur.

In addition to the vertical dimensions of visual space, Previc (1998) also formalized the structure of spatial representations in general in terms of the different regions relationship to the body. Peripersonal space is the space nearby an individual in which they are able to reach out and grasp and touch objects – in other words, action space. Extrapersonal space lies beyond this region, but Action Extrapersonal is still near enough that an individual could move and act within this space. Beyond this, Ambient Extrapersonal space extends to the boundaries of our visual field and awareness. These functional divisions of space into different regions amount essentially to unique spatial frames of reference. A spatial reference frame is a theoretical construct for how the brain represents different regions of space, which essentially is equivalent to a coordinate system centered around a particular easily identifiable point in space (Heilman, Watson, & Valenstein, 2003). For example, some reference frames are egocentric and may be retinotopic (i.e., centered around the point of fixation), head-centered, or body-centered about the torso midline. Reference frames may also be allocentric, that is, centered around an external object or scene. At any given moment, multiple reference frames are employed by the brain to coordinate the best possible representation of space for a particular task. In Previc's model, the body and its potential for action are prioritized in delineating how these reference frames are established. Peripersonal space is particularly important because it is where we actively engage and interact with the world. Thus, we should expect to find a close linking between vision and our body and action systems in this region in particular.

What evidence exists for how visual and embodied factors interact to change behavior? Much of the research on embodied attention has focused on how environmental or perceptual variables influence attention and subsequent physical responses. For example, a number of studies have investigated the kinematics of reaching movements in the context of different visual displays and demonstrated how the presence of visual distractors can affect the trajectory and speed of a reaching movement to a target (Tipper, Lortie, & Baylis, 1992; Pratt & Abrams, 1994; Howard & Tipper, 1997). Tipper, et al. (1992) utilized a panel with a 3 x 3 array of LEDs which would light up yellow (target) or red (distractor). Participants rested their hand in front of the panel, and reached out to touch the yellow target when cued. However, when a red distractor also lit up between their hand's starting position and the target, their time to reach the target was significantly slower. This occurred whether the starting position was near themselves at the bottom of the panel or far from them on the opposite side of the panel. This suggested that the inhibitory effects of the distractor were occurring in an action-based reference frame. Howard and Tipper (1997) studied the trajectory path of reaches in a similar paradigm. As participants reached to a far target location, a distractor would appear in one of several locations around the path of the reach. They found that the trajectory of the reach deviated away from the distractors, changing the path of the reach. Thus, it is evident that low level visual features, as basic as a light that irrelevant to the task, can influence reaching behavior in basic ways.

The physical affordances of an object can also affect how responses are made. An affordance is a feature of an object or of the environment that allows for a particular action to be made. For example, a chair affords sitting, while the handle on a mug affords grasping. Tucker and Ellis (2004) had participants respond to the presentation of objects in one of two ways – with a small pinch or a full hand-grasp. Responses were faster when the affordances of the displayed object corresponded to the type of response to be given (e.g., hammer for hand-grasp). Tipper, Paul, and Hayes (2006) conducted a similar experiment, but had participants attend either to the affordance of the object or to an irrelevant feature, such as color. The same compatibility effect was found when affordance was attended, but was not observed when color was attended. This suggested that attention to action relevant feature was necessary for visual features to influence responding, but it is possible nonetheless for higher level features to affect physical responses.

Although visual features of the environment can influence how actions and responses are carried out, relatively few studies have examined how current body part configurations and actions might influence the allocation of visual attention. Grubb and Reed (2002) studied the effect of trunk orientation on spatial attention orienting. Participants performed a target detection task while orienting their torso straight ahead, to the right, or left (all the while maintaining a forward head position). They found a spatial bias in the form of faster response times (RTs) to targets appearing in the direction the torso was oriented, demonstrating how the basic orientation of the body can affect the allocation of visual attention. Grubb, Reed, Bate, Garza, & Roberts (2008) investigated the effects of trunk orientation on attention during a walking task. They found similar trunk orientation biases when participants were walking, especially during higher motor-load conditions (i.e., slower walking which took more effort). This bias was not present when participants were standing still, however, suggesting that an embodied factor such as trunk orientation becomes more important when it is potentially relevant to upcoming events.

In summary, interactions between embodied factors and visual attention should be expected for a number of theoretical, ecological, and neurological reasons. Research in this area, however, tends to focus on how visual features influence physical responses. Fewer studies have investigated how the body might affect visual processes, but some have demonstrated how body orientation can have an effect on spatial attention orienting. Next we discuss how the hands in particular can affect attention.

The Hands and Attention

The orientation of the body and trunk can influence where we are able to reach and grasp, but ultimately the hand serves as the effector that we use to interact with the world. As human beings we rely greatly on our hands, whether we are grasping objects, manipulating tools, or even communicating with gestures. Thus, we should expect a tight linking between the visual systems that guide our behavior and the various networks involved in controlling our hand position and movements. Further, this link should be bidirectional to facilitate the updating of visual systems as we move and execute our actions. Accordingly, recent studies have demonstrated that the orientation and position of the hands appears to have a significant influence on the orienting of attention.

A potentially important neurological link between vision and hand representations comes from studies with non-human primates investigating visuo-tactile bimodal neurons (see Graziano, Yap, & Gross, 1994). Of particular importance are bimodal neurons that respond both to tactile stimuli presented on the hand and to visual stimuli presented on or near the hand. The response of these neurons to visual stimuli decreases as a function of the distance between the visual stimulus and the hand (Graziano & Gross, 1998). Further, when the hand moves to a different position, the receptive fields of the cells move with the hand, but not with the eyes, suggesting that these cells encode space in hand-centered coordinates (Graziano, Yap, & Gross, 1994). This suggests that bimodal neurons such as these may be responsible for integrating information across visual and tactile modalities, specific to the hand in this case, in order to facilitate the grasping of objects and processing of visual information near the hands (Ladavas, di Pellegrino, Farnè, & Zeloni, 1998).

A hand-based reference frame has also been implicated in human neuropsychological studies. For example, optic ataxia is a condition in which patients cannot accurately reach to an object unless they first fixate their gaze on the object (Farah, 2003). Buxbaum and Coslett (1998) reported a unique patient, however, who had difficulty fixating on locations other than to where he was reaching. In other words, the patient's gaze seemed to be captured by his hand position and unable to disengage from a hand-based frame of reference. Coslett and Lie (2004) found that tactile extinction in two patients with right parietal damage was alleviated in the contralesional hand when the ipsilesional hand was positioned proximal to it. Finally, Schendel and Robertson (2004) reported a patient with a right hemianopsia (i.e., blindness due to occipital lobe damage) resulting in vision loss in his left hemifield. This vision loss was attenuated, however, when he held his left hand up near a display screen of targets. When his hand was held proximal to the targets, he demonstrated a significant increase in his ability to detect targets in the previously blind hemifield. Thus, it is evident that hand position can alleviate certain neuropsychological visual deficits, perhaps by recruiting additional neural systems to contribute to perceptual processing. At a minimum, these case studies further support the utilization of a hand-centered reference frame in visual attention processing.

More recent studies with neurologically intact individuals further support a hand-centered frame by demonstrating that hand position can bias visual attention to the space near the hand (Abrams, Davoli, Du, Knapp, & Paull, 2008; Reed, Grubb, & Steele, 2006; Reed, Betz, Garza, & Roberts, 2010). Reed et al. (2006) tested participants in a standard predictive spatial cuing paradigm, in which participants had to detect a target appearing in one of two laterally positioned locations, just following the cuing of one of the locations (Figure 1). Trials in which targets appeared in the cued location were valid, while those in which they appeared in the non-cued location were invalid, and attentional shifts were inferred from faster RTs in valid relative to invalid trials. The key manipulation was to have participants position their non-responding hand up near the screen, so that it was proximal to one of the lateral target locations. In addition to finding a standard validity effect, an effect was found in which responses to targets appearing proximal to the hand were detected faster overall, regardless of cue validity. In a subsequent experiment, hand position was manipulated so that it was still held up, but not as near the target location. There was no hand effect for the more distal location, demonstrating that that this facilitation depended on the hand’s physical proximity to the target location. The effect was also not due to having a visible object on one side of the display, as an arbitrary visual anchor in place of the hand by the screen produced no effects. Finally, the visual input was an important contribution for the effect, as it was present but weaker when the hand location was hidden from view. Similarly, proprioceptive inputs alone also resulted in a weaker, but present effect. This was demonstrated in a final experiment in which a stuffed rubber glove was held near the screen and the participant wore an identical glove on their hand, which rested in their lap, to provide a tactile link to the fake hand. In all of these experiments, the hand was not relevant to the purely visual detection task, but its location apparently biased attention, facilitating target detection in the space near it. Furthermore, the effect of the hand did not interact with cue validity; instead an overall facilitation of target detection near the hand was observed, regardless of cue validity. This lack of interaction suggested that visual attention was generally biased to the space near the hand, potentially from additional processing contribution from bimodal neurons.

Although bimodal neurons offer a neurological explanation for the attentional bias found near the hand, it is also possible that the bias exists for the functional purpose of facilitating potential actions with the hand. If this is true, then the spatial topography of the bias around the hand might reflect its functional nature. To investigate this, Reed et al. (2010) compared the relative detection facilitation for targets appearing near differing regions around the hand and arms. In an initial experiment, they manipulated hand position such that the target would appear either near the palm side in “grasping space” or near the back of the hand in “hitting/avoidance space”. Though a bias effect was found in both conditions, it was significantly greater in the palm-side condition, consistent with the functional importance of the hand for grasping objects. Palm-side was next compared to the space near the inside of the forearm, with similar results in which relatively greater facilitation was found for targets appearing near the palm. A subsequent experiment investigated whether this functional topography could be extended in space through the use of a tool. After practicing using a small rake, participants held the rake up near the screen instead of their hand. The bias effect was found for this condition, but it was not present when the hand was held in the same position without rake. Finally, conditions were compared in which either the prongs of the rake or the back of the rake faced the target location. The facilitation was observed when the prongs faced the target location, but not for the back of the rake condition, suggesting that the same functional topography observed around the hand could be extended through the use of a tool. Thus, the attentional bias from the hand appears to be functionally related to the affordances of the hand or any tools it might be employing, suggesting the importance of contextual factors and task relevance in this effect.

The biasing effect of the hand appears to be functional, but in the above studies the hand's position is not explicitly relevant to performing the task. Participants were required to respond with a button press when a target appeared, but their non-responding hand was the one held up and was otherwise unoccupied. In order to investigate the effect of having the responding hand near the target locations, we conducted an experiment in which the response mouse was positioned near the screen where the non-responding hand was positioned in the previous experiments (Reed, Garza, et al., *in preparation*). We directly compared this to the standard condition in which the response was given with a mouse on the desk and the non-responding hand was held proximal to the target location. Importantly, the condition labels emphasized where the response would occur (i.e., desk, screen), and participants could see and were aware of the conditions labels. When responding near the screen, the same bias effect was observed, wherein targets appearing near the hand were detected faster, though this hand was now responding. Interestingly however, for the desk condition, which was identical to conditions in previous experiments with one hand held up, the familiar pattern of data were reversed. RTs were now slower near the hand held up, but faster on the same side as the responding hand. This pattern of data suggested a stimulus-response compatibility effect, in which targets appearing on the same side as the response receive facilitation, even though the response was given on the desk. Further, this occurred despite the non-responding being held up near the screen, in contrast to previous experiments. One key difference with this experiment was that the response location was emphasized in the condition label, instead of the hand to be held up. This suggests that factors such as the task instructions, emphasis, and labels brought about this change from the previous result in this paradigm. The implication is that the hand-bias effect is subject to top-down influences such as participant interpretation of the task, and more broadly the context in which the hand is positioned and the particular goals of the individual.

Another study investigating the effect of hand position on visual attention under a different context than the above studies also found somewhat inconsistent result (Abrams et al., 2008). Abrams et al. investigated the effect of hands held near the screen in a visual search paradigm, but instructed participants to hold both hands up near the screen. On the display, an array of randomly positioned letters (Es or Us) appeared, in addition to a single target letter (H or S), and participants had to respond as to which letter appeared. Abrams et al. found that visual search was slower when the hands were held up near the screen than when they were placed in the lap. They interpreted this finding as an inability to attentionally disengage from items near the hands, consequently slowing the search. However, the placement of both hands near the screen is problematic because the greater context of the experimental setup is known to affect the outcome of hand-based effects on attention. It is possible that the slower search times may have resulted from interactions between the two hands, and not from the hands affecting attention directly. Regardless of the interpretation, these disparate results across attention paradigms highlights the importance of task context for this effect.

Although the hand-bias effect is subject to top-down influences, one study has demonstrated how the hand has a clear bottom-up effect on perception. Cosman & Vecera (*in press*) investigated the effect of the hand in a figure-ground experiment. Assigning what is figure and what is ground is typically considered a perceptual process that occurs preattentively (Julesz, 1984; Kimchi & Peterson, 2008). In this study, participants performed a visual working memory task in which they viewed ambiguous two-region figure-ground displays, and subsequently reported which region appeared in the previous display. When one hand was held up to one side of the display, participants were faster at remembering the region near the hand compared to that opposite the hand. This effect was not found when a wooden dowel was placed near the screen, suggesting that the hand positioned influenced figure-ground assignment by increasing the likelihood of the region near the hand being assigned as figure. This finding suggests that the hand can alter visual perception very early in processing, perhaps in a bottom-up manner.

In summary, the position of the hand can affect visual perception and attention in fundamental ways. Hand-based effects on visual attention have been demonstrated in neuropsychological patients and healthy individuals across a number of studies. Although data from non-human primates suggests the bimodal neurons may a play a role in biasing attention to the space near the hand, behavioral data from humans suggests that the source of the bias may derive from top-down as well as bottom-up sources. It is not clear from the behavioral data how early or late in processing the effect is occurring. The current study aims to shed light on this issue by considering the effect of the hand through the use of electroencephalography (EEG) to better understand the time course of processes related to this effect. Specifically, this study investigates how classic ERP signatures of attention might be modulated by the presence of the hand.

ERP and attention

EEG studies using event-related potentials (ERP) have been utilized extensively in studies on attention because certain ERP waveforms, or components, have been associated with specific perceptual and cognitive processing stages (Luck, 2005). Because EEG can be measured at a very high temporal resolution as processing is occurring in real time, the resulting ERPs are good indicators for distinguishing among early versus late effects of the experimental manipulation that might not be observable from behavioral measures. Spatial cuing paradigms similar to that used by Reed et al. (2006, 2010) have been well studied using EEG and ERP (Hopfinger, Luck, & Hillyard, 2004).

In particular, several ERP components have been shown to discriminate among different attentional effects. The P1 (a positive deflection occurring in the ERP around 80-130 ms) and the N1 (a negative deflection occurring in the ERP around 150-200 ms) are early ERP components thought to reflect selective attention mechanisms (see Figure 2, from Hopfinger & Mangun, 2001). The P1 and N1 appear over posterior to central regions of the scalp, and are maximal in the hemisphere contralateral to the side of presentation (left vs. right) of a visual stimulus. Both show relatively greater amplitudes (i.e., enhancements) to stimuli appearing in attended regions of space compared to those appearing in unattended regions. In other words, the amplitudes of these components are enhanced for targets appearing in recently cued locations (i.e., validly cued), relative to responses for targets appearing in noncued locations (i.e., invalidly cued). However, the P1 and N1 are also enhanced during different tasks. The P1 is enhanced for validly cued targets in both discrimination and detection tasks, suggesting it reflects a primarily bottom-up, reflexive attentional mechanism (Hopfinger & Mangun, 2001). The N1, by contrast, is enhanced for validly cued targets in discrimination tasks, but not detection tasks (Vogel & Luck, 2000), suggesting the volitional addition of processing resources for making difficult discriminations (Luck, 1995). Importantly, the N1 but not the P1 is sensitive to cross-modal tactile cuing (Kennett, Eimer, Spence, & Driver, 2001). Kennett et al. (2001) cued participants on their left or right hand with a vibrotactile stimulus before an LED target would light up near one of the hands. They found enhanced responses at the N1 over occipital sites when the side of the visual target corresponded to that of the tactile cue, but not at the P1. This finding suggested that multimodal information can influence attentional selection at a relatively early stage of processing, but not as early as the P1.

The N1 has separable posterior and anterior forms with slightly different latencies (Luck, 1995). He, Fan, Zhou, & Chen (2004) investigated the N1 response to space- and object-based cues. Specifically, they utilized two horizontally oriented, rectangular visual stimuli that extended across the display and could be cued peripherally at either end. An invalid target that appeared in the same rectangle as the cue was object-based, but an invalid target that appeared in a different rectangle was space-based.

Interestingly, they found modulatory effects of attention on the anterior N1 when space-based cues, but not on the posterior N1. Their findings suggested that the anterior N1 is more sensitive to space-based than object-based attention manipulations, while the posterior N1 is more sensitive to object-based attention shifts. He, Humphreys, Fan, Chen, & Han (2008) confirmed their findings with a topographical analysis which demonstrated that the anterior N1 had a unique scalp distribution and again was enhanced for spatial, but not object-based, cues. Finally, Vogel & Luck (2000) presented participants with a arrays of colored letters to which they had to respond only when a particular color was present, and black letters to which they were required to simply give a detection response. In one of the conditions, speed was emphasized by giving participants feedback about their response times. This latter condition resulted in enhanced anterior N1 amplitudes relative to the other conditions, which the authors suggested was related to the preparation of the motor response which likely was heightened in this particular condition. Thus, because the anterior N1 is sensitive to spatial shifts in attention as well as cross-modal tactile-visual cuing, and may be related to motor response preparation, it is a good candidate for identifying modulations of attention related to the proximal location of the hand to a visual stimulus.

The P3 is a later component that occurs around 300 ms as a large pronounced positivity over central regions of the scalp (Key, Dove, & Maguire, 2005). Although the P3 is easily identifiable and therefore frequently studied, its precise association with a particular cognitive process is less well understood, perhaps because of its pervasiveness across paradigms (Luck, 2005). The classic result associated with the P3 is an enhancement to infrequently occurring stimuli relative to frequently occurring ones, and its amplitude increases as the frequency of targets decreases (Duncan-Johnson & Donchin, 1977). This sensitivity to target probability has been interpreted as reflecting the updating of one’s current context or environment (Donchin & Coles, 1988). However, the P3 is sensitive to attention allocation, and has been used as an index of how much attention is effortfully being used in a particular task (e.g., Jonkman et al., 2000). Finally, in a recent study, Simon-Dack et al. (2009) demonstrated an enhancement in the P3 when multimodal visual and tactile stimuli corresponded. They investigated the ERP response of viewing a visual stimulus, specifically a laser pointer, presented on or near the hand. Attention was increased when the laser shone on the participants finger compared to when it was presented just above the finger, as reflected by enhancements to both the N1 and the P3. Their findings suggest that the P3 may be sensitive to the integration of visual information with inputs from proprioceptive and somatosensory areas. Thus, the P3 is also a good candidate to assess how the allocation top-down attention might be modulated by hand position near the screen.

Current Study

The current study utilizes ERP in order to explore the neural mechanisms underlying the hand-based effect on attention. All of the previous behavioral studies investigating this effect have only measured response times to visual stimuli, making it difficult to draw strong conclusions about how hand position affects attention at different stages of processing. In particular, it is not clear whether the source of attentional bias is bottom-up, perhaps deriving from the tactile and proprioceptive inputs of the hand’s position. It is also possible that top-down inputs are more influential, whether from the functional affordances the hand adds by making targets candidates for action, or from participants explicit awareness of their hand position. Thus, the current study aims to investigate the relative contributions of these potential sources of bias in this effect by studying ERPs which will provide unique insight into early and late stages of processing. Further, because the ERP components under investigation have been well studied in previous visuospatial cuing studies, it will be possible to make stronger inferences about the sources of bias revealed by effects at particular components.

In order to investigate how the presence of the hand might modulate standard attentional effects on these ERP components, we modified the behavioral paradigm developed in Reed et al. (2006) to adapt it to an ERP methodology. First, non-predictive cues were used in this study to ensure that the relative contributions of the *visual cues* were exogenous and bottom-up in nature. Reed et al. (2006) used predictive cues to ensure strong validity effects in their original study, but subsequent work has demonstrated that non-predictive cues are sufficient to elicit validity effects in this paradigm while still observing the bias from the hand (Reed et al., *in preparation*). Second, a visual shield was added to block participants' view of their hands in this study in order to equate visual inputs across conditions. Reed et al. (2006, experiment 3) observed the hand-based effect even when the view of the hands was shielded, although it was slightly weaker as a result. Thus it is possible that a weaker effect might be obtained from using the visual shields, but ERP is a more sensitive and direct measure that can detect smaller cognitive difference that cannot always be detected behaviorally.

The current study also included three experimental conditions: Resting, Up, and Away. In the Resting condition, participants rested their non-responding hand flat on the table, as they would in a classic visuospatial cuing experiment. This condition served as a baseline control condition in which standard ERP results were predicted and would provide confirmation of the effectiveness of the basic paradigm. In the Up condition, participants held their non-responding hand up near the screen by one of the target locations, as was done in Reed et al. (2006). This condition was the critical experimental manipulation from which it would be possible to test the overall effect on standard ERPs of holding a hand up and the specific effect the hand might have on responses to targets appearing near the hand. In the Away condition, participants held their non-responding hand up vertically and away from the screen, with an elbow resting on the table. Because it is unknown what the effect holding a hand up would be on the ERPs, the away condition was designed to control for this variable while maintaining the hands' distance from the target location. Further, Reed et al. (2006) included an experiment in which the hand was held up, but away from the target location, which resulted in an attenuation of the hand-based effect. By including this similar condition, it might be possible to infer the relative contribution of hand-proximity (e.g., as opposed to top-down awareness of hand position) to the overall hand-bias effect. A noteworthy difference between this design and the prior behavioral experiments is that Reed and colleagues (2006; 2010) only compared two conditions in any experiment; for example, one experiment compared conditions in which the non-responding hand was held up near the screen to those in which it was resting on the desk. The design of the current study with three conditions maximizes the efficiency of this initial exploratory EEG study by essentially combining experiments 1 and 4 from Reed et al. (2006).

Finally, the current study increased the number of trials per condition to increase power and decrease noise in order to obtain a high enough signal-to-noise ratio for statistically significant ERPs. Previous ERP studies have utilized a greater number of trials per condition than the current study (e.g., He et al., 2008; Vogel & Luck, 2000), but the number of conditions and the need to counterbalance hand-side precluded the use of such a great number of trials in order to limit the overall session length to a reasonable time. Thus, hand-side as a counterbalance variable was collapsed into a Side variable, with levels ipsilateral and contralateral (i.e., target appears on same side or opposite side of screen as hand, respectively). Categorizing the data in this manner allowed for the doubling of trials per factor cell. However, it should be noted that previous behavioral studies (e.g., Reed et al., 2006, 2010) always included the fully expanded lateralized variables (e.g., left and right hand), and in some cases found lateralized effects in which the hand-bias was stronger for the left than the right hand. It is possible, therefore, that collapsing across hand-size may diminish observed behavioral effects.

Consistent with previous ERP studies utilizing spatial cuing paradigms, a validity effect was predicted to occur for each of the discussed ERP components in which responses to validly cued targets would have a greater amplitude relative to invalidly cued targets. The critical comparisons for the determining hand-based effects on attention in the ERPs are between the Up and Away condition. If simply holding a hand up affected ERPs, then main effects of condition should be observed for one or both of these conditions, relative to the Resting condition. If holding a hand near the screen is critical, then main effects of condition should differentiate the Up condition from the Resting condition. If the proximity of the hand to the target matters, then significant Side by Condition interactions should be observed, in particular for the Up condition. Finally, although previous behavioral studies have not found validity to interact with the hand-bias effects, it is possible that such interactions might be detectable with ERP. Thus, a three-way interaction between Validity, Side, and Condition would indicate that hand proximity not only has an effect on attention, but that the hand can influence the effect of visual cues on attention. Modulations of the different ERPs due to hand position will give insight to the relative contribution of bottom-up and top-down influences elicited by the hand.

Chapter 2: Methods

Participants

Forty-one University of Denver undergraduates (14 male, mean age = 20.6 years) participated for extra credit in Psychology courses. The first nine participants were pilot subjects to ensure that the EEG system worked properly and to train lab personnel; these data were excluded from subsequent analyses. Technical difficulties during testing prevented the completion of the experiment for one participant; this data was also excluded from analyses. One additional participant was excluded for reporting a having a history of serious traumatic head injury. A total of 30 participants' data was submitted for subsequent data processing and analysis.

Stimuli and Apparatus

Stimuli were presented on a 24-inch wide screen monitor with E-prime1.0 for Net Station software (Psychological Software Tools, Pittsburgh, PA) to time-lock stimulus presentation and behavioral responses with EEG recording. Stimuli consisted of a fixation cross (2°), two square target locations (2°), and a solid target circle (2°). Target location squares were located 12.7° to each side of the fixation cross, and the target appeared centered within each square. Stimuli were black against a white background.

Two white foam-core boards (36 cm high, 47 cm deep) were situated vertically on a table in front of the participant to shield participants' view of their hands and equate visual inputs across conditions (Figure 3a). Each board was positioned 0.6° outside each target location and extended outward from the monitor to participant. Participants sat approximately 50 cm in front of the computer monitor with their arms resting outside of the foam-core boards. Responses were given on a four-key button box resting on the table. Depending on the condition, the non-responding hand was positioned in one of three positions depending on the condition. In the Resting condition, it rested flat on the table; in the Up condition, it was held up near and lateral to the target location on the monitor, but still outside the foam-core board, with the palm facing inward (see Figure 3b); in the Away condition, the was held up but away from the monitor with the elbow resting on the table (see Figure 3c).

Electroencephalogram (EEG) Recording

EEG was recorded using a 128-channel Geodesic Sensor Net (Electrical Geodesics Inc., EGI) and data acquisition software (Netstation, EGI). The Sensor Net was a cap consisting of 128 silver/silver chloride (Ag/AgCl) electrodes embedded in sponges soaked in a NaCl electrolyte solution before recording. The circumference of participants' heads were measured to determine the appropriate cap size for their head. Two additional measurements were made to identify reference points on the scalp for proper placement: one over the top of the head from the nasion to inion, and the second over the top of the head from the left to the right preauricular points. The midpoint of these measurements were marked on the scalp with a red grease pencil to indicate the location of Cz. The cap was placed on the head first by aligning the vertex electrode (Vref) with this mark, and bringing the outer edges of the cap down over the rest of the scalp. After securing the chinstrap, the electrodes were distributed evenly across the scalp, including two electrodes positioned below the eyes to record the electrooculogram.

All signals were recorded referenced to a single vertex electrode, sampled at 250 Hz, and filtered at .1 to 100 Hz. Impedances were checked online prior to recording and were accepted when they were below 50 Kohms. EEG was recorded continuously within each experimental block.

Procedure

Participants performed a standard spatial cuing paradigm with a detection response (e.g., Posner & Presti, 1987). The display timing and number of trials were modeled after He et al. (2008) in order to optimize the paradigm for EEG collection. He et al. (2008) found enhancements of the anterior N1 when targets were cued with peripherally located, space-based cues, as in the current study. On the display, the black fixation cross was flanked on each side by a square target location, and participants were instructed to fixate on the cross and not move their gaze away from it. At the start of each trial, the borders of one of the two target location squares darkened by becoming bold (the visual cue). After an SOA of 150 ms, the target circle appeared either in the cued location (valid trial; 45% of total trials) or in the non-cued location (invalid trial; 45% of total trials). Participants responded to the appearance of the target as quickly as possible on the button box. A variable inter-trial interval of 1500-2500 ms followed before a new trial began. On catch trials (10% of total trials), a target would not appear in either of the locations, and participants were required to withhold a response. Each block consisted of 120 trials (54 valid, 54 invalid, 12 catch), resulting in a total of 720 trials for the entire testing session.

Before the start of each block, participants were instructed how to position their non-responding hand in accord to the particular condition for that block (i.e., Resting, Up, or Away). In the Resting condition, participants held their non-responding hand flat on the table in front of them. In both the Up and Away conditions, participants held their non-responding hand up by resting an elbow comfortably on the table. In the Up condition, the hand was positioned near the target location on the screen, but outside the visual shield, with the palm open and facing inward (see Figure 3b). In the Away condition, the hand was positioned vertically and laterally, approximately 60 cm from the monitor, with the palm held comfortably open (see Figure 3c). Each condition was performed twice, once for each hand, for a total of 6 blocks, and blocks occurred in random order. Participants were given the opportunity to rest their eyes between each block, and impedances were rechecked every two blocks. The overhead lights were dimmed during testing and turned back on during breaks.

Prior to the experimental blocks, participants performed a brief practice block of the Up condition with the left hand consisting of 14 trials (six valid, six invalid, two catch trials) to ensure they understood the task.

Behavioral Data Processing

Errors (i.e., responses to catch trials) were tabulated for each participant. Eight participants responded excess of 15% of the catch trials and were excluded from further analysis. Results from previous studies (e.g., Reed et al., 2010) have indicated that this high degree of errors reflect inattention to the task resulting in aberrant data patterns. For the remaining participants, mean response times (RTs) were calculated for each condition (Resting, Up, Away), trial validity (Valid, Invalid), and target side with respect to non-responding hand (Ispilateral, Contralateral). To eliminate errors from anticipation and inattention, only RTs within a 150 to 900 ms time window were included in the mean calculation. One participant was excluded from further analysis for having RTs that exceeded this time window greater than an average of 15% of the total trials, because the generally slow response times likely reflected inattention.

Finally, because we were interested particularly in how hand-position might modulate validity effects in the ERPs, only participants who demonstrated reliable validity effects behaviorally were included in subsequent analyses. This was defined as having faster overall RTs to valid relative to invalid trials in at least four out of the six experimental blocks. In addition, we were also concerned that the extended length of this experiment may have contributed to participant fatigue and inattention (see *Behavioral Analyses by Block* below) and as a result, participants would stop responding to the cues and stop displaying a validity effect. By these criteria, an additional three participants were excluded from further analysis.

EEG Artifact Removal and Data Reduction

The EEG data were processed offline using Net Station 4.1 software (Electrical Geodesics Inc., EGI). The continuous data were first digitally filtered using 0.1 Hz high-pass and 90 Hz low-pass elliptical filters, based on filters used by previous studies (e.g., He et al., 2008). The data were next segmented into 900 ms epochs (100 ms pre-cue baseline, 150 ms SOA between cue and target, and 650 ms post-target), anchored to target onset (target = 0 ms time point), and labeled according to condition (Resting/Up/Away), trial validity (Valid/Invalid), and target proximity to the non-responding hand (Ipsilateral/Contralateral for targets appearing on the same/opposite side of the monitor as the hand, respectively). The segments were visually inspected for artifacts, and were excluded from further analysis if they contained evidence of eyeblinks or eye-movements, which result in large amplitude fluctuations that can significantly alter ERPs if they remain in the averages. The remaining segments were scanned for off-scale activity and were marked bad for containing activity greater than +/- 150 µV, movement artifact, or high frequency noise. Individual channels that were marked bad in more than 60% of the segments for each participant were excluded from the entire recording. Segments containing more than eight bad channels (not including channels marked bad for the entire recording) were excluded from further analysis. Three participants were excluded from further ERP analysis for having too few artifact free trials per condition. The remaining artifact-free trials for each segment type were averaged together to produce 12 ERPs [Condition (3) x Validity (2) x Side (2)] for each participant. The number of artifact free trials included in the average for each segment type ranged from 32 to 54 (M = 43.7; SD = 6.21). Channels that previously were marked bad for the entire recording were replaced using spherical-spline interpolation. All data were mathematically converted to the average reference and then baseline corrected by subtracting the mean voltage of the 100 ms pre-cue baseline from the voltage value at each time point in the remainder of the segment.

ERP Selection and Definition

Previous ERP studies investigating the anterior N1 have found validity effects over central leads (e.g., He et al., 2008; Zhou & Chen, 2004). Thus, a central channel group corresponding roughly to Cz and slightly posterior was selected to analyze the P1/N1 complex (Channels vref, 32, 55, & 81; see Figure 4a). A peak-to-peak measure was utilized to maximize any differences between conditions occurring across both the P1 and N1. This peak-to-peak measure was defined as the difference between the maximum peak amplitude of the P1 and the minimum peak amplitude of the N1. Following a visual inspection of individual participants' ERPs, windows for each component were defined that would encompass the peak amplitude for a given component for every individual, while not including the peak from other components. Thus, the peak amplitude of the P1 was defined as the maximum point of the ERP relative to baseline within a 60 to 150 ms time window. The peak of the N1 was defined as the minimum point within a 120 to 220 ms time window. Then, for each channel, the peak amplitude of the P1 was subtracted from the peak amplitude of the N1. The resulting values for each channel were averaged together to obtain the value for the group.

The P3 was also observed over central leads, but was more widespread and identifiable of a larger area. In order to maximize the signal-to-noise ratio of the P3, a larger channel group was chosen for these analyses, corresponding roughly to Cz and CPz (Channels 7, 107, vref, 32, 55, 81, 38, 54, 62, 80, & 88; see Figure 4b). Because it has a less well-defined peak, mean amplitude was used to analyze the P3, defined as the average amplitude within a 300 to 500 ms time window. The means for each channel were averaged together across the channel group.

Finally, due to technical difficulties with achieving good scalp contact with leads over occipital regions, the overall quality of the data at occipital leads was noisy and not optimal, precluding analyses of posterior P1 and N1 components.

Chapter 3: Results and Discussion

Alpha was set at the .05 level for all analyses. All *t*-tests are two-tailed, and all reported effects are Greenhouse-Geisser corrected where appropriate.

Behavioral Analyses

In order to confirm the replication of the basic cuing paradigm and hand-bias effect, RTs were first analyzed in an omnibus Analysis of Variance (ANOVA). Of the 30 participants who successfully completed the experiment, nine were excluded for excessive responding to catch trials or slow RTs, and an additional three were excluded for signs of inattention evident by a lack of consistent validity effect in their individual data. Mean RTs from the remaining 18 participants were submitted to a 3 X 2 X 2 repeated measures ANOVA with factors Condition (Resting, Up, Away), Validity (Valid, Invalid), and Side (Ipsilateral, Contralateral). Confirming the basic cuing paradigm, a main effect of Validity was found [$F(1,17) = 8.79$, $p < .01$, $MS_e = 7{,}655.27$], in which responses to validly cued targets [$M = 345$ ms, $SE = 16.7$] were faster than responses to invalidly cued targets [$M = 357$ ms, $SE = 18.4$]. The hand-bias effect was not replicated in the behavioral analysis, neither as a main effect of Condition [$F(1,17) = 1.11$, $p = .33$, $MS_e = 2404.54$], nor in the Condition X Side interaction [$F(2,34) = 0.61$, $p = .53$, $MS_e = 130.58$]. There were no interactions of a potential hand-bias effect with Validity either: in the two way Condition X Validity interaction [$F(2,34) = 1.14$, $p = .325$, $MS_e = 259.79$] nor in the three-way Condition X Validity X Side interaction [$F(2,34) = 1.14$, $p = .325$,

$MS_e = 259.79$]. No other main effects or interactions were significant (see Table 1 for full statistics).

Although the two-way and three-way interactions in the omnibus ANOVA were not significant, we predicted validity effects at each of the conditions which potentially could be modulated by hand position. Thus, *a priori* paired *t*-tests comparing validity in each condition and location were conducted in order to determine where the strongest validity effects were occurring. Validity effects were significant in the Resting condition on both the Ipsilateral [$t(17) = 3.23$, $p < .01$] and the Contralateral sides [$t(17) = 2.23$, $p < .05$], in which RTs to valid trials were faster than those to invalid trials (see Table 2 for full statistics)]. In the Up condition, a similar validity effect was found on the Contralateral side [$t(17) = 2.53$, $p < .05$], but not on the Ipsilateral side [$t(17) = 1.70$, $p = .11$]. Finally, in the Away condition, a marginally significant validity effect was found on the Contralateral side [$t(17) = 1.97$, $p = .06$], but it was not significant on the Ipsilateral side [$t(17) = 1.37$, $p = .19$]. In summary, a validity effect was found across sides in the Resting condition, but it was only found contralateral to the hand in the Up and Away conditions. This pattern of results across suggests that although the interactions were not significant in the omnibus ANOVA, there may have been some influence of the hand on validity effects when it was held up either near or away from the screen.

These behavioral results are different from previous experiments using similar paradigms (Reed et al. 2006, 2010). However, as discussed in the introduction, a number of differences exist between the prior studies and this one. In addition to the EEG measure and as a result of using it, the length of this experiment had to be extended considerably relative to previous studies. This occurred both as the result of the inclusion of an extra condition (i.e., Away) as an extra control comparison, and of the extension of the number of trials in individual blocks to include enough trials achieve good signal-to-noise ratio in the ERP. Further, previous studies investigating this effect typically include about 36 subjects for each experiment in order to achieve enough power to discriminate among effects in a 2 X 2 factorial design. Although 41 participants total were tested in the current study, an unusually high attrition for this paradigm was observed, partly due to technical difficulties with EEG recording, but also due to a large number of catch trial responders. Repeated responding to catch trials is typically regarded as a sign of inattention or fatigue on the part of the participant. This high level of inattention among the participants, which resulted in the high attrition rate and consequent lack of power, may have been due to the extended length of the experimental blocks and session overall. In order to investigate this hypothesis further, we conducted a block analysis on the behavioral data to explore the possibility of fatigue or inattention effects.

Behavioral Analysis: Block Analysis

In order to determine the overall effect of the session length on mean RTs and validity, a 2 X 6 repeated-measures ANOVA with factors Validity (Valid, Invalid) and Block (Block 1, 2, 3, 4, 5, 6) was conducted using the means from the 18 participants who met the criteria to be included in the final analysis. A main effect of Validity was found [$F(1,17) = 8.79$, $p < .01$, $MS_e = 7,655.27$], in which responses to validly cued targets [$M = 345$ ms, $SE = 16.7$] were faster than responses to invalidly cued targets [$M = 357$ ms, $SE = 18.4$]. Note this is identical to the main effect of validity found in the original omnibus ANOVA on RTs. A main effect of block was also significant [$F(5,85) = 8.93$, $p < .0001$, $MS_e = 18865.03$], in which RTs appeared to decrease following after the first and second block, after which they reached an asymptote and remained steady for the remainder of the experiment (see Figure 5). Paired *t*-tests between consecutive blocks confirmed that the mean RT for Block 1 [*M* = 388 ms, *SE* = 19.0] was greater than the mean RT for Block 2 [*M* = 371 ms, *SE* = 16.3; *t*(17) = 2.27 p < .05], and that the mean RT for Block was greater than that for Block 3 [*M* = 347 ms, *SE* = 15.9; *t*(17) = 3.55 p < .01]. The rest of the paired comparisons were not significant (all *t*'s < 1, *n.s.*; see Table 2 for full statistics). The decreasing asymptotic curve of RTs across blocks suggested a prevalent learning effect was occurring in which participants' ability to perform the task increased over time.

Such a learning effect could decrease the variability of the sample over time, leading to a ceiling effect that could conceal other effects as the experiment carried on. To test this hypothesis, paired *t*-tests comparing validity were conducted at each block. Significant validity effects were found in Blocks 1, 2, 4, and 5, (all p < .05) and a marginally significant validity effect was found in Block 3 (p = .052), but the validity effect in Block 6 was not significant (*t* < 1, *n.s.*; see Table 3 for full statistics). This pattern of results suggest that enough variability existed among the RTs until the final block, at which point the mean RTs to valid versus invalid trials were statistically indistinguishable. In other words, the visual cues seemed to have little or no effect on participants' attention once they reached the 6th block. Together with the previous analyses, this suggests that participants gradually became better at the detection task until Block 3 when their RTs reached a ceiling. After this, however, their performance at detecting the target may have continued to improve until the visual cues had no effect on their visual attention. Although this is not a clear sign of fatigue, it does suggest a particular form of inattention as peripherally located visual cues are typically thought to automatically, *endogenously* shift attention in their direction. This did not occur until the 6th block, suggesting that the overall length of the experiment contributed to this inattention.[1]

Because the analysis of validity over block suggested that the learning effect did not settle until the third block, it was possible that the hand-bias effects might be found by only analyzing the first three blocks. However, because block order was randomized across participants, there was little overlap among the particular conditions performed by each participants in the first three blocks. Thus, in order to investigate this possibility, data from the first three blocks were analyzed with condition as a between subjects variable to ensure that each participant had at least two full blocks of a particular condition. This resulted in approximately one-third of the entire sample being allocated to each condition. Specifically, the Resting condition had five participants, the Up condition had six participants, and the Away condition had five participants. The RTs from these participants were analyzed in a 2 X 2 X 3 repeated measure ANOVA with within subjects factors Validity (Valid, Invalid) and Side (Ipsi-, Contralateral) and between subjects factor Condition (Resting, Up, Away). None of the effects from this analysis were significant (see Table 4). However, splitting Condition into a between subjects variable resulted in a very small N for each group. In consideration of this limitation, the three-way interaction of Validity X Side X Condition is of potential interest [$F(1,13) = 1.755$, $p = .212$, $MS_e = 220.103$]. In the general pattern of mean RTs, a weak validity effect can observed for both sides in the resting condition, and potentially although to a lesser

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[1] Analyses including the participants excluded for responding to catch trials and for not having validity effects resulted in this same pattern of results.

degree for the contralateral side in the Up and Away conditions (Figure 6). However, the validity effects are either potentially not present for the ipsilateral side in the Away condition, or reversed for the ipsilateral side in the Up condition. This suggests that the hand-bias effect may have been observable earlier in the experiment before learning effects decreased variability in participants performance later in the session.

In summary of the behavioral data, validity effects were found confirming the basic paradigm. Although the hand-based bias was not replicated behaviorally, paired comparisons suggested that holding a hand up (both near to and away from the screen) may have affected validity effects in locations near the hand. This possibility was supported by analyses using only the first three blocks of data in order to avoid contamination by learning effects in the latter portion of the experiment. Factors such as having small N due to attrition, inattention, and lack of variability due to learning may have decreased power to such an extent that the critical interactions for a replication were apparent in the omnibus ANOVA. Nevertheless, because ERP is a more sensitive measure than behavioral RTs, it is possible that hand-based affects on attention may be observable in the ERPs that were not apparent in the behavioral data.

ERP Analysis: P1 & N1

Of the 18 participants included in the behavioral analyses, three additional participants were excluded from ERP analysis for having too noisy or too flat ERPs with non-distinct components, leaving a total of 15 participants for ERP analysis. Figure7 plots the grand average of the ERP for valid and invalid trials in the Resting condition at the vertex electrode. The P1 is observable as a positive deflection peaking at around 80 ms, and the N1 is observable as a negative deflection at 150 ms.

In order to confirm the effects of visual cuing (i.e., validity effects) on early components in the ERP and to test how hand position might modulate early ERPs, the P1/N1 peak-to-peak measure was analyzed in an omnibus ANOVA. Mean peak amplitude differences between the P1 and N1 were submitted to a 3 X 2 X 2 repeated measures ANOVA with factors Condition (Resting, Up, Away), Validity (Valid, Invalid), and Side (Ipsilateral, Contralateral). The main effect of Validity was not significant [$F(1,14) = 1.79$, $p = .202$, $MS_e = 2.254$], suggesting that the validity effect observed in the behavioral results was not reflected or detectable in the P1/N1 complex. A hand-bias effect was not observed, either as a main effect of Condition [$F(1,14) = 1.824$, $p = .180$, $MS_e = 1.714$], nor as an interaction of Condition X Side [$F(1,14) = .092$, $p = .903$, $MS_e = .107$]. Finally, none of the interactions with Validity were significant, including the critical three-way interaction [$F(2,28) = .656$, $p = .505$, $MS_e = .754$]. Thus there was no detectable validity effect in the P1/N1 complex, nor was there an observable effect of the hand. None of the other main effects or interactions in this omnibus analysis were significant (see Table 5 for full statistics).

Although there were no significant effects in the omnibus analysis, and because validity effects were predicted based on previous studies and the behavioral results, paired *t*-tests comparing valid and invalid trials were conducted to determine if any validity effects were occurring in any of the conditions or sides. A significant validity effect was found in the Up condition, contralateral to the hand [$t(14) = 2.79$, $p < .02$] in which valid trials had a greater amplitude peak difference [$M = 3.76$ µV , $SE = .505$] than invalid trials [$M = 3.14$ µV, $SE = .441$]. All other paired comparisons were not significant.

These results are different from previously reported results that used a subset of these data (Garza, Reed, & Snyder, 2009). In that preliminary subset of the subject group, validity effects were found for both sides in the Resting condition, and for the contralateral side in the Up condition. These previous results suggested that the P1/N1 complex was sensitive to trial validity in the Resting condition, but that when the hand was held up, amplitude for invalid trials near the hand were increased to the same level as that for valid trials, eliminating the validity effect. Although the results in the current study are not statistically significant, the same pattern of data is still observable in the ERPs across these two conditions (Figure 8).

In summary, the early ERP components did not indicate significant influences of the hand on visual attention. None of the statistical tests from the omnibus ANOVA were significant and only one of the directed comparisons of validity was significant. Cognitive process can have effects on the latency of the peak of ERP components in addition to their amplitude (Luck, 2005). The latency of the N1 was thus analyzed in similar statistical analyses as those above, but none of those effects were significant. Finally, visual inspection of the grand means suggested that leads over the right hemisphere might have more pronounced effects than leads over the left hemisphere. Because non-predictive, peripherally located visual cues are known to affect the amplitude of both the P1 and the N1, it is likely that non-optimal testing factors in this particular study masked observable results. In particular, the lack of significant results in these early ERP components may have been due to poor signal-to-noise ratio due to a smaller than desirable number of trials per condition and the same potential lack of power that affected the behavioral results.

ERP Analysis: P3

Although significant effects were not found for the earlier components, it was possible that more top-down effects on attention were occurring at the later P3 component, or that influences from somatosensory or proprioceptive inputs could be reflected later (Simon-Dack et al., 2009). It was also possible that earlier, masked effects from the P1 or N1 could be observable downstream. Further, the P3 is a larger, more robust ERP component that requires fewer trials to achieve a more reliable signal. The P3 is observable in Figure 7 as a large slow wave that begins at around 300 ms and continues for approximately 200 ms.

In order to test whether trial validity had an effect on the amplitude of the P3, and to determine if hand position modulated any validity effects observed there, the mean amplitudes for the P3 were analyzed in an omnibus ANOVA. Mean amplitudes for the P3 were submitted to a 3 X 2 X 2 repeated measures ANOVA with factors Condition (Resting, Up, Away), Validity (Valid, Invalid), and Side (Ipsilateral, Contralateral). A main effect of Validity was found [$F(1,14) = 11.88$, $p < .01$, $MS_e = 5.597$], in which the mean amplitude in response to validly cued targets [$M = 2.42$ µV, $SE = .450$] was greater than that to invalidly cued targets [$M = 2.07$ µV, $SE = .411$], consistent with the validity effects observed in the behavioral results. A hand-bias effect independent of Validity was not observed either as a main effect of Condition [$F(1,14) = .128$, $p = .863$, $MS_e = .200$], nor as an interaction of Condition X Side [$F(1,14) = .933$, $p = .394$, $MS_e = .580$]. However, the Condition X Validity interaction was significant [$F(2,28) = 3.72$, $p < .05$, $MS_e = 1.502$], suggesting that validity effects were modulated by hand-position in at least one of the conditions. The three-way Condition X Validity X Side interaction was not significant [$F(2,28) = .257$, $p = .729$, $MS_e = .219$], suggesting that the hand-bias interaction with Validity was not localized to the region near the hand. No other main effects or interactions were significant (see Table 6 for full statistics).

Paired *t*-tests comparing validity at each condition were conducted in order to explore the Condition X Validity interaction. The validity effects were significant in both the Resting [$t(14) = 2.56$, $p < .05$] and the Away [$t(14) = 4.47$, $p < .001$] conditions, but not in the Up condition [$t(14) < 1$, *n.s*. Figure 9]. In the Resting condition, mean amplitude was greater for valid trials [$M = 4.82$ µV, $SE = .873$] than for invalid trials [$M = 3.92$ µV, $SE = .813$]. Similarly, in the Away condition, mean amplitude was also greater for valid trials [$M = 5.14$ µV, $SE = .940$] than for invalid trials [$M = 3.91$ µV, $SE = .900$]. These results suggest that cue validity had an effect on the P3 when the hand was resting or held away from the screen in which the mean amplitude for the component was greater for validly cued targets than invalidly cued targets. When the hand was held up near the screen, however, no validity effect was observed. Although the three-way interaction was not significant, the pattern of means in Up condition appeared to be that of a validity effect in the contralateral location, and a reversal of this pattern in the ipsilateral location, near the hand. This would suggest that the amplitude of the P3 was affected by hand proximity such that the validity effect in this region was reversed. To test whether the contralateral validity effect or the ipsilateral reverse validity effect were significant, paired comparisons of validity were conducted for each location. Neither paired *t*-test was significant (all *p*'s > .05). To test whether hand proximity was modulating P3 amplitude for a particular validity type, location was compared for valid and invalid trial types. Again, neither paired *t*-test was significant (all *p*'s > .05).

It was possible that the observed effects at the P3 were actually the result of downstream effects from the P1/N1 complex that may have influenced later components. In order to test this hypothesis, Pearson correlations were conducted for each condition between the peak-to-peak amplitude measure from the P1/N1 and the mean amplitude of the P3. None of the correlations across ERP components were significant (see Table 7), suggesting that the effects observed at the P3 were not a result of earlier effects occurring at the P1/N1.

In summary, the results from the analysis of the P3 confirmed the effect of the visual cues on attention in the ERP and indicated a potential hand-based effect on attention. The amplitude of the P3 was greater for valid trials than for invalid trials for both control conditions (Resting and Away). There was no validity effect present when the hand was held near the screen, suggesting that hand proximity modulated the validity effect. Although it appeared as though the validity effect reversed for targets appearing near the hand, this could not be confirmed by paired comparisons. Because there were no statistically significant differences in the Up condition, it is not clear whether hand proximity was affecting the amplitude of the P3 in this condition or whether the simple act of holding the hand up near the screen affected the amplitude for both sides. Because the P3 reflects higher level cognition, it is possible that the modulation of this particular component may have been due to top-down influences, such as the participants interpretation of the condition. In other words, participants were directly instructed to position their hand near the screen for the Up condition, and away from it or resting in the other two conditions. It is possible that their explicit knowledge of the experimental manipulation in this manner may have altered their perception of the task or their strategy in performing it. As noted earlier, the P3 can reflect many different higher level cognitive processes, so it is not clear from these results alone what might be driving this particular effect. However, it is noteworthy that positioning the hand near the screen can affect validity effects in the P3 at all.

Chapter 4: General Discussion

Summary

This study is the first to investigate hand-based bias effects on visual attention using ERP. Previous behavioral studies have demonstrated that holding a hand near the screen during a spatial cuing task can bias attention to the space near hand, facilitating responses to targets appearing in that space (Reed et al., 2006, 2010). The aim of the current study was to investigate the relative bottom-up and top-down contributions of hand-based effects on visual attention with ERP. Participants performed a detection task in three conditions, in which their hand was either resting on the table (Resting condition), up near the screen (Up condition), and up away from the screen (Away condition), and both early and later occurring ERPs were analyzed to attempt to discriminate between bottom-up and top-down effects on attention, respectively.

For the behavioral results, we predicted to replicate the original hand-based attentional bias in the behavioral results that was found in previous behavioral studies. A general validity effect was found, which confirmed the basic visual cuing paradigm. None of the critical interactions with and between the factors of condition and hand-side were significant. The lack of a condition X hand-side interaction indicates that the hand effect from previous behavioral studies was not replicated. The limitations that may have contributed to this lack of replication will be described below.

Despite the lack of replication in the behavioral results, we hypothesized that because ERP is a more direct and sensitive measure, hand-based effects might still be observable in the ERPs. For all of the ERP components, we predicted to observe enhancements (i.e., greater amplitudes) in response to validly cued trials relative to invalidly cued trials. We additionally hypothesized that hand position could modulate of these validity effects in responses to targets appearing near the hand. First, the P1/N1 complex was analyzed using a peak-to-peak measure to maximize potential differences in amplitude across conditions. Unfortunately, none of the effects in the omnibus ANOVA for these early components were significant. The N1 and P1 are both typically enhanced to validly cued targets, but this was not found in these data, even though a general validity effect was present in the behavioral results. In a previously presented abstract using a subset of these data (Garza et al., 2009), we found a general validity effect in the Resting condition and a localized one in the Contralateral side of the Up condition, but not in the Ipsilateral side of the Up condition side. In these previous results, it appeared as though responses to invalid, but not valid, trials were getting an extra enhancement from the proximity of the hand, diminishing the validity effect. The same general pattern of data was observed here, but because none of the statistical tests were significant, concrete conclusions could not be drawn.

The last set of analyses investigated potential effects of the hand on later attentional processes by examining the mean amplitude of the P3 component. Consistent with the behavioral results, a general validity effect was found for the P3 in which the mean amplitude was greater in response to validly cued trials than to invalidly cued trials. Further, an interaction between condition and validity revealed that validity effects were present for the two control conditions (i.e., Resting and Away), but were not for the critical Up condition. Although the pattern of data in the Up condition suggested that a validity effect might be present contralateral to the hand, but not near it, these differences were not significant in the analyses. Thus, the most we can conclude from these results is that holding a hand up to the screen altered the response of the P3, regardless of the location of the target with respect to the hand. This result likely was not the result of noise from holding a hand up in general, as the validity effect was still present in the Away condition.

The P3 is thought to reflect more top-down influences on attention such as context updating (Donchin & Coles, 1988) and the volitional allocation of attention (e.g., Jonkman et al., 2000). It is possible, therefore, that the act of holding a hand near the screen altered participants' engagement with the task and the influence of bottom-up cue validity at this later stage of processing. In other words, the cues may have shifted attention early on in a bottom-up manner, but the context of the Up condition may have masked ongoing effects of cue validity later in the ERP. We know from recent experiments in our laboratory that task instruction and experimental context can have a significant effect on the behavioral outcome of hand-position experiments (Reed et al., *in preparation*). Although holding a hand up near the screen was not explicitly relevant to the detection task in the current study, participants were clearly aware of their hand position and the instructions to place them near the screen as an experimental manipulation. This awareness of the situation may contribute to the lack of validity effect in the P3 observed in the Up condition. Although it is possible that the effects at the P3 may have reflected downstream attentional effects from earlier components, correlations between the P1/N1 and P3 were not significant. However, because the overall ERPs may have been too noisy to achieve good signal-to-noise ratio at these earlier components, the lack of significant correlations may have occurred as a result of this noise. Determining the precise effect that hand position had on the P3 requires more study.

Theoretical Implications

Recent behavioral studies have demonstrated how hand-position can affect visual attention in bottom-up (Cosman & Vecera, *submitted*), as well as in top-down directions (Reed et al., *in preparation*). Although the current study was largely inconclusive, findings at the P3 suggested that top-down influences related to hand position may have altered how bottom-up visual cues were processed later in cognition. Given the potential for both top-down and bottom-up influences in these effects of hand position on visual attention, it is useful to interpret these findings within the context of the biased competition model of attention (Desimone & Duncan, 1995; Duncan, 2006). In this model, attention is defined by the competition among stimuli entering the processing stream. Each stimulus may be represented perceptually at the earliest stages of processing, but stimuli with more salient features (e.g., brightness) will “win” the competition to be selected for further processing. This competition represents bottom-up, stimulus driven types of attention. Importantly, the competition is biased in a top-down direction from other cortical areas, depending on an individual’s task, goals, and other contextual factors, to favor one stimulus for selection over others. Because the competition among stimuli can occur across sensory modalities, and the source of the bias may originate from multiple brain regions, this model provides a mechanism for how influences from different neural systems may be integrated for functional and goal oriented behavior.

With respect to the attentional bias of the hand on visual attention, the model provides a good framework from which to continue exploring the neural mechanisms underlying this effect. Bottom-up and top-down factors appear to interact to produce the behavioral effects observed so far. It might be the case that the various bottom-up features introduced when the hand is present add to the competition already in progress among the various visual stimuli in the experiments. Further, top-down factors may play a greater role in classic visual attention experiments when participants are explicitly asked to perform the unusual task of placing their hand near the screen. In spatial cuing paradigms, the visual cue shifts attention to a target location in a bottom-up manner. In the current study, additional competition may originate from the proximity of the hand in the form of tactile, proprioceptive, and even additional visual information. This is all subject to top-down bias from higher level executive systems, however, depending on the goals and interpretation of the task by the participant. Because embodied factors can potentially influence attention from both directions, future studies should aim to identify what particular embodied factors predominate in the control of attention as well as the direction of their influence.

Limitations and Recommendations for Future Study

The results of the current study were limited by a number of shortcomings in the design and execution of the experiment. Unfortunately, the predicted results regarding the influence of hand position generally were not observed in the behavioral data, nor in the ERPs. Many of the null findings in this study, however, may have stemmed from issues of low power, high attrition, lack of engagement by the participants, and possibly some minor technical difficulties. Despite these shortcomings, it is important to remember that this was the first ERP study to investigate hand-based effects on attention, and it provided many indications of how future studies should proceed.

The lack of replication in the behavioral results may have occurred for a number of reasons. First, the sample size of the data set was too small due to an exceptionally high attrition rate. More participants were excluded from analysis than anticipated for frequent responses to catch trials. This reduced the sample size of the data, but it also suggested that inattention may have been a general problem during testing. A noteworthy difference between this study and the previous behavioral ones was the length of the testing session. Because ERPs require a greater number of trials per condition than behavioral studies, the length of the blocks was more than doubled relative to previous studies. Further, the previous behavioral studies typically only included two conditions per experiment – an experimental condition and a control. The current study included an additional control in the Away condition, but this also increased the overall length of the testing session by a third. Thus, a second factor that may have produced the lack of replication was the length of the experiment, which potentially contributed to inattention and fatigue. Block analyses demonstrated that RTs became consecutively faster until the 3rd block, suggesting the existence of a learning effect. Such a learning effect could result in a floor effect in which RTs reach their maximum speed, regardless of experimental condition. It is also possible that participants became good enough at the detection task that they were able to mentally disengage from the other aspects of the experiment not relevant to achieving the goal of responding quickly and accurately. Such an effect could potentially decrease overall variability in responding, consequently masking interactions with critical variables. Paired comparisons revealed a lack of validity effect in the final block, even for the participants who met all the criteria to be included in the final analysis. This suggested that the visual cues were not affecting visual attention by the end of the testing session, again possibly due to fatigue or disengagement from the more peripheral aspects of the experiment.

The limited results from the ERP data, especially among the earlier occurring ERP components, may have resulted from poor signal-to-noise ratio and lack of power. Typical ERP studies investigating effects at the P1 and N1 can include up to four times the number of trials per condition as that used in the current study in order to achieve a good signal-to-noise ratio. Using such an extensive number of trials in the current study would have significantly increased the testing time, the length of which was already an issue. We attempted to ameliorate this limitation by collapsing left and right hand conditions into the factor Side, with contralateral and ipsilateral target locations. Although this effectively doubled the number of trials per condition, it may not have been enough to obtain observable effects at these early components. Coding in this manner also had the cost of limiting the types of hemispheric laterality analyses possible. Although it was possible to compare effects across brain hemispheres in general, it was not possible to investigate lateralized responses to stimuli in particular visual hemifields. In previous behavioral studies (Reed et al., 2006, 2010), the effect of hand position on attention was often lateralized, appearing stronger when the left hand was held up, relative to the right hand. It is further possible, therefore, the effect observed in the current study was weakened from collapsing over hand-side. Because of these limitations and nulls findings, it is perhaps too early to draw strong conclusions about the potential effect of hand position on these early ERP components.

Because the overall length of this experiment was such a central limitation, future studies should aim to reduce the length of the testing session, or build in safeguards that can compensate for problems stemming from the length. First, the current study used three conditions in a single experiment to maximize efficiency and control. It might be more effective in this case, however, to implement the conditions in a between subjects design, or else to conduct a series of experiments with 2 X 2 that sequentially rule out confounds. Second, the number of trials per condition requires a delicate balance in order to obtain the amount of data necessary for a good signal-to-noise ratio in the ERPs, while ensuring that participants do not succumb to fatigue and inattention. Having fewer conditions would certainly help with this issue as well, but a large number of trials would still be needed for clear data. An additional recommendation, therefore, would be to include more breaks from the task and divide the testing session into smaller blocks. Third, a more engaging task than simple target detection could be used to better maintain participants' attention throughout testing. A discrimination task (e.g., responding to red vs. blue targets with a forced-choice button response) could help to ensure that participants stay engaged with the task, and it would allow the analysis of error rates as additional measure of engagement. However, it would be important first to determine how hand-bias might transpire in such a discrimination task, because an alternate task may engage different neural systems (e.g., ventral processing stream for color discrimination) to result in a different overall pattern of results.

Finally, the overall length of the experiment could be reduced simply by utilizing a paradigm with few factors. Although an aim of the current study was to adapt the paradigm utilized by Reed et al. (2006, 2010) to an adapted ERP study, it might be the case that a spatial cuing paradigm is not the best suited method for an initial ERP investigation of hand-based effects on attention. Not only does spatial cuing require a great number of trials to produce effects in the P1 and N1, but including cue validity adds an extra factor that can potentially interact with the variable of interest, hand position. Spatial cuing is just one among many paradigms that have been utilized to study attention, and others may be better suited for ERP. For example, an oddball paradigm, in which participants are required to respond only to infrequent targets in a stream of frequent and infrequent stimuli, would eliminate validity as a factor, decrease the number of necessary trials, and still reflect effects on attention in ERP.

Another potential error in the design of this experiment that was not recognized until data collection was complete was the lack of a temporal ‘jitter’ between the cue and the target. In other words, although the ERPs were time-locked to the target, there was no variation in timing between the cue onset and target onset. Thus, the ERPs were also essentially time-locked to the cue, and ongoing ERPs in response to the cue may have contaminated the response to the target which was of interest. This is a distinct possibility given the short SOA of 150 ms. However, concern for this issue is eased somewhat by previous studies that have used similar paradigms without a jitter between cue and target (e.g., He et al., 2008), and by the grand mean in the current study appearing generally similar to those in the previous study. The current study also used a peak-to-peak measure to analyze the P1/N1 complex, which may have helped diminish this concern by subtracting out any lasting effects from the cue.

Further limitations of the current study had less to do with the design and more to do with data collection and the testing apparatus. The current study used a high-density EEG recording cap (EGI, Electrical Geodesics, Inc.), in which the electrical sensors are embedded in electrolyte soaked sponges that rest on the participants scalp. Although this recording method has many advantages over more traditional EEG recording systems, including more data from the high-density recording and ease of electrode application, it is not without imperfections. Foremost among the issues with the cap is its basic fit across participants, particularly over posterior regions of the scalp. Although the cap is designed to fit snugly, for many participants it was difficult to achieve good contact with the scalp for occipital leads, because of a number of factors including hair length, hair type, and even basic head shape. These factors are particularly problematic for the EGI caps used in the current study because the electrodes are embedded in sponges that sit on top of the scalp. Because of the shape and size of the sponges, it is not always possible to obtain a good degree of contact with the scalp with certain hair types. As result of this limitation, data from leads over occipital regions were generally too noisy for analysis.

Another relative advantage of the EGI system is that the electrical impedance at each electrode does not need to be as low as in gel-based, low impedance systems in order to obtain a good signal. The recommended setting is to keep impedances below a 50 Kohm threshold. During pilot testing, however, we discovered that noise from leads across the scalp could be significantly reduced by ensuring the impedance at the vertex electrode, which served as the reference for all other leads, was reduced as much as possible. Frequently, this meant lowering its impedance measure to less than 10 Kohms, even after it was well below the recommended threshold. This was not done to every electrode, however, and it leads to speculation about the quality of data collected from other leads that were considered ‘good’. This is of particular importance for the P1 and N1 components, which are relatively small and potentially subject to being masked by noise.

In an issue related to the previous shortcoming, the data from certain participants appeared to be contaminated by a high frequency noise that was apparent even during recording. This seemed to occur randomly to particular participants, and although reducing the impedance of the reference electrode helped reduce the noise, it could not always be eliminated completely. The source of the noise could not be localized, but correspondence with two other laboratories using the EGI system revealed similar problems for them. One possible cause of the noise may stem from the usage of relatively old electrode caps, though this hypothesis is only speculative. An outside source may also be contributing to the noise as the testing rooms are not electrically shielded from the outside environment. Further testing and communication with EGI is needed to determine the origin of this problem.

In summary, the prevalence of null findings in this study may stem from a number of limitations in its design and implementation. The largest issue appeared to be related with the length of the testing sessions, which could be reduced in future studies by limiting the inclusion of conditions and taking advantage of paradigms and designs that would reduce participant fatigue and inattention. Finally, technical limitations may have reduced the quality of the ERP data.

Future Directions

This study provided an initial step towards understanding how the body and its effectors might influence attention at a neural level. It showed limited support for an influence of the hand on attention in the P3, 300 to 500 ms following target onset. However, a number of questions remain regarding how to interpret this finding. The P3 observed in central electrodes in this study may be a downstream effect of occipital ERPs that were too noisy to be observed independently. Alternatively, the P3 may be indicative of somatosensory inputs integrating with visual inputs. Finally, this result also may suggest that top-down influences of hand position bias attention by creating a task context which indicates that targets appearing near it may be candidates for action.

A first step in exploring potential effects of the hand on visual attention would be to explore how it occurs in paradigms other than spatial cuing. For example, visual search paradigms with a laterally positioned hand near the screen would allow for a more precise mapping of the topography of the hands' region of influence. By manipulating the number of items in the search and task difficulty, it would be possible to determine whether hand-proximity changes the saliency of nearby targets. Including singleton distractors designed to automatically capture attention in the search display would provide a method for determining how bias from the hand interacts with bottom-up capture effects, or whether the hand captures attention in a bottom-up manner itself. Finally, it is not clear whether hand-position is simply directing spatial attention, or if it is additionally enhancing visual perception in the space near the hand. The use of different discrimination tasks (e.g., brightness discrimination) or types of targets (e.g., spatial frequency gratings) could help ascertain whether hand proximity has a direct effect on perception, or whether it is first biasing attention and consequently changing perception.

Top-down influences of the hand on attention could be studied through the use of oddball paradigms. One advantage of using an oddball design is that the relative frequency of targets to distractors can be manipulated, which has the effect of altering how much attention participants allocate to the appearance of a particular stimulus. The addition of the hand near the screen in this paradigm could inform how much the simple placement of the hand changes top-attention. Changing the instruction set and emphasis of importance of the hand could provide further insight into how individuals’ awareness of their hand factors into the overall biasing effect.

In addition to using new paradigms, new measures and methods of analysis could be used to further investigate this effect. Analysis of continuous EEG would provide an additional angle from which to understand the neural mechanisms underlying this behavioral effect. For example, activity in the alpha band (8-14 Hz) is known to decrease with the onset of a visual cue, even before the appearance of a target, an effect that might reflect attentional readiness in preparation for the target (Thut, Nietzel, Brandt, & Pascual-Leone, 2006). It is possible that this sort of readiness might continuously be present whenever a hand is held up near a screen, or that activity in the alpha band following cue onset could decrease to even greater degrees when the hand is present. These hypotheses could be examined by analyzing levels of alpha activity in windows before and after the appearance of cues and targets, with and without hand presence. Furthermore, gamma band (30-130 Hz) activity has been related to increases in attention preceding target onset (Tallon-Baudry, Bertrand, Hénaff, Isnard, & Fischer, 2005), and has been linked to the binding and integration of perceptual features of attended stimuli (Keil, Gruber, & Müller, 2001). It is possible that changes in gamma band activity could reflect the cross-modal integration hypothesized to underlie the effect of the hand on visual attention.

Finally, a better understanding of this effect, both behaviorally and neurally, could have important implications for patients suffering from spatial attention disorders due to stroke or traumatic brain injuries. Hemispatial neglect is a syndrome commonly defined as a failure to report, orient, or respond to stimuli presented in space contralateral to the lesion, and that is not the result of primary sensory or motor deficits (Heilman, Watson, & Valenstein, 2003). The contemporary understanding of neglect is that it is heterogeneous syndrome that affects a number of interacting cognitive processes including spatial attention, motor programming, and spatial representation (Vallar, 1998). Given this heterogeneity, patients may be able to recruit intact neural systems to facilitate their attentional performance, and behavioral training to strategically position a hand in optimal locations might be one way to do so. Thus, future studies investigating if and how this hand-based effect on attention manifests in such patients could be important in the development of novel therapies to treat their deficits.

In conclusion, the effect of the body, and particularly hand-position, on visual attention is a relatively understudied aspect of cognition, despite having potentially widespread implications for theories of attention, multimodal sensory integration, and translational relevance for patients with spatial attention deficits. The current study was the first to investigate the neural mechanisms underlying the behavioral hand-based effect on visual attention reported by Reed et al. (2006). The findings revealed that holding a hand near the screen can alter the occurrence of a validity effect in the P3, suggesting that top-down influences from the positioning of the hand may play a role in this effect. Unfortunately, a number of flaws limited the findings from earlier ERP components and from the behavioral data. However, these limitations provide important guidelines for how future studies investigating this effect should proceed. Future studies should continue to investigate what aspects of this effect originate from bottom-up and top-down sources, while continuing to ground this effect in the greater attention literature.

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Table 1

Full Statistics for Behavioral (RTs) Omnibus ANOVA (Condition X Validity X Side)

	F	*p*	MS_e
Condition	1.113	0.332	2404.54
Validity	8.785	0.009*	7655.27
Side	0.074	0.789	24.41
Cond X Val	1.141	0.325	259.78
Cond X Side	0.610	0.527	130.58
Val X Side	0.037	0.850	7.042
Cond X Val X Side	0.938	0.400	98.19

Table 2

Full Statistics for Behavioral (RTs) Analysis by Block (Validity X Block)

	F	p	MS_e
Block	8.929	>0.001*	18865.03
Validity	8.708	0.009*	7533.71
Block X Val	0.703	0.582	144.71

Table 3

Paired Comparisons (RTs) of Valid vs. Invalid Means at Each Block

	t	*p*	*SE*
Block 1	2.265	0.037*	6.58
Block 2	2.501	0.023*	5.39
Block 3	2.087	0.052	5.92
Block 4	3.391	0.003*	3.32
Block 5	2.543	0.021*	5.35
Block 6	0.907	0.377	5.78

Table 4

Full Statistics for Behavioral (RTs) from Blocks 1-3, Omnibus ANOVA (Validity X Side X Condition) with Condition as a between subjects factor

	F	*p*	MS_e
Validity	0.830	0.379	541.17
Validity X Condition	1.139	0.350	742.46
Side	2.397	0.146	487.40
Side X Cond	0.710	0.510	144.42
Condition	0.204	0.818	8481.14
Val X Side	0.121	0.734	15.16
Val X Side X Cond	1.755	0.212	220.10

Table 5

Full Statistics for P1/N1 Omnibus ANOVA (Condition X Validity X Side)

	F	*p*	MS_e
Condition	1.824	0.180	1.714
Validity	1.791	0.202	2.254
Side	0.936	0.350	0.709
Cond X Val	0.218	0.753	0.273
Cond X Side	0.092	0.903	0.107
Val X Side	0.600	0.451	0.426
Cond X Val X Side	0.656	0.431	1.288

Table 6

Full Statistics for P3 Omnibus ANOVA (Condition X Validity X Side)

	F	*p*	MS_e
Condition	0.128	0.863	0.200
Validity	11.887	0.004*	5.590
Side	0.028	0.870	0.020
Cond X Val	3.715	0.039*	1.500
Cond X Side	0.933	0.394	0.580
Val X Side	0.000	0.999	0.000
Cond X Val X Side	0.257	0.729	0.219

Table 7

Correlations of P1/N1 & P3 for each condition

	Pearson	*p*
UpValNr	-0.021	0.93
UpValOp	0.003	0.99
UpInvNr	0.057	0.84
UpInvOp	0.231	0.41
RsValNr	-0.007	0.98
RsValOp	0.324	0.24
RsInvNr	0.097	0.73
RsInvOp	0.328	0.23
AwValNr	0.0575	0.84
AwValOp	0.183	0.51
AwInvNr	0.342	0.21
AwInvOp	-0.086	0.76

Figure 1.

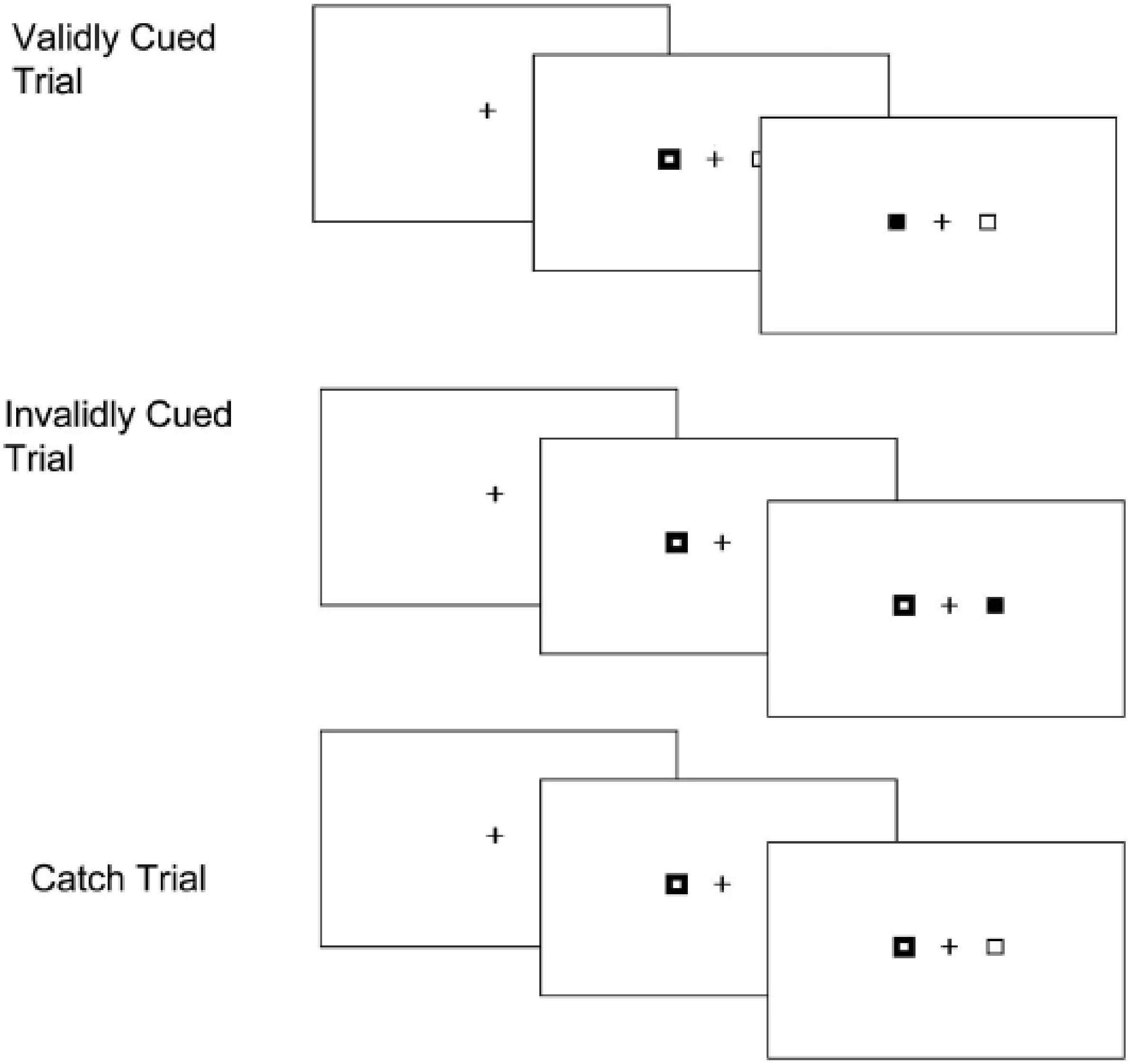


Figure 1. Examples of a valid, invalid, and catch trial from Reed et al. (2006). One target location was cued by darkening, and a target subsequently appeared in the same location (valid), opposite location (invalid), or not at all (catch).

Figure 2.

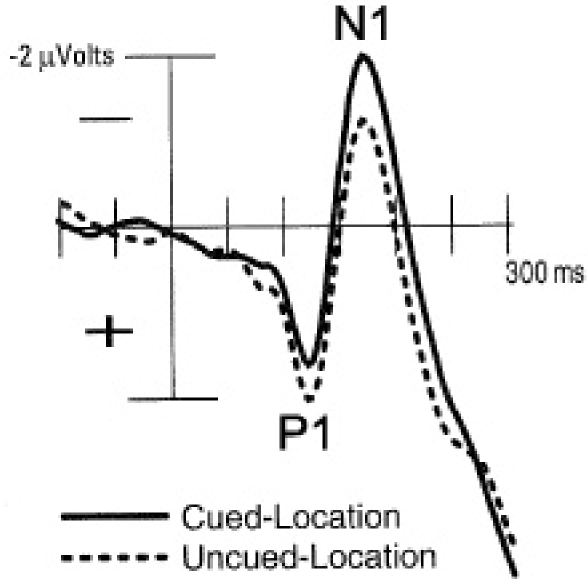
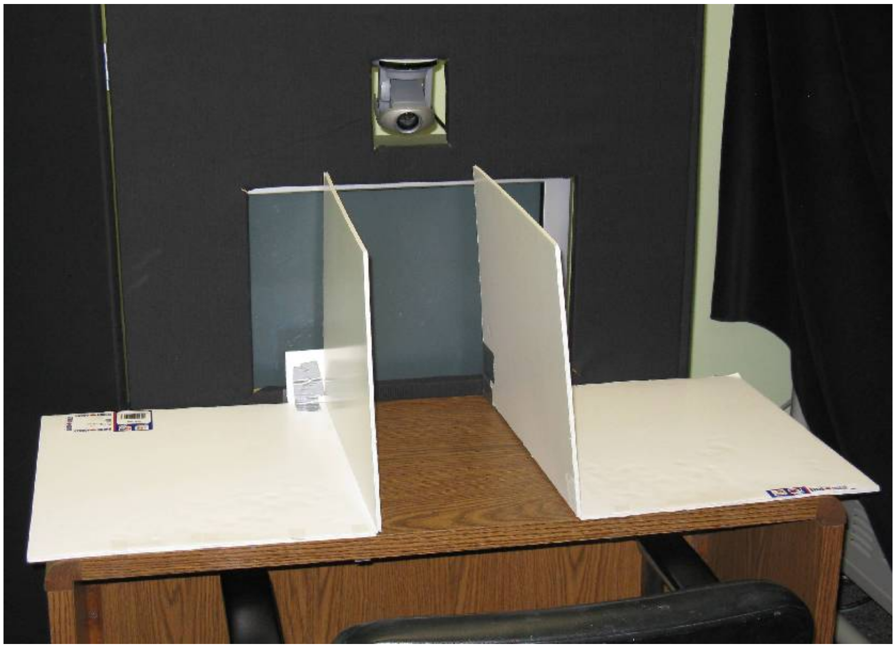


Figure 2. From Hopfinger & Mangun, (2001): The P1 and N1 components of the early ERP response to a visual target. Note that the N1 is enhanced at the cued location in this example from a discrimination task.

Figure 3a.

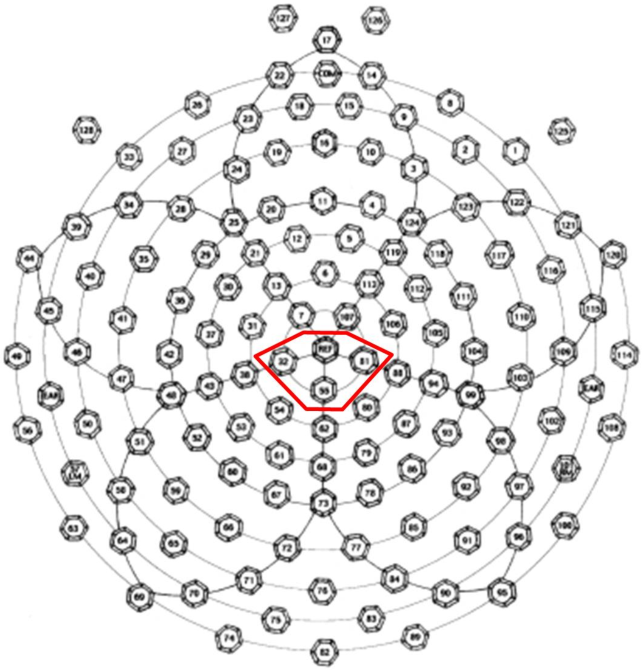


3b.

3c.

Figure 3. a) Experimental setup with white foam-core shields to equate visual inputs across conditions. b) Hand position for the Up condition. c) Hand position for the Away condition.

Figure 4a.



4b.

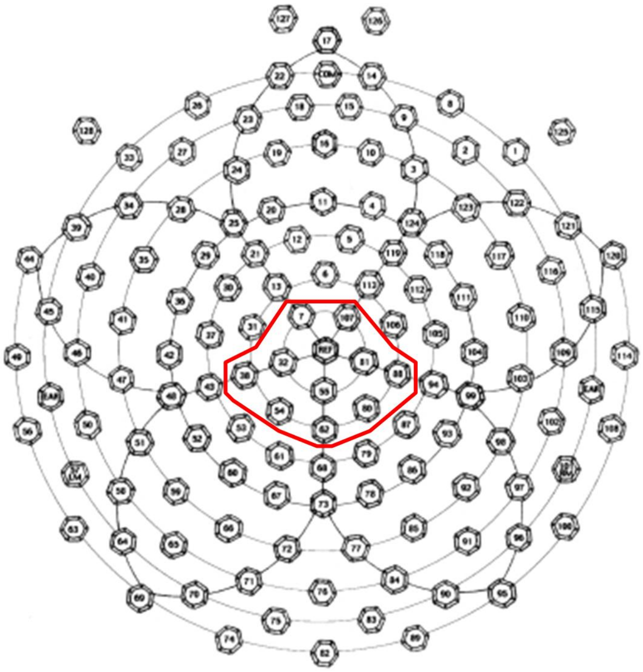


Figure 4. a) Electrode group defined for analysis of the P1/N1 complex (channels vref, 32, 55, & 81), corresponding roughly to Cz. Electrode group defined for analysis of the P3 component (channels 7, 107, vref, 32, 55, 81, 38, 54, 62, 80, & 88), covering a widespread, central region.

Figure 5.

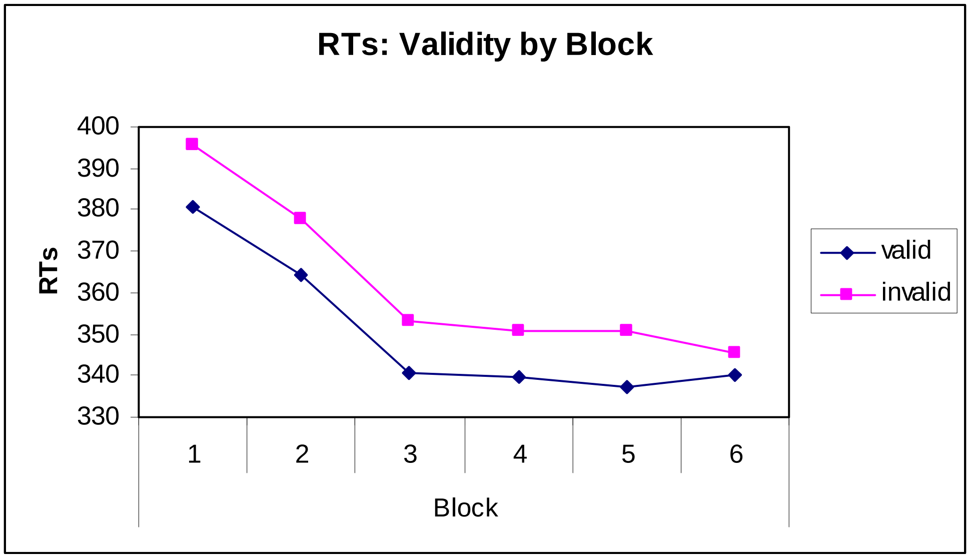
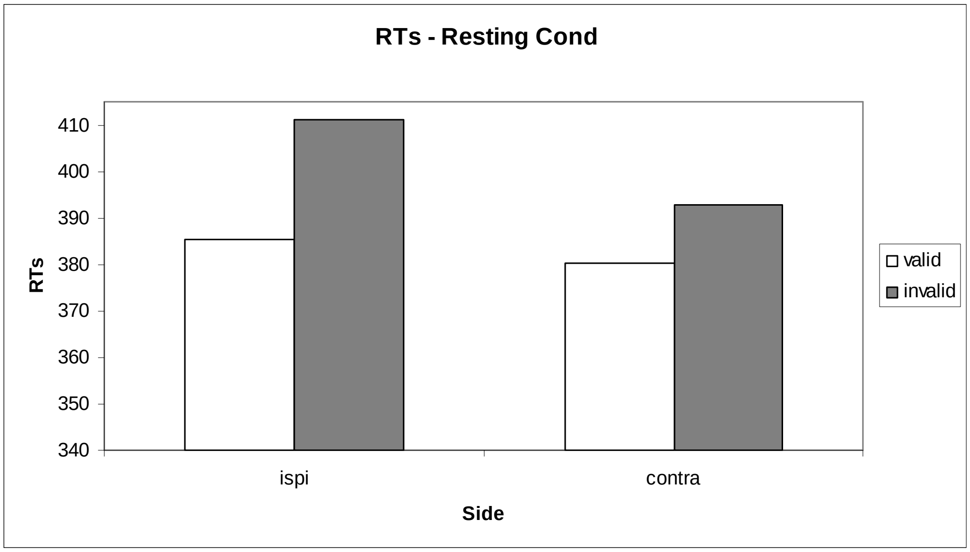
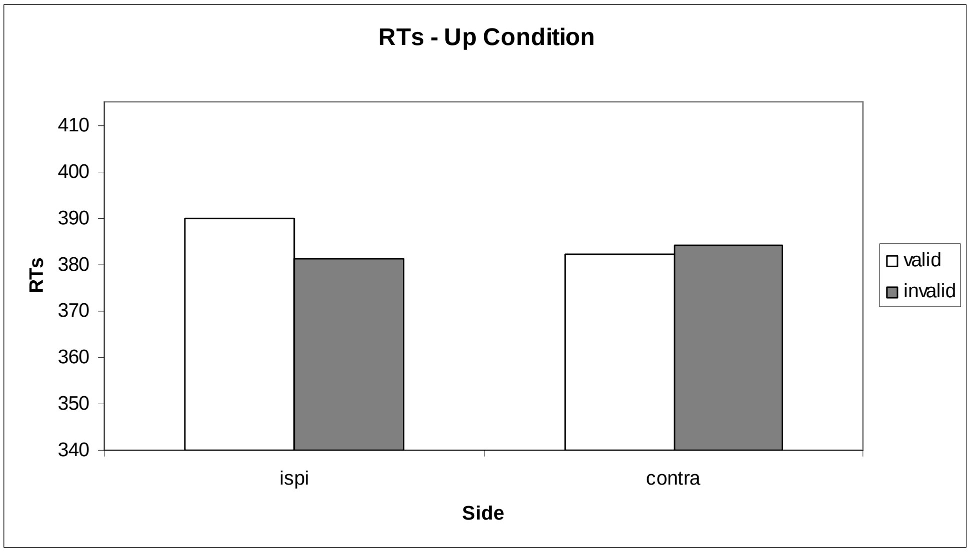


Figure 5. RTs to valid and invalid trials at each block. RTs decrease after Blocks One and Two, and then asymptote at Block Three. Validity effects were significant or marginally significant in all blocks except Block Six.

Figure 6a.


RTs - Resting Cond
410
400
390
380
370
360
350
340
RTs
ispi
contra
Side
valid
invalid

6b.


RTs - Up Condition
410
400
390
380
370
360
350
340
RTs
ispi
contra
Side
valid
invalid

6c.

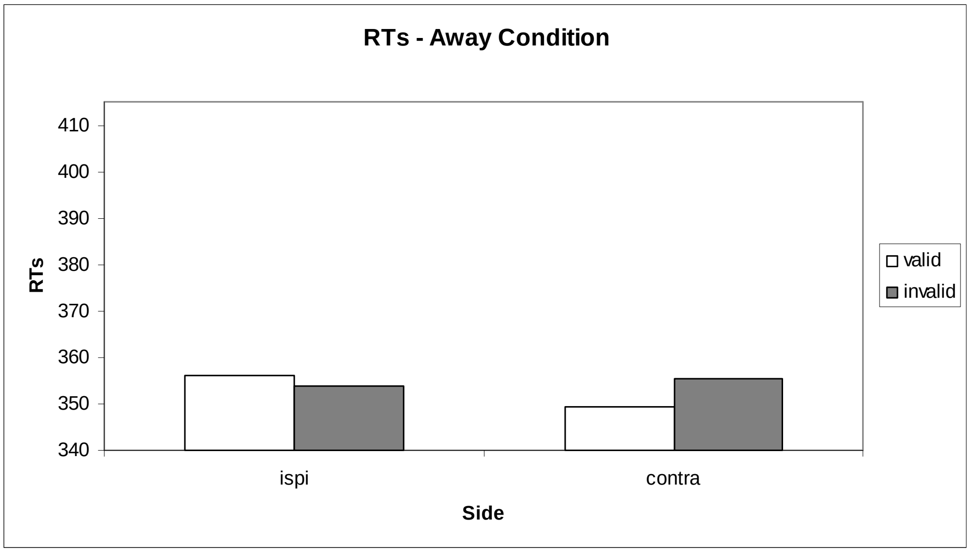


Figure 6. Bar chart of mean RTs,from the first 3 blocks. The a) Resting, b) Up, and c) Away conditions were analyzed as between-subjects factors. Each chart depicts mean RTs for valid and invalid trials at each side (Ispilateral and Contralteral). Although none of the differences were significant because of the relatively small N from splitting condition into a between-subjects factor, the overall pattern suggests some effect of hand position on validity at each side. In the Resting condition, the mean RT is faster to valid compared to invalid trials invalid trials, regardless of side. In the Up condition, the validity effect appears greatly diminished on the Contralateral side, and possibly reversed on the Ipsilateral side. In the Away condition, the validity appears slightly diminished on the contralateral side, but either not present or potentially reversed on the ipsilateral side.

Figure 7.

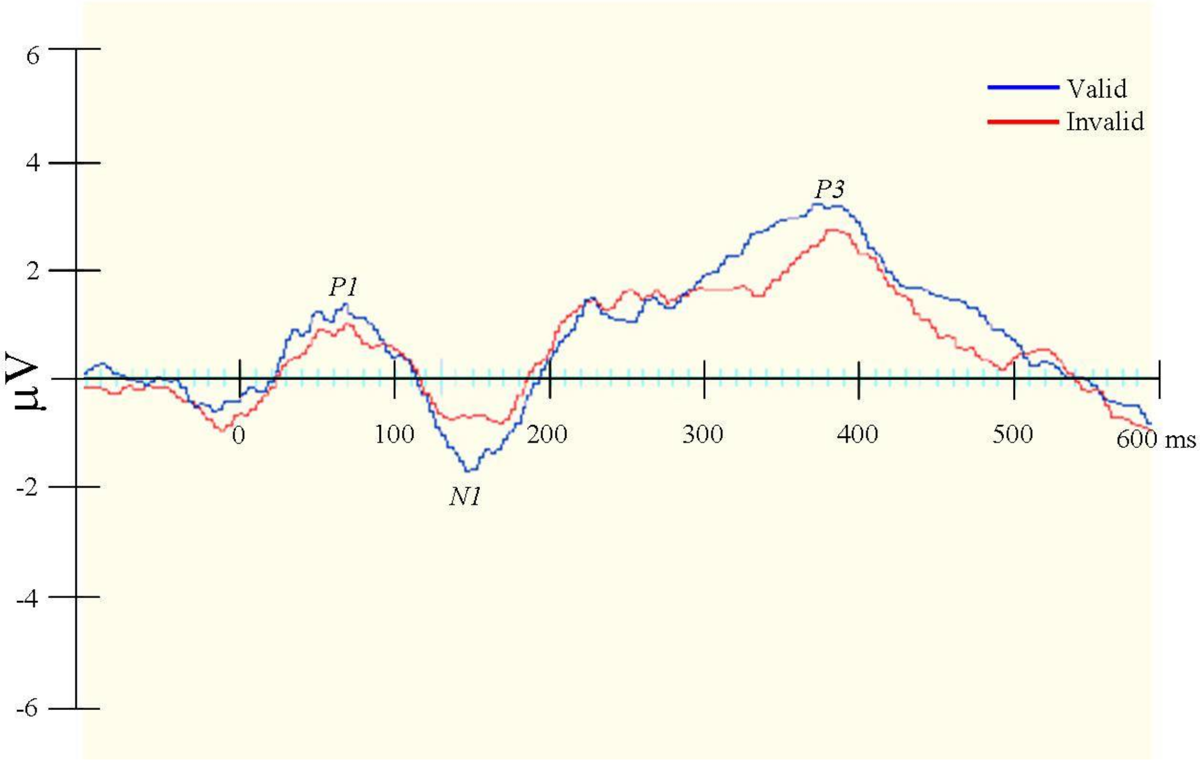
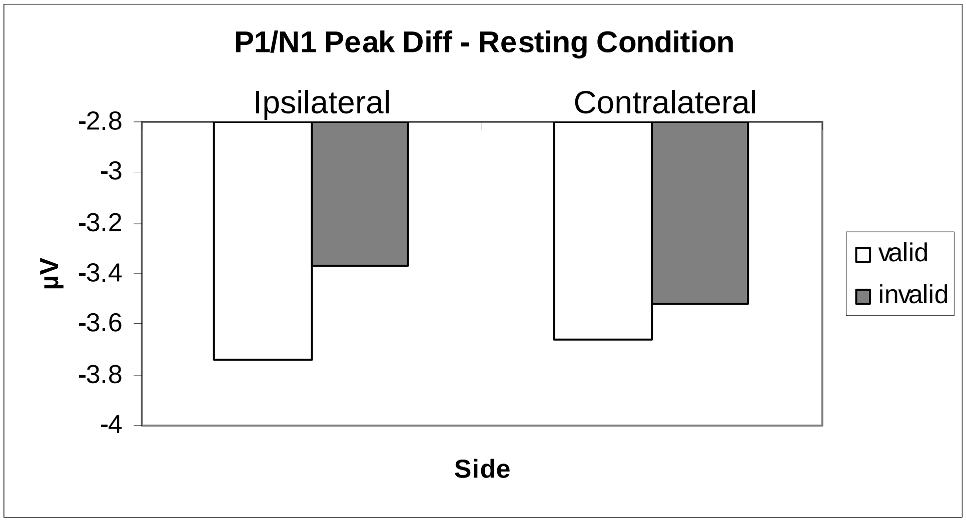
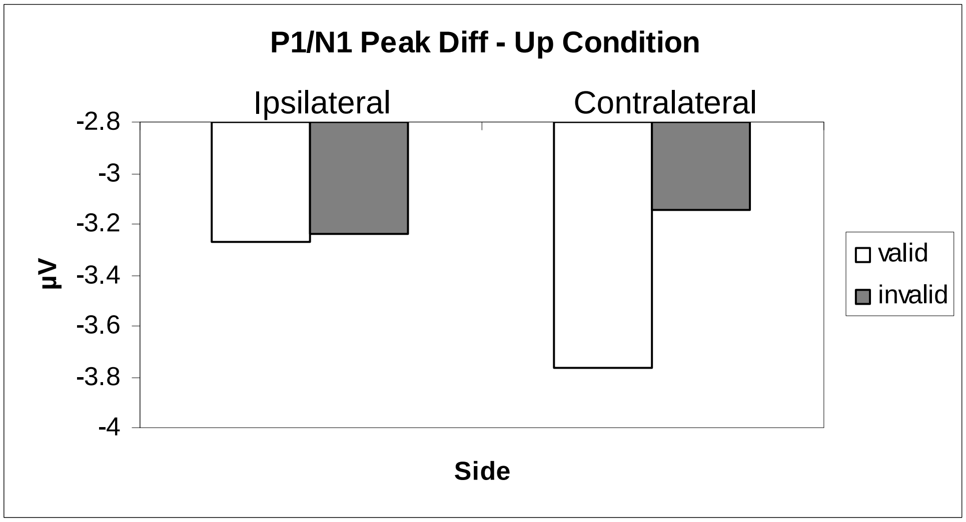


Figure 7. Grand average ERP waveform for valid and invalid trials in the Resting condition. The P1 is visible as a positive deflection peaking at about 80 ms. The N1 is visible as a negative deflection peaking at about 150 ms. The P3 is the larger, positive slow wave starting at about 300 ms and returning to baseline at about 500 ms.

Figure 8a.


P1/N1 Peak Diff - Resting Condition
Ipsilateral
Contralateral
-2.8
-3
-3.2
-3.4
-3.6
-3.8
-4
µV
Side
□ valid
▨ invalid

8b.


P1/N1 Peak Diff - Up Condition
Ipsilateral
Contralateral
-2.8
-3
-3.2
-3.4
-3.6
-3.8
-4
µV
Side
□ valid
▨ invalid

8c.

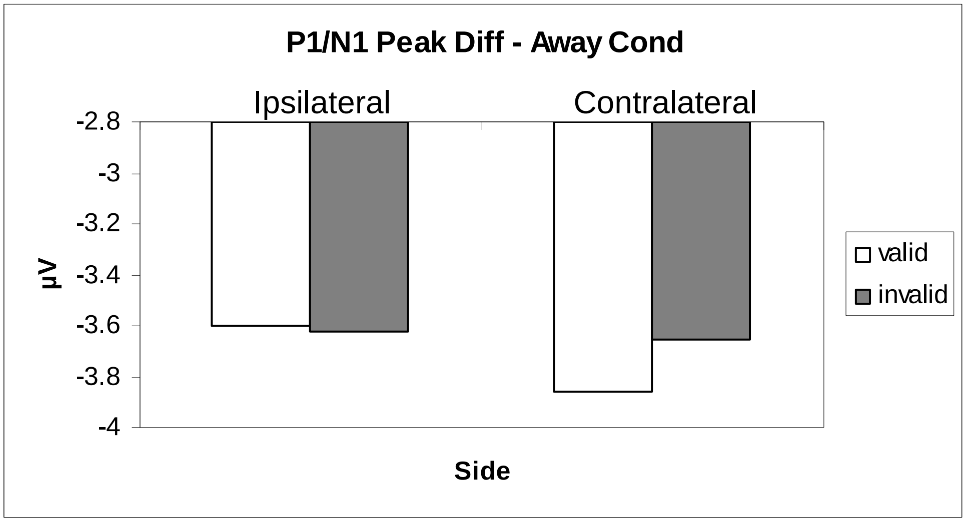
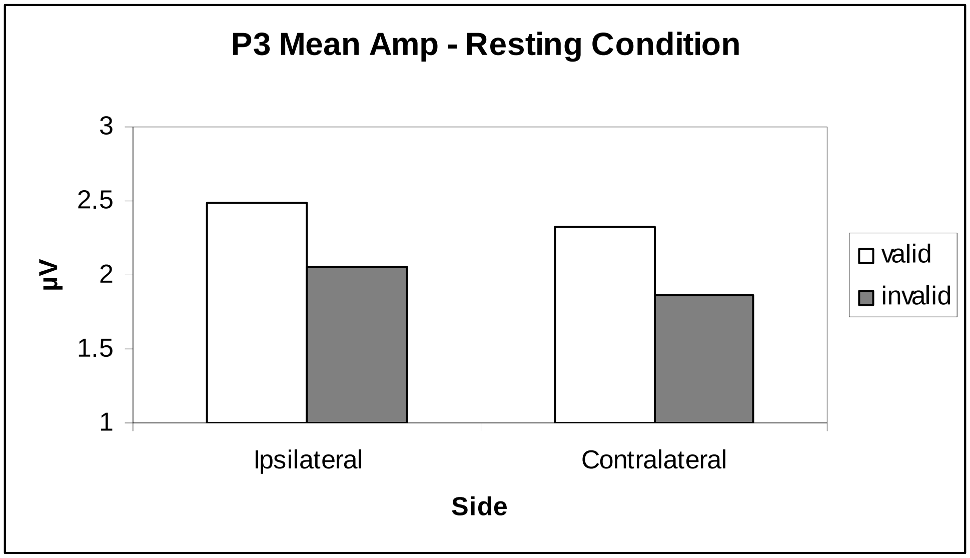
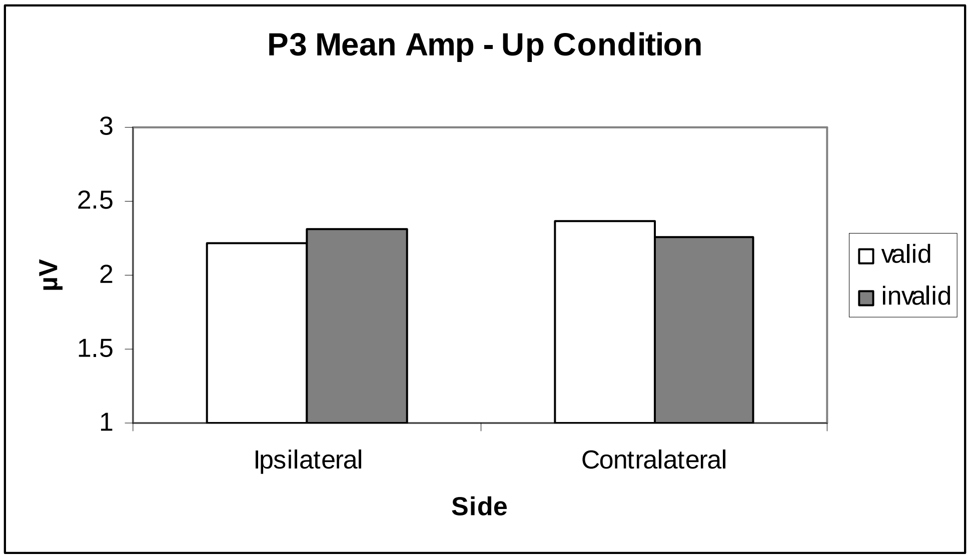


Figure 8. Bar chart of the mean peak amplitude difference between the P1 and N1 components, for the a) Resting, b) Up, and c) Away conditions. Each chart depicts mean amplitudes for valid and invalid trials at each side (Ispilateral and Contralteral). In the Resting condition, the mean amplitude is enhanced for valid relative to invalid trials, regardless of side. In the Up condition, this is also true on the Contralateral side, but not on the Ipsilateral side. Although none of these differences are significant, the pattern of results are the same as previously reported significant results using a subset of these data.

Figure 9a.


P3 Mean Amp - Resting Condition
3
2.5
2
1.5
1
µV
Ipsilateral
Contralateral
Side
☐ valid
▨ invalid

9b.


P3 Mean Amp - Up Condition
3
2.5
2
1.5
1
µV
Ipsilateral
Contralateral
Side
☐ valid
▨ invalid

9c.

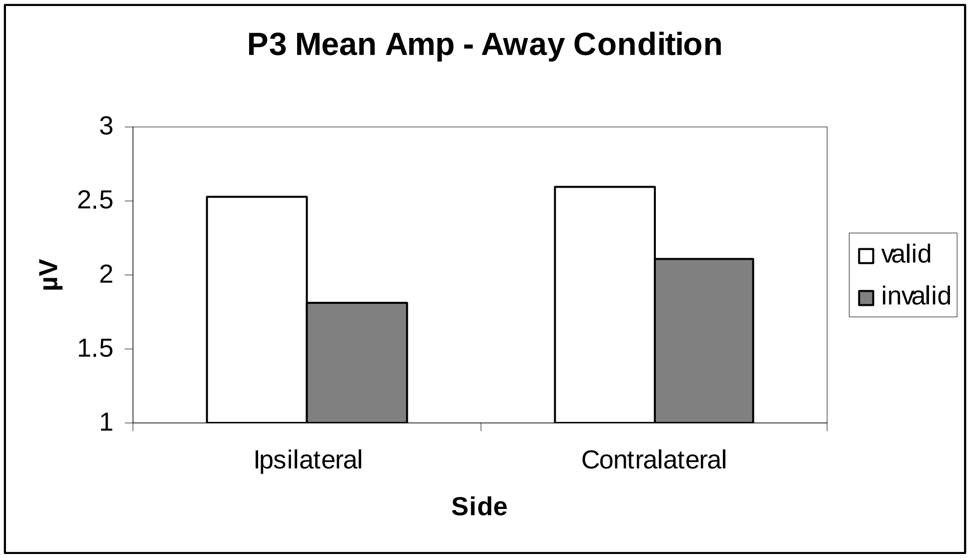


Figure 9. Bar chart of the mean amplitude of the P3 component, for the a) Resting, b) Up, and c) Away conditions. Each chart depicts mean amplitudes for valid and invalid trials at each side (Ispilateral and Contralteral). Main effects of Validity were found in the Resting and Away conditions, in which the mean amplitude is significantly enhanced for valid relative to invalid trials on both sides, but not in the Up condition. None of the differences in the Up condition were significant.