

**ISOLATING INVOLUNTARY ATTENTION HOLD:
A STUDY OF DISTRACTION**

Emily Leonard Parks

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Approved by:

Joseph Hopfinger

Charlotte Boettiger

Kelly Giovanello

Neil Mulligan

Keith Payne

ABSTRACT

EMILY LEONARD PARKS: Isolating involuntary attentional hold: A study of distraction
(Under the direction of Joseph Hopfinger)

Distraction occurs when voluntary focus is disrupted by bottom-up influences on attention and must be reoriented back to task-relevant goals. Human neuroimaging studies suggest that the right temporo-parietal junction (TPJ) plays a critical role in the reorienting of attention following distraction (e.g. Corbetta & Shulman, 2002). However, the neural processes by which distraction affects perception and subsequent actions are unclear. Here, we investigated the neural mechanisms of distraction when attention is differentially captured by a distracting stimulus; specifically, when attention is involuntarily *oriented to* versus *held on* a task-irrelevant item. First, we conducted two behavioral studies (Experiments 1 & 2) to determine experimental conditions that held attention, versus those that simply oriented attention. We provided novel results that neutral faces involuntarily hold attention a greater extent than places, increasing distraction. Using fMRI, we then examined differences in neural activity between these conditions to investigate the neural correlates of involuntary orienting and hold (Experiment 3). Lastly, we explored whether attentional hold effects would manifest in a traditional spatial cuing paradigm (Experiments 4a & 4b). fMRI analyses revealed a hemispheric asymmetry in the brain regions involved in the reorienting of attention. Activity in the *right* TPJ was enhanced for distractors that oriented and held attention, as compared to distractors that only oriented attention. Further, these same

distractors produced activation in the *left* TPJ, while distractors that merely oriented attention did not. These novel results might add to previous studies of reorienting in which TPJ activation was limited to the right hemisphere. We suggest that in these prior studies, attention was oriented to distractors, but may not have been held to the extent required to elicit left TPJ activation. The absence of hold may have led to the right-dominant activity observed. Further, using a traditional cuing paradigm, we found no evidence of extended hold, suggesting that the hold demonstrated in Experiments 1-3 did not reflect delays at early perceptual processing stages. Overall, involuntary orienting and hold were associated with different neural signatures, providing novel evidence that these two processes reflect partially distinct mechanisms.

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DEDICATION

This work is dedicated to my dad, Dr. David C. Leonard.

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CHAPTER 1

INTRODUCTION

The human cognitive system is limited, and thus, can only process a small portion of the vast amount of stimuli that are encountered in the environment. Selective attention mechanisms are required to prioritize this system, establishing which stimuli are relevant or important and which are not. Attentional selection mechanisms are critical for facilitating fast and accurate perception, cognition, and action towards stimuli in the environment (e.g. Yantis, 1996). Specifically, selective attention has been shown to produce faster and more accurate responses to stimuli located in attended locations as compared to unattended locations (Pashler, 1998; Posner, Snyder, & Davidson, 1980). Further, evidence suggests that the allocation of attention is influenced by several factors including bottom-up, reflexive capture to stimuli that are highly salient in their physical features, and top-down voluntary orienting toward task-relevant stimuli (Berger, Henik, & Rafal, 2005; Cheal & Lyon, 1991; Hopfinger & West, 2006; Jonides, 1981; Müller & Rabbitt, 1989; Posner & Cohen, 1984). In other words, attentional selection may be guided by internal drives, such as current task goals, or by immediate demands in the environment, such as the sudden appearance of a threat. It is the competitive interaction between these two attentional systems which ultimately determines our perception of the surrounding visual world. For example, top-down goals have been shown to bias the perception of sensory inputs; however, the strength of this bias depends on the physical salience of the items within the visual scene (Kastner, De

Weerd, Desimone, & Ungerleider, 1998; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999; Kastner & Ungerleider, 2001; Moran & Desimone, 1985; Reynolds, Chelazzi, & Desimone, 1999). On the other hand, items that are highly physically salient can involuntarily attract attention (Treisman & Gelade, 1980). In these cases, “saliency” can be defined by various stimulus attributes including luminance, color, motion, orientation, size, etc. (as reviewed in Wolfe & Horowitz, 2004). Further, while there is debate concerning whether the capture of attention is automatic or contingent on top-down goals (e.g. Folk, Remington, & Johnston, 1992; Theeuwes, 1993), one stimulus feature, novelty, has been shown to strongly attract attention (i.e. Kim & Hopfinger, 2010).

Recent work has demonstrated that stimulus attributes beyond physical salience can also influence the allocation of attention. These include higher-order attributes such as item memory (Chanon & Hopfinger, 2008; Parks & Hopfinger, 2008), emotional valence (e.g. Bannerman, Milders, & Sahraie, 2010; Fox, Russo, Bowles, & Dutton, 2001; Fox, Russo, & Dutton, 2002; Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004a; Koster, Verschuere, Crombez, & Van Damme, 2005), and addiction-relatedness (Chanon, Sours, & Boettiger, 2010; Shin, Hopfinger, Lust, Henry, & Bartholow, 2010). Critically, the mechanisms by which such items capture attention remain unclear. While early work on attentional capture focused on how such items influence the initial orienting of attention, new evidence suggests that the subsequent time during which attention is involuntarily *held* on the captured items may be equally, if not more, important. For example, Chanon and Hopfinger (2008) used eye-tracking to show that fixations during scene-viewing were more frequent, and importantly, lasted for a longer duration on “old” (previously studied) items versus “new” (never before seen) items. Further, similar results were demonstrated using a different

paradigm, the attentional blink (AB) paradigm. The AB refers to the finding that the detection of a target in a rapid serial visual presentation (RSVP) stream causes a marked impairment for detecting a second target presented shortly after the first target (within 200-500 msec) (Broadbent & Broadbent, 1987; Chun & Potter, 1995; Raymond et al, 1992). Using this paradigm, Parks and Hopfinger (2008) provided evidence that memorially unique items (“old” items among “new” items) hold attention significantly longer than non-memorially unique items, as measured by a protracted AB (see Figure 1). Interestingly, in both of these studies, it was the hold of attention that was most affected, and this hold was at least partially involuntary in nature. More specifically, in the initial eye-tracking study, the attentional hold by “old” items was not influenced by task instructions or self-reported strategies (Chanon & Hopfinger, 2008). Further, in the latter AB study, there was a cost associated with holding attention on a given target, yet a strong hold was still found (Parks & Hopfinger, 2008). These studies suggest that a higher-order stimulus feature, namely memory, affects the allocation of involuntary attention. This effect was specific to the hold of attention, and not to the orienting (i.e. the *initial* capture) of attention. Thus, understanding how properties of a stimulus affect the allocation of attention to that stimulus requires an examination of both the orienting and hold of attention.

The behavioral studies described thus far highlight the importance of dissociating the stages of attentional capture, including both the initial orienting and the later hold. However, this dissociation has not been considered at the neural level, especially in reference to *involuntary* attention. In contrast, several neuroimaging studies have examined the mechanisms underlying *voluntary* attention. These previous studies have implicated a distributed network within the dorsal frontal and parietal cortices with the voluntary

allocation of attention. This network includes the frontal eye fields and the superior parietal cortex (including the intraparietal sulcus and the superior parietal lobule) (Brefczynski & De Yoe, 1999; Corbetta & Shulman, 2002; Gandhi, Heeger, & Boynton, 1999; Ress, Backus, & Heeger, 2000; Giesbrecht, Woldorff, Song, & Mangun, 2003; Hopfinger, Buonocore, & Mangun, 2000; Kastner, et al, 1999; Kastner & Ungerleider, 2000; Somers, Dale, Seiffert, & Tootell, 1999). Recent work using event-related fMRI has attempted to isolate the orienting and maintenance of voluntary attention within this dorsal frontoparietal network (Thakral & Slotnick, 2009; Vandenberghe et al, 2001; Yantis et al, 2002). In these studies, participants performed one of two spatial attention tasks: orienting attention from one peripheral location to another, or maintaining attention at a peripheral location. Across several studies, it was found that voluntary shifts of attention were associated with activity in the superior parietal lobule (SPL) (Le, Pardo, & Hux, 1998; Liu, Slotnick, Serences, & Yantis, 2003; Yantis & Serences, 2003), while the voluntary maintenance of spatial attention was associated with more lateral parietal regions such as the intraparietal sulcus (IPS) (Vandenberghe et al, 2001; Yantis et al, 2002). Similar results have been found in studies employing RSVP tasks (Serences & Yantis, 2007; Kelley, Serences, Giesbrecht, & Yantis, 2007), and motion detection tasks (Thakral & Slotnick, 2009). Further support for the role of the IPS in the voluntary maintenance of attention has also come from studies of patients with spatial neglect, who exhibit a loss of awareness and orienting towards visual space contralateral to a brain lesion (typically in the right parietal lobe). It was found that neglect patients with damage to an area within the posterior parietal cortex, between the IPS and the inferior parietal lobule, were significantly worse at sustaining voluntary attention on a particular spatial location, as compared to stroke patients and healthy controls. Interestingly, this effect

was not found when neglect patients had to maintain attention on non-spatial, verbal material (Malhotra, Coulthard, & Husain, 2009). Once more, these results implicate the IPS in the maintenance of voluntary spatial attention. Overall, work from various paradigms and methodologies suggests that the SPL is critical for the orienting of attention, while the IPS seems more critical for the spatial maintenance of attention. Again, these effects refer to the goal-driven, *voluntary* shifting and maintenance of attention.

Of course, successful interaction within the environment requires that behavior not only reflect internally-directed goals, but also reflect unexpected changes in the environment such as novel, threatening, or rewarding stimuli. As described above, much work has implicated the dorsal frontoparietal network in the internally-driven, voluntary aspects of attention. In addition to this network, a second network has been associated with the detection of physically salient items within the environment. This network, known as the *ventral* frontoparietal network, largely overlaps with the dorsal frontoparietal network, but also includes right hemispheric regions such as the inferior frontal gyrus (IFG) and the temporal parietal junction (TPJ). Switching between top-down goals within the individual and bottom-up saliency within the environment depends on the interaction between the dorsal and ventral frontoparietal networks (as reviewed in Corbetta, Patel, & Shulman, 2008). In particular, this switching requires a mechanism known as the reorienting of attention. Reorienting occurs when attention must be quickly oriented to a task-relevant location after being recently oriented to another place. For example, a distractor may involuntarily attract attention, requiring the reorienting of attention back to a task-relevant location. One region within the ventral frontoparietal network, the right TPJ, has been found to be critically involved in the reorienting process (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000;

Corbetta, Kincade, & Shulman, 2002; Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005; Corbetta et al, 2008; Hahn, Ross, & Stein, 2006; Kincade, Abrams, Astafiev, Shulman, & Corbetta, 2005; Peelen, Heslenfeld, & Theeuwes, 2004; Serences, Shomstein, Leber, Golay, Egeth, & Yantis, 2005; Vossel, Thiel, & Fink, 2006). The TPJ is anatomically defined as the region at the intersection of the superior temporal sulcus, the inferior parietal lobule, and the lateral occipital cortex. Activation within the right TPJ is typically found when participants are cued to expect a target in one location, but it appears in another location (i.e. invalid trials in a classic cuing paradigm) (Arrington, Carr, Mayer, & Rao, 2000; Kincade et al, 2005; Vossel et al, 2006). Thus, the right TPJ is often considered the “circuit breaker,” switching attention between bottom-up orienting (e.g. to a distractor) and top-down orienting (e.g. to a target). Interestingly, Hopfinger and Mangun identified an ERP component that appears to parallel the effects of the TPJ (Hopfinger & Mangun, 2001). This component, termed the Ipsilateral Invalid Negativity (IIN), is uniquely evoked when involuntary attention has been captured to one location and must be rapidly disengaged and reoriented to a different location. The IIN peaks around ~200-250 msec latency, and it is distributed over temporal-parietal scalp electrode sites, consistent with a potential neural generator in the TPJ. In sum, both neuroimaging and electrophysiological work has provided evidence that the TPJ (especially in the right hemisphere) plays an important role in the reorienting of attention following involuntary distraction. Little is known, however, concerning how involuntary orienting versus involuntary hold differentially influence the reorienting process. Further, it is unclear if reorienting reflects a different mechanism from the initial orienting of attention.

While behavioral studies have begun to examine involuntary attentional processing, much remains unclear concerning the neural correlates of involuntary attention. No study, to

our knowledge, has attempted to dissociate the neural mechanisms underlying *involuntary* orienting versus hold. We suggest that this gap in the literature is based on two key limitations inherent within the methodologies and the vocabulary used to study attention. First, the relatively recent advent of fMRI has allowed for an incredible expansion in the understanding of attention; however, this appreciation is restricted to a relatively poor temporal level, given the sluggish nature of fMRI (Kim, Richter, Ugurbil, 1997). Thus, using this technique, it is difficult to distinguish between the orienting and hold of involuntary attention, which both occur within a very short time period (Cheal & Lyon, 1991). In fact, it has proven difficult to separate voluntary and involuntary attention using fMRI methodologies, despite extensive evidence from behavioral, electrophysiological, and neuropsychological work suggesting that these attentional systems reflect two qualitatively different processes (Cheal & Lyon, 1991; Hopfinger & West, 2006; Jonides, 1981; Muller & Rabbitt, 1989; Posner & Cohen, 1984).

Another impediment to understanding attention is that there are often inconsistencies regarding how to define the processing stages within attention. For example, the “hold” of attention has been interchangeably characterized as the following: the “dwell” of attention on an item, the “disengagement” of attention from a (potentially distracting) item, and/or the “reorienting” of attention away from one item and on to another. Theoretically, these terms clearly represent different stages of attentional processing. However, when described empirically, they are often not distinguished. For example, Duncan and colleagues (1994) designed a paradigm to specifically examine attentional dwell time. In this paradigm, participants identified two sequential objects separated by various temporal durations (i.e. used multiple stimulus onset asynchronies). Dwell time was associated with the length of

time that the identification of the first object continued to interfere with that of the second object (Duncan, Ward, & Shaprio, 1994). However, the construct of “dwell time” used here did not consider the time required to disengage and reorient attention to the second object. Thus, despite the authors’ claims, this experiment failed to isolate attentional dwell time. In summary, this example highlights just one of many instances in which terms relating to attention have been over-generalized or miss-used.

The primary purpose of the current study was to investigate the neural mechanisms underlying involuntary capture, including both the initial orienting and the later hold of attention. We used an innovative design in conjunction with fMRI, bypassing several limitations inherent in previous studies of involuntary attention mentioned above. First, we determined experimental conditions that orient attention, versus those that orient and hold attention. Thus, the separation of attentional orienting and hold was not dependent on the temporal resolution of the fMRI, but instead, was based on the comparison of two experimental conditions. Using these conditions, we explored the neural regions activated by items that solely oriented attention versus those that also held attention. Again, by defining the experimental conditions based on their temporal effect on attention, we circumvented the temporal limitations of fMRI.

Second, we operationalized our use of “attentional capture” at both the theoretical and the empirical level. Specifically, we defined involuntary capture as the orienting of attention, followed by the subsequent hold of attention. By our definition, orienting includes the initial focus/capture of attention and the early perceptual processing needed to interpret the attended item. The initial capture may reflect a spatial shifting of attention, or instead, may reflect a

non-spatial engagement of attentional resources to specific features or objects (see Corbetta & Shulman, 2002 for review). The subsequent hold of attention is considered to represent the combination of three processing stages: (1) the attentional dwell, or time during which additional (potentially higher-order) processing of the attended item occurs; (2) the disengagement of resources from the attended item, potentially representing a preparatory stage for a change in attentional focus; and (3) the reorienting of attention away from the item. Unfortunately, the latter two processes have proven quite difficult to empirically separate. Thus, here we jointly refer to the disengagement and reorienting of attention as “attentional transfer” (i.e. the processes required to transfer attention from one focus to another). In brief, here, attentional capture is composed of orienting and hold; with hold reflecting attentional dwell and attentional transfer (disengagement and reorienting).

The methodology used here was based on a novel continuous performance task developed by Kim and Hopfinger (2010). Using this task in conjunction with fMRI, Kim and Hopfinger (2010) recently explored the neural basis of distraction (i.e. involuntary capture by task-irrelevant items). In the scanner, participants completed an orientation discrimination task at central fixation, while distracting stimuli were presented at random time intervals in the periphery (See Figure 2). It was found that participants demonstrated distraction (as evidenced by decreased accuracy and slower response times to the central target task), but only when the distractor represented the abrupt appearance of a new object. An equivalent luminance change to an existing object did not capture attention. At the neural level, the onset of a new object produced activity in distractor processing regions of visual cortex, and critically, was also found to significantly reduce activity in target processing regions. These effects demonstrate the competitive interplay between distractor and target

processing regions. In addition to these effects on visual processing, regions in the parietal and temporal lobe (i.e. IPS and TPJ) were also found to show increased activity related to the appearance of the new object distractor. Interestingly, behavioral measures of distraction were associated with the extent of activity in the IPS and TPJ. These results suggest that the attentional processes supported by the IPS and TPJ are related to the degree of distraction suffered by individuals. Overall, this study provided an improved understanding of the neural correlates of involuntary attentional capture, but did not attempt to dissociate the neural mechanisms specific to orienting versus hold.

However, simple modifications to the experimental design used by Kim and Hopfinger (2010) can allow for such an examination. Specifically, to explore the processing stage(s) at which a distractor affects attention, the behavioral performance on the target task during the *first* appearance of the distractor can be compared to that during the *continued* presence of the distractor. If performance is impaired when the distractor onsets as compared to when the distractor is no longer present, this would suggest that attention was involuntarily *oriented* to the distractor. If performance continues to be impaired after the onset of the distractor, this would provide evidence that attention was also *held* by the distractor.

Given these assumptions, we chose to manipulate the continuous performance task developed by Kim and Hopfinger. The first goal of the current study was to determine distractor qualities that involuntarily orient and/or hold attention. We predicted that highly luminant items would involuntarily orient attention, as many previous studies suggest that physically salient stimuli reflexively capture attention (i.e. Jonides & Yantis, 1988; Turrato & Galfano, 2000). Further, work at both the neurophysiological and psychophysical levels suggests that items with enhanced luminance are processed more quickly and more

accurately than those with less luminance (e.g., Bundesen, 1990; Maunsell & McAdams, 2000; Pashler & Badgio, 1985; Proulx & Egeth, 2008; Reynolds & Desimone, 2003). At the physiological level, it has been shown that neuron populations that are selective for a certain feature (such as preferred orientation) will respond more strongly when an item possessing that feature is made brighter (Maunsell & McAdams 2000; Moran & Desimone 1985; Reynolds, Pasternak, & Desimone 2000). This response is considered a bottom-up process designed to bias neuronal competition in favor of the more salient, brighter stimulus. Additionally, Johannes and colleagues have found that stimuli that are highly luminant result in larger ERP amplitudes to early visual processing components such as the P1 and the N1, but do not increase the duration of these components (Johannes, Munte, Heinze, & Mangun, 1995). Several studies have also examined the effect of physical saliency on behavioral measures of attention. For example, Kean and Lambert (2003) modified a dot probe paradigm in which participants fixated on a central point in preparation for a peripheral dot target, which could appear to the left or right of fixation. The participants' task was to press a button corresponding to the location of the target. Before the appearance of the target, two cue stimuli were briefly presented randomly on either side of fixation, corresponding to the potential location of the upcoming target. At short cue-to-target intervals, participants detected the dot target more quickly when it replaced a more luminant cue, as compared to a less luminant cue (Brauer & Dannemiller, 2006; Kean & Lambert, 2003). In all, these neurophysiological and behavior results suggest that physically luminant items enhance the initial orienting of attention. Therefore, in the current study, we chose to manipulate distractor luminance as a means to isolate attentional orienting.

The means with which to isolate attentional hold in the current study were less clear. Recent work from our lab provided preliminary evidence that fearful faces hold attention (Parks, et al, in prep). In this study, the continuous performance task developed by Kim and Hopfinger (2010) was adapted to investigate distraction by fearful faces. Participants completed a challenging orientation discrimination task in the periphery, while maintaining fixation on a central point. Task-irrelevant distractors also appeared at fixation at random time intervals. Half of the distractors were emotionally-neutral pictures of places (e.g. pictures of buildings and landscapes), and the other half were pictures of faces with fearful expressions. The onset of both these distractor types was found to immediately orient attention, producing similar levels of distraction for places and faces. As compared to places, fearful faces produced longer distraction, as demonstrated by increased reaction times to targets presented *following* distractor onset (See Figure 3). Based on this experiment alone, it is unclear if the results are driven by the emotional valence of the distractor (i.e. fearful versus neutral valence) or by the type of distractor-object (i.e. face versus place). Therefore, the second goal of the current study was to determine which factor led to the enhanced attentional hold in the study by Kim and colleagues (Parks et al, in prep). Once established, we could then use this factor to study attentional hold at the neural level.

Given that a critical function of attention is to direct focus to potentially damaging or threatening stimuli in the environment (e.g. LeDoux, 1996; Yantis, 1996), we predicted that the emotional valence of the face, and not object identity, led to the hold of attention. Previous evidence suggests that emotion determines the degree to which stimuli are processed and the speed at which they can be processed (Anderson & Phelps, 2001; Öhman, Flykt, & Esteves, 2001a; Vuilleumier & Schwartz, 2001). One such set of evidence comes

from work on patients with right parietal damage experiencing a phenomenon known as spatial extinction. Spatial extinction occurs when patients have difficulty perceiving a stimulus in the visual field *contralateral* to the damaged hemisphere when that stimulus is presented simultaneously with another stimulus in the visual field *ipsilateral* to the brain damaged region. More specifically, patients will ignore the contralesional stimuli, and only report the ipsilesional stimuli. However, this impairment is not observed when the items are presented individually (e.g. Vuilleumier & Rafal, 2000). Interestingly, patients with parietal damage show less spatial extinction for emotional facial expressions as compared to neutral ones. In other words, on trials that contain the simultaneous presentation of bilateral stimuli, patients' ability to detect stimuli in the visual field contralateral to the damaged hemisphere is enhanced for emotional stimuli (e.g. pictures of spiders) as compared to neutral stimuli (e.g. pictures of flowers) (Fox, 2002; Vuilleumier & Schwartz, 2001a, 2001b). Further, attention to pictures of mutilated bodies, dangerous animals, angry or threatening faces, or pain are prioritized over other emotionally neutral events (e.g. Crombez, Eccleston, Baeyens, & Eelen, 1998; Mogg, McNamara, Powys, Rawlinson, Seiffer, & Bradley, 2000). Lastly, using a predictive spatial cuing paradigm, Fox and colleagues (2001; 2002) found that threatening stimuli, as compared to neutral stimuli, affect the hold of attention and not the initial capture of attention. Thus, threatening or fearful emotion seems to serve as a critical factor in determining what environmental stimuli are "important".

Based on these results in particular, we hypothesized that the hold of attention found by Parks and colleagues (in prep) was driven by the emotional valence of the face distractors. To test this hypothesis, Experiment 1 employed a similar procedure to that used by Parks and colleagues (in prep), except that the distractors were either images of places or of faces with

a *neutral* expression. The purpose of Experiment 1 was to determine what factor holds attention: negative facial expressions or faces themselves. Unexpectedly, the latter factor was found to drive the attentional hold effect, as the onset *and* the continued presence of neutral face distractors impaired target performance (see Experiment 1). Based on these results, our later experiments used neutral face distractors to investigate the neural mechanisms of attentional hold.

In sum, previous literature provided evidence that highly luminant images orient attention, and the results of Experiment 1 revealed that images of neutral faces orient and hold attention. Therefore, we chose to use these factors – luminance and object identity – as a means to isolate the neural mechanisms underlying involuntary attentional orienting and hold. Specifically, we manipulated both the brightness and the object-identity of the distractors in a continuous performance paradigm similar to that developed by Kim and Hopfinger (2010). In Experiment 2, we used a behavioral version of this design to determine if there were interacting effects between the factors of interest (luminance and object-identity). In question was if a bright face would enhance both orienting and hold. In Experiment 3, we used a similar design in combination with fMRI to explore the brain mechanisms underlying the orienting and hold of involuntary attention. Specifically, we examined how activity in attentional processing regions such as the TPJ and the SPL was modulated by distractors that involuntarily orient attention versus those that both orient and hold attention. We predicted that activity within the TPJ would be strongest in conditions leading to attention hold, as this region has been linked to the reorienting of attention following distraction (Corbetta et al, 2008). When attention is involuntarily held, reorienting to the task may be more difficult, necessitating increased activation of the TPJ. Further,

successful reorienting might initiate a subsequent increase in parietal activation to boost voluntary attentional control.

Overall, Experiments 1-3 employed a novel continuous performance task that allowed for a clear and distinct separation between attentional orienting and hold. Distractors that exogenously oriented attention were expected to impair task performance on simultaneously presented targets. Distractors that held attention were expected to continue to weaken performance on later targets. Of note, in these experiments, each target was presented for a duration of one second. Thus, as defined in this paradigm, orienting effects occur within one second of a distractor's onset, while hold effects do not initiate until one second after the distractor's onset. This hold effect is quite late compared to classic involuntary attention effects. For example, previous research suggests that involuntary attention can act quickly, biasing sensory processing within 100 msec of stimulus onset. Further, involuntary attention effects often reverse after 300 msec post-stimulus onset (Posner & Cohen, 1984). Because our attentional hold effects were found at least 1000 msec after distractor onset, it is unclear if they initiated at an early processing level (e.g. lower-order sensory processing) or at a later processing level (e.g. higher-order processing). Both of these attentional processing stages likely manifest in less than a second after stimulus onset. The design of Experiments 1-3 simply cannot distinguish between these two possible mechanisms.

Thus, an additional goal of this study was to examine if the extended hold on neutral faces would also manifest in a more traditional paradigm designed to isolate early attention effects. By focusing on the first 100-400 msec following stimulus onset, we could determine if the hold effects found in Experiment 1 (and later in Experiments 2 and 3) reflected changes

in early or late stimulus processing. To accomplish this goal, Experiment 4a and 4b employed a classic spatial cuing task. Similar to the continuous performance task utilized in Experiments 1-3, this task was used to isolate involuntary attention, and to empirically separate the effects of attentional orienting and hold. Unlike Experiments 1-3, this task was designed to highlight *early* attention effects.

In a classic spatial cuing task, a single cue is briefly presented in one of two possible target locations (Posner & Cohen, 1984). The cue can be valid (occurring at the upcoming target location) or invalid (occurring at the location opposite to that of the upcoming target). The effect of a cue's validity depends on its predictability and the temporal lag between the cue and target. Of importance here, different temporal periods can be isolated by adjusting this lag. Further, if the cue is predictive of the upcoming target location, voluntary attention mechanisms can be employed to improve task performance, with the cue's location indicating the likely location of the target. Valid predictive cues typically result in a small benefit in task performance, as attention is already focused on the target location. In contrast, invalid predictive cues result in a large decrement in task performance, as attention must be disengaged from the invalid cue and reoriented to the target location. These effects are typically slow to engage and produce a strong, sustained advantage at attended locations.

Non-predictive cues, on the other hand, provide no information about the upcoming target's location, and participants are instructed to ignore them. Thus, any attention to non-predictive cues should be involuntary in nature. As mentioned previously, involuntary attention can act quickly, facilitating responses to items at valid locations for the first few hundred msec. However, when the cue and target are separated by intervals greater than 300 msec, the opposite effect can occur, leading to slowed responses at the valid location. This

effect is called “inhibition of return (IOR)”, as attention is inhibited from returning to the location where it was previously captured (Posner & Cohen, 1984).

In Experiment 4, we used a non-predictive spatial cuing paradigm to examine involuntary attention. To isolate early attention effects, the temporal lag between the cues and targets was kept short (<400 msec). Facilitated attentional orienting by a cue-of-interest was evidenced by the speeding of responses on valid trials containing that cue as compared to valid trials containing a control cue. This facilitation was termed a “validity effect.” Attentional hold by a given cue was evidenced by the slowing of responses on invalid trials containing that cue as compared to invalid trials containing a control cue. On invalid trials, attention must be disengaged and reoriented to the target location. The longer that attention is held on an invalid cue, the worse performance was expected to be on the subsequent target. Thus, differences between performance on invalid cues-of-interest and invalid control cues represent differences in the hold of attention.

Previously, Fox and colleagues used the principles described above as a means to investigate how the valence of a face cue affects attention (Fox, Russo, & Dutton, 2002). Experiment 1 of that study used a spatial cuing paradigm in which participants performed a target localization task. The cue was a schematic drawing of either an angry or a neutral face and was 75% predictive of the upcoming target location. The cue-to-target SOA was 300 msec. It was found that the valence of the face cue did not affect response times on valid trials. Critically, however, reaction times on invalid trials were significantly influenced by cue validity. Participants were slower to respond on invalid trials when the face was angry as compared to when it was neutral. These results suggest that it is the hold, and not the orienting of voluntary attention that is most affected by emotional valence (Fox et al, 2002).

Again, the goal of Experiment 4 was to investigate if *neutral* faces, as compared to places, would involuntarily hold attention when early attention effects are isolated. This goal was accomplished through the use of non-predictive cues and a relatively short cue-to-target SOA. Interestingly, faces were not found to strongly hold attention here, suggesting that the hold found in Experiments 1-3 likely affected later, higher-order processing stages.

In summary, distraction occurs when voluntary focus is disrupted by bottom-up influences on attention and must be reoriented back to task-relevant goals. Human neuroimaging studies suggest that the right temporal parietal junction (TPJ) plays a critical role in the reorienting of attention following distraction (e.g. Corbetta & Shulman, 2002). However, the neural mechanisms by which distraction affects perception and subsequent actions are unclear. While previous work on attentional capture focused on how stimuli initially draw attention, the subsequent time during which attention is involuntarily *held* on the captured items may be equally, if not more, important. Yet, no study to our knowledge has attempted to identify the neural underpinnings underlying involuntary hold. In the present study, we investigated the behavioral and neural mechanisms underlying distraction by isolating two stages of involuntary capture: attentional orienting and hold. We first determined experimental conditions that hold attention, versus those that simply orient attention. Then, we examined differences in neural activity between these conditions. In Experiment 1, we manipulated the object identity (i.e. neutral face vs. place) of distracting stimuli during a task requiring focused voluntary attention. Reaction times revealed that attention was involuntarily *held* by neutral face distractors. In Experiment 2, we added the additional factor of physical salience (i.e. luminance) in order to differentially elicit attentional orienting and hold. Attention was involuntarily *oriented* by bright distractors to a

greater extent than dim distractors, and attention was involuntarily *held* longer for faces as compared to places. Experiment 3 examined the neural correlates of involuntary orienting versus hold by manipulating both the luminance and object-identity of distracting stimuli. Lastly, in Experiment 4a and 4b, we explored whether the attentional hold by faces (found in the previous experiments) would manifest in a more traditional attention paradigm designed to isolate early levels of stimulus processing.

CHAPTER 2

EXPERIMENT 1: CONTINUOUS PERFORMANCE TASK, MANIPULATING OBJECT-TYPE

Recent work from our lab investigated the mechanisms underlying distraction by task-irrelevant, fearful faces (Parks, Kim, & Hopfinger, Experiment 1, in prep). Participants completed a continuous orientation discrimination task in the periphery, while maintaining fixation on a central point. Distractors appeared at fixation at random time intervals. Again, the distractors were task-irrelevant; and therefore, attention to these items was expected to impair task performance. Half of the distractors were emotionally-neutral images of places (e.g. pictures of buildings and landscapes), and the other half were images of faces with fearful expressions. The onset of the distractor was found to immediately capture attention, regardless of whether the distractor was a place or a fearful face. However, fearful faces continued to hold attention, as demonstrated by slower reaction times to targets occurring during the sustained presence of fearful face distractors as compared to place distractors (See Figure 3). Because there was a direct cost associated with attending to fearful face distractors, this slowing reflects an increased hold of *involuntary* attention. Whether this involuntary hold was driven by the emotional valence of the distractor (i.e. fearful versus neutral) or by its object-identity (i.e. faces versus places) was unclear. Thus, the goal of Experiment 1 was to determine which of these two factors led to the involuntary hold of

attention to fearful faces. To do this, we compared distraction by places to that by neutral faces.

The methods and procedures in Experiment 1 were similar to those used by Parks and colleagues (Parks et al, in prep) (See Figure 4). Participants performed a discrimination judgment regarding the orientation of a red letter ‘T’, located in the upper periphery of the screen. The ‘T’ target changed orientation every second, but never disappeared, and therefore, was not a perceptual “new object.” Although the ‘T’ target was located in the periphery, participants were required to maintain fixation on a central point. Thus, participants had to sustain covert *voluntary* attention in the upper periphery to respond to the target. At random time intervals (see Methods section for details), distractor images were presented at fixation. The distractors were either images of neutral places or of neutral faces. Participants were instructed to ignore these distractors and continue with the peripheral discrimination task. Any involuntary capture to these distractors would lead to impaired target performance on the voluntary attention task. If such an impairment is present during the *first* appearance of the distractor as compared to after the offset of the distractor, this would suggest that the distractor involuntarily *oriented* attention. If target performance continues to be impaired following the onset of the distractor, as compared to after its offset, this would provide evidence that attention was involuntarily *held* by the distractor.

Based on the results of Parks and colleagues (Parks et al, Experiment 1, in prep), we predicted that the initial capture of attention would be equally strong for both neutral face and neutral place distractors. Of particular interest was whether the *neutral* faces would involuntarily hold attention. If the hold of attention previously found for fearful faces was

due to the emotional valence of the distractor (i.e. fearful versus neutral), then the neutral face here should *not* hold attention. Conversely, if the previous effect was instead driven by the object-identity of the distractor (i.e. faces versus places), then neutral faces should hold attention.

Methods

Participants. Thirteen right-handed undergraduate students from the University of North Carolina at Chapel Hill were recruited and were compensated with credit in their Introduction to Psychology course. Two participants were removed from the analyses, as one participant reported having a serious concussion, and the second participant could not accurately perform the task (Across several conditions, accuracy for this subject was more than three standard deviations from the mean of all other subjects.). Each participant was required to have 20/20 or corrected to 20/20 vision, and to be free from neurological and psychiatric disorders. Informed consent was obtained prior to participation in the study, although participants were kept naïve of the experimental hypotheses.

Materials and Procedures. (See Figure 4 for an overview of experimental design.) Participants were told to maintain fixation upon a centrally located point throughout the block. In the upper right peripheral field (5.17° above and 5.17° right from the central fixation point), a target was presented overlapping a black fixation cross. The target consisted of a continuously present red letter ‘T’ (RGB value “255, 0, 0”) that randomly changed its orientation every second. Participants were asked to discriminate the target’s orientation, pressing the first button on the response pad if the ‘T’ was oriented in the horizontal or vertical direction (i.e. 0° , 90° , 180° , or 270°), and pressing the second button

when the letter was oriented in a diagonal direction (i.e. 45°, 135°, 225°, or 315°).

Participants were instructed to respond as quickly as possible without sacrificing accuracy.

Throughout the experimental blocks, the target never disappeared; and thus, was not considered a new perceptual object. This is important as previous work using this task suggests that new objects automatically capture attention (Kim & Hopfinger, 2010). As participants performed the peripheral target task, distractor items abruptly appeared or disappeared at the center of the screen. Distractors consisted of grayscale photographic images. The images were either of neutral faces or of places, obtained from the Ebner database (Ebner, 2008). We used thirty-six unique images of faces and thirty-six unique images of places. The distractors were presented in random order, for four seconds each, and there were an equal number of trials of each distractor condition. Participants were instructed that the central distractor image was task-irrelevant and should be ignored. The central positioning of the distractors was designed to promote involuntary capture to the distractors. For all conditions, the background color was dark gray (RGB value “55, 55, 55”). The interstimulus interval (ISI) between distractors was counterbalanced, as either 3, 4, 5, or 6 seconds. Throughout the experiment, there were an equal number of each ISI. Each participant performed six runs, with each run containing 204 target events.

Before the experimental runs, participants performed a passive viewing run in which they maintained central fixation as each distractor stimulus (i.e. the distractors in the experimental paradigm) was presented twice for 2 seconds, with an ISI of 1 second. The stimuli were presented in random order. Participants were instructed that the images would later be used in the experiment and that they should pay attention to the images on the screen. Thus, the distractors used in the experimental runs were not novel to the participants. Next,

participants completed a practice block that was similar to the experimental runs, except that no distractor stimulus was presented. The practice run contained 75 target events.

Results

Two-way ANOVAs were performed on both the reaction time and accuracy to the targets. Factors included distractor-type (neutral face or place), and target-position (T1/T2/T3/T4/T5/T-baseline). T1 represents the targets occurring with the onset of the central distractor. T-baseline comprised all target positions following T5 and was defined separately for each distractor condition. Responses faster than 150 msec or slower than 1150 msec were removed from the analyses, and only correct responses were included in the analyses of response times.

Reaction Time (See Figure 5). For reaction time, the ANOVA revealed no main effect of distractor-type [$F(1,10) = 0.056$, $p = 0.818$; face = 555.075 ms; place = 555.997 ms]. There was a significant main effect of target-position [$F(5,50) = 51.234$, $p < 0.001$], and a significant interaction between distractor-type and target-position [$F(5,50) = 4.424$, $p = 0.002$; face: T1 = 597.804 ms, T2 = 562.829 ms, T3 = 551.087 ms, T4 = 532.787 ms, T5 = 549.103 ms, T-baseline = 536.841 ms; place: T1 = 594.253 ms, T2 = 553.569 ms, T3 = 543.187 ms, T4 = 547.612 ms, T5 = 551.030 ms, T-baseline = 546.331 ms].

To further explore this interaction, we conducted paired t-tests in conjunction with the B-H procedure to correct for multiple comparisons (Benjamini & Hochberg, 1995). For both distractor types, reaction times to T1 (i.e., to the target occurring at the onset of the distractor) were significantly slower than those to the respective T-baseline condition (Face-T1: $M = 597.804$ ms, $SD = 66.897$; Face-Tbaseline: $M = 536.841$ ms, $SD = 56.018$) [$t(10) =$

5.352, $p < 0.001$]; (Place-T1: $M = 594.253$ ms, $SD = 70.674$; Place-Tbaseline: $M = 546.331$ ms, $SD = 61.290$) [$t(10) = 10.606$, $p < 0.001$]. This finding suggests that the onset of either distractor significantly slowed reaction times to the target task. Following the onset of the distractor, participants were able to immediately re-orient to the target task when the distractor was a place, but not when it was a neutral face. In fact, the involuntary hold of attention on the face distractors extended to T3, as participants were significantly slower in responding to T2 and to T3, as compared to T-baseline, when the distractors were faces (Face-T2: $M = 562.823$ ms, $SD = 56.188$; Face-Tbaseline: $M = 536.841$ ms, $SD = 56.018$) [$t(10) = 5.352$, $p < 0.001$]; (Face-3: $M = 551.087$ ms, $SD = 54.232$; Face-Tbaseline: $M = 536.841$ ms, $SD = 56.018$) [$t(10) = 3.272$, $p = 0.004$]. No such difference was observed during the presence of place distractors (Place-T2: $M = 553.569$ ms, $SD = 59.900$; Place-Tbaseline: $M = 546.331$ ms, $SD = 61.290$) [$t(10) = 1.289$, $p = 0.113$]. These results provide strong evidence that attention was involuntarily held by the neutral face distractors.

By T4, face distractors no longer held attention (Face-T4: $M = 532.787$ ms, $SD = 56.886$; Face-Tbaseline: $M = 536.841$ ms, $SD = 56.018$) [$t(10) = -2.00$, $p = 0.037$, not significant with B-H correction]. In fact, at T4 target performance was not significantly different from baseline performance for either distractor type. However, there was a significant difference in the reaction times to T4 when the distractor was a neutral-face versus a place (Face-T4: $M = 532.787$ ms, $SD = 56.886$; Place-T4: $M = 547.612$ ms, $SD = 58.874$) [$t(10) = -3.563$, $p = 0.003$], with *faster* responses for targets occurring with face distractors as compared to place distractors. Thus, just before the offset of the distractor, there was an enhancement in target performance in the presence of face distractors, but not place distractors. This enhancement was followed by another significant slowing in reaction

time at the offset of the face distractors, but not the place distractors (Face-T5: $M = 549.103$ ms, $SD = 57.143$; Face-Tbaseline: $M = 536.841$ ms, $SD = 56.018$) [$t(10) = 4.411$, $p < 0.001$]; (Place-T5: $M = 551.031$ ms, $SD = 70.346$; Place-Tbaseline: $M = 546.331$ ms, $SD = 61.290$) [$t(10) = 0.794$, $p = 0.223$]. A similar pattern was observed for *fearful* faces in the previous study by Parks and colleagues (Parks et al, Experiment 1, in prep). Specifically, both studies found that the initial hold of attention on face stimuli (at T2 and T3) was followed by a relative improvement in task performance (at T4) and then by a relative decline in performance at face offset (at T5). In combination, these results demonstrate that both the onset and offset of faces can preferentially capture attention, leading to distraction.

Accuracy. For accuracy, no significant main effects of distractor-type [$F(1,10) = 1.202$, $p = 0.299$; face = 89.68%; place = 89.17%] or of target-position [$F(5,50) = 1.386$, $p = 0.246$; T1 = 88.23%; T2 = 89.27%; T3 = 89.96%; T4 = 90.93%; T5 = 89.37%; T-baseline = 88.78%] were found. The interaction between these two factors was also not significant [$F(5,50) = 1.260$, $p = 0.296$].

Discussion

In Experiment 1, we investigated whether the involuntary hold of attention on *fearful* faces previously found by Parks and colleagues (Parks et al, Experiment 1, in prep) was driven by the emotional valence of the distractor (fearful versus neutral) or by its object-identity (face versus place). Specifically, we used a continuous performance task to examine attentional capture by two types of irrelevant distractors: images of neutral faces and of neutral places. While both neutral-face and place distractors initially captured attention, only face distractors involuntarily held attention. In fact, this hold was still present three seconds

after the onset of the face distractor. Thus, the involuntary hold of attention previously found for fearful faces was not due to the emotional valence of the distractor, but instead was driven by the object-identity of the distractor (i.e. the fact that it was a face). Further work is required to determine if this hold by faces reflects extended dwell on the distractor, delayed disengagement from the distractor, and/or difficulty in spatially reorienting from the distractor to the target location.

In addition, we provided evidence that the offset of a face stimulus might lead to a second increase in distraction. Specifically, we found that the disappearance of face distractors, but not place distractors, hindered target performance at T5 as compared to T-baseline. These results are in line with the notion that faces are highly biologically- and socially- relevant to humans, and that face offset may uniquely engage attention as compared to other object stimuli (as discussed in Palermo & Rhodes, 2007). However, given that the timing of distractor offset in Experiment 1 was not randomized, it is also possible that attentional capture to faces versus places was differentially affected by participants' expectation of the timing of distractor offset. To better understand the mechanisms at work here, a more direct test of the effects of face offset on attention is required.

Overall, Experiment 1 provided strong evidence that faces, regardless of valence, involuntarily hold attention. To our knowledge, these results are the first to directly demonstrate this effect. While the hold of attention by neutral faces was initially unexpected (given previous work suggesting that negative valence holds attention (Fox et al, 2001; Fox et al, 2002)), these results are in line with previous studies highlighting the unique ability of faces to attract attention. For example, work by Ro and colleagues suggests that attention is preferentially allocated to faces rather than to objects in a scene (Ro, Russell, & Lavie,

2001). In addition, infants prefer to look at upright as opposed to inverted schematic faces (Mondloch, Lewis, Budreau, Maurer, Dannemiller, & Stephens, 1999). While this research suggests that humans are biased to attend to faces, the current work is the first to demonstrate that neutral faces not only capture, but also involuntarily hold attention. Importantly, Experiment 1 also identified a stimulus quality that leads to enhanced attentional hold. This quality, the property of being a face, was later manipulated in Experiment 3, in conjunction with fMRI, to explore the neural mechanisms underlying attentional hold.

CHAPTER 3

EXPERIMENT 2: CONTINUOUS PERFORMANCE TASK, MANIPULATING LUMINANCE & OBJECT-TYPE

The overall goal of this dissertation was to examine the neural processes underlying the involuntary capture of attention, including the initial orienting and the subsequent hold of attention by a distractor. To achieve this goal, we first identified stimulus qualities that lead to enhanced orienting and to enhanced attentional hold, respectively, on a distractor. In regards to the former, previous work has demonstrated that highly luminant (i.e. bright) items involuntarily orient attention to a greater extent than less luminant (i.e. dim) items (e.g. Johannes, Munte, Heinze, & Mangun, 1995; Kean & Lambert, 2003). Thus, to isolate involuntary *orienting*, we manipulated distractor luminance by including either a bright gray or a dim gray border around each distractor image. Based on the results of Experiment 1, we chose the property of being a face, as compared to a place, to isolate the involuntary *hold* of attention. Of interest here was whether there would be an interaction between luminance-border (bright vs. dim) and object-type (face vs. place).

Similar to Experiment 1, in Experiment 2 participants performed a discrimination judgment regarding the orientation of a red letter 'T', located in the upper right-hand corner of the screen. The 'T' target changed orientation every second, but never disappeared. Although the 'T' target was located in the periphery of the screen, participants were required to maintain fixation on a central point. At random time intervals, distractor images appeared

at fixation. The distractors were images of either neutral faces or places surrounded by a gray border. The border was either bright gray or dim gray. Thus, there were four distractor conditions: faces with a bright gray border, faces with a dim gray border, places with a bright gray border, and places with a dim gray border. Participants were instructed to ignore these distractors and to simply perform the peripheral discrimination task.

As in the previous experiment, if the onset of a distractor involuntarily *orients* attention away from the target location, then behavioral performance should be impaired at T1 as compared to baseline performance following the offset of the distractor. Further, if performance continues to be impaired after the onset of the distractor, this would provide evidence that attention was *held* by the distractor. We predicted that distractors with a bright gray border would involuntarily orient attention to a greater extent than those with a dim gray border. Based on the results of Experiment 1, we also hypothesized that face distractors would involuntarily hold attention for a longer duration than place distractors. Whether an interaction would be found between luminance-border and object-type was unclear.

Methods

Participants. Twenty-four right-handed undergraduate students from the University of North Carolina at Chapel Hill were recruited and were compensated with credit in their Introduction to Psychology course. Each participant was required to have 20/20 or corrected to 20/20 vision, and to be free from neurological and psychiatric disorders. Two participants were removed for the following reasons: One participant reported having three recent concussions, and the second participant reported having a brain lesion. Informed consent

was obtained prior to participation in the study, although participants were kept naïve of the experimental hypotheses.

Materials and Procedures. The experimental design was similar to that of Experiment 1. Participants were told to maintain fixation upon a centrally located point throughout the block. In the upper right peripheral field (5.17° above and 5.17° right from the central fixation point), a target was presented overlapping a black fixation cross. The target consisted of a continuously present red letter ‘T’ (RGB value “255, 0, 0”) that randomly changed its orientation every second. Participants were asked to discriminate each target’s orientation, pressing the first button on the response pad if the ‘T’ was oriented in the horizontal or vertical direction (i.e. 0° , 90° , 180° , or 270°), and pressing the second button when the letter was oriented in a diagonal direction (i.e. 45° , 135° , 225° , or 315°). Participants were instructed to respond as quickly as possible without sacrificing accuracy. As participants performed the peripheral target task, distractor items abruptly appeared or disappeared at the center of the screen. Distractors consisted of black and white images surrounded by a gray border. The images were either of neutral faces or of places, obtained from the Ebner database (Ebner, 2008). The thick outline borders were either a dim gray (RGB value “81, 81, 81”) or a bright gray color (RGB value “149, 149, 149”). (See Figure 6 for an overview of experimental stimuli). The distractors were presented in random order, for four seconds each, and there were an equal number of trials of each distractor condition. For all conditions, the background color was dark gray (RGB value “55, 55, 55”). The ISI between distractors was counterbalanced as either 3, 4, 5, or 6 seconds. Throughout the experiment, there were an equal number of each ISI. Participants were instructed to ignore

the central distractor image. Each participant performed six runs, with each run containing 272 target events.

Before the experimental runs, participants performed a passive viewing block in which they maintained central fixation as each distractor stimulus (i.e. the distractors in the experimental paradigm) was presented twice for 2 seconds, with an ISI of 1 second. The stimuli were presented in random order. Participants were instructed that the images would later be used in the experiment and that they should pay attention to the images on the screen. Next, participants completed a practice block that was similar to the experimental runs, except that no distractor stimulus was presented. The practice run contained 82 target events.

Results

Three-way ANOVAs were performed on both the accuracy and on the reaction times to the targets. Factors included luminance-border (bright or dim), distractor-type (face or place), and target-position (T1/T2/T3/T4/T5/T-baseline). T1 represented the targets occurring with the onset of the central distractor. T-baseline comprised all target positions following T5 and was defined separately for each distractor condition. Responses faster than 150 msec or slower than 1150 msec were removed from the analyses, and only correct responses were included in the analyses of response times.

Reaction Time. For reaction time, the ANOVA revealed no main effect of distractor-type [$F(1,21) = 3.127, p = 0.092$; face = 603.199 ms; place = 600.310 ms]. There were significant main effects of target-position [$F(5,105) = 58.497, p < 0.001$] and of luminance-border [$F(1,21) = 7.209, p = 0.014$; bright = 604.708 ms; dim = 598.800 ms], with the latter suggesting that participants responded more slowly to distractors with bright borders than to

those with dim borders. In addition, significant interactions between distractor-type and target-position [$F(5,105) = 3.157, p = 0.011$; face: T1 = 639.591 ms, T2 = 604.520 ms, T3 = 592.670 ms, T4 = 588.179 ms, T5 = 597.845 ms, T-baseline = 596.388 ms; place: T1 = 637.363 ms, T2 = 593.394 ms, T3 = 586.372 ms, T4 = 591.917 ms, T5 = 599.571 ms, T-baseline = 593.245 ms], and luminance-border and target-position [$F(5,105) = 3.772, p = 0.004$; bright: T1 = 646.979 ms, T2 = 597.979 ms, T3 = 589.763 ms, T4 = 595.117 ms, T5 = 601.232 ms, T-baseline = 597.180 ms; dim: T1 = 629.974 ms, T2 = 599.936 ms, T3 = 589.279 ms, T4 = 584.978 ms, T5 = 596.184 ms, T-baseline = 592.452 ms] were found. However, no significant interaction was found between distractor-type and luminance [$F(1,21) = 0.575, p = 0.457$; face: bright = 607.217 ms, dim = 599.180 ms; place: bright = 602.200 ms, dim = 598.421 ms], nor between distractor-type, luminance-border, and target-position [$F(5,105) = 0.733, p = 0.600$].

Given these latter non-significant interactions, we performed two additional analyses, collapsing the reaction time data by distractor-type, and also by luminance-border. Using paired t-tests in conjunction with the B-H procedure (Benjamini & Hochberg, 1995), we first compared trials with face distractors to those with place distractors by collapsing across luminance-border (See Figure 7). For face distractors, reaction times to T1 (i.e., to the target occurring at the onset of the distractor) were significantly larger than those to the respective T-baseline condition (Face-T1: $M = 639.591$ ms, $SD = 71.544$; Face-Tbaseline: $M = 596.388$ ms, $SD = 65.767$) [$t(21) = 9.747, p < 0.001$]. This comparison was also significant for place distractors (Place-T1: $M = 637.363$ ms, $SD = 71.115$; Place-Tbaseline: $M = 593.245$ ms, $SD = 65.375$) [$t(21) = 8.841, p < 0.001$]. Thus, for both distractor-types participants were slower to respond to a target when the distractor first onset as compared to when the distractor had

already offset and was no longer present. Critically, this difference was also significant at T2 (as compared to T-baseline) for the face distractors (Face-T2: $M = 604.520$ ms, $SD = 63.343$; Face-Tbaseline: $M = 596.388$ ms, $SD = 65.767$) [$t(21) = 2.487$, $p = 0.010$], but not for the place distractors (Place-T2: $M = 593.394$ ms, $SD = 63.120$; Place-Tbaseline: $M = 593.245$ ms, $SD = 65.375$) [$t(21) = 0.041$, $p = 0.484$]. Furthermore, there was a significant difference in reaction times to T2 when the distractor was a face versus when it was a place (Face-T2: $M = 604.520$ ms, $SD = 63.343$; Place-T2: $M = 593.942$ ms, $SD = 63.200$) [$t(21) = 3.827$, $p < 0.001$], again with slowed responses for targets occurring with face distractors. These findings provide evidence that involuntary attention was held longer when the distractor was an image of a face as compared to when it was an image of a place. Of additional note, the hold on faces reversed just before its offset, as participants responded *faster* to faces at T4 as compared to T-baseline (Place-T4: $M = 591.917$ ms, $SD = 68.149$; Place-Tbaseline: $M = 593.245$ ms, $SD = 65.375$) [$t(21) = -2.815$, $p = 0.005$]. This effect, however, did not extend to T5, at which time performance returned to baseline levels. Thus, this pattern mirrors that of Experiment 1 (and the pilot study by Parks et al, in prep), suggesting that the initial hold of attention on faces preceded a relative improvement in task performance (at T4). This brief improvement was then followed by a relative decline in performance at face offset (at T5). Overall, the results of Experiment 2 again demonstrated that faces can preferentially orient and hold attention, leading to distraction.

In the next set of analyses, we collapsed the data across object-type to compare distraction by stimuli with dim gray borders to those with bright gray borders (See Figure 8). For both distractors with dim and bright gray borders, reaction times to T1 were significantly slower than to those at their respective T-baseline condition [Dim-T1: $M = 629.974$ ms, $SD =$

73.581; Dim-Tbaseline: $M = 592.452$ ms, $SD = 65.647$ [$t(21) = 8.278$, $p < 0.001$]; Bright:-T1: $M = 646.980$ ms, $SD = 69.706$; Bright-Tbaseline: $M = 597.180$ ms, $SD = 65.580$ [$t(21) = 9.806$, $p < 0.001$]]. Thus, regardless of the luminance of the gray border, participants were slower to respond to a target when the distractor first onset as compared to when the distractor had already offset. This difference was not significant at T2 (as compared to T-baseline) for either luminance-border [Bright-T2: $M = 597.979$ ms, $SD = 61.088$; Bright-Tbaseline: $M = 597.180$ ms, $SD = 65.580$ [$t(21) = 0.206$, $p = 0.419$]; Dim-T2: $M = 599.936$ ms, $SD = 66.116$; Dim-Tbaseline: $M = 592.452$, $SD = 65.647$ [$t(21) = 2.302$, $p = 0.032$, not significant with B-H correction]], suggesting that attention was not held by distractors with either dim or bright gray borders. However, significant differences were found between conditions at T1, as participants were significantly slower to respond to distractors with bright versus dim gray borders (Bright-T1: $M = 646.980$ ms, $SD = 69.706$; Dim-T1: $M = 629.974$ ms, $SD = 73.581$) [$t(21) = 4.202$, $p < 0.001$]. These results provide evidence that the orienting, and not the hold, of attention to the distractor was enhanced when its border was highly luminant.

Accuracy. For accuracy, a marginal effect of distractor-type was found [$F(1,21) = 4.161$, $p = 0.054$; face = 87.61%; place = 88.21%]. There was a significant main effect of target-position [$F(5,105) = 8.621$, $p < 0.001$], but not of luminance-border [$F(1,21) = 1.286$, $p = 0.270$; bright = 87.14%; dim = 88.14%], although a significant interaction between these two factors was found [$F(5,105) = 6.030$, $p < 0.001$]. Additionally, a three-way interaction was found between distractor-type, luminance-border, and target-position [$F(5,105) = 3.277$, $p = 0.009$]. As with the reaction time data, we then conducted paired t-tests to explore these interactions, using the B-H procedure to correct for multiple comparisons (Benjamini &

Hochberg, 1995). These tests revealed similar patterns to that of the reaction time data. Specifically, at T1, participants were significantly less accurate to face distractors with bright borders as compared to those with dim borders, further suggesting that face distractors with bright borders strongly captured attention (Face-Bright: $M = 83.85\%$, $SD = 7.349$; Face-Dim: $M = 87.63\%$, $SD = 6.431$) [$t(21) = 3.480$, $p = 0.001$]. Additionally, participants responded more accurately to faces with bright borders at T3 as compared to this condition's baseline accuracy, perhaps reflecting a speed-accuracy trade-off at T3 (FaceBright-T3: $M = 91.10\%$, $SD = 4.422$; FaceBright-Tbaseline: $M = 86.88\%$, $SD = 5.112$) [$t(21) = 4.853$, $p < 0.001$]. Lastly, an unexpected effect was found at distractor offset (T5), at which time, participants responded more accurately to place distractors with dim borders as compared to baseline performance for this condition (PlaceDim-T5: $M = 90.48\%$, $SD = 6.810$; PlaceDim-Tbaseline: $M = 87.69\%$, $SD = 4.845$) [$t(21) = 3.587$, $p < 0.001$].

Discussion

Experiment 2 used a continuous performance task to examine attentional capture by irrelevant distractors. For all four distractor conditions, participants were slower to respond to a target when the distractor first onset (T1) as compared to when the distractor had already offset and was no longer present. Thus, all of the distractor conditions involuntarily captured attention. Further, at T1, distractors with a bright gray border led to slower target performance as compared to distractors with a dim gray border, suggesting that the *orienting* of attention to the distractor was enhanced when its surrounding border was highly luminant. After distractor onset (at T2), target performance continued to be impaired when the distractor was an image of a face, but not of a place, providing evidence that involuntary

attention was *held* longer for the face versus place distractors. This hold by faces likely reflected one or more of the following attentional mechanisms: extended dwell on the face distractor, delayed disengagement from the face distractor, and/or difficulty in spatially reorienting attention from the face distractor to the target location. In summary, we successfully determined qualities of a distractor that led to enhanced orienting and to enhanced hold. Images with bright borders involuntarily oriented attention to a greater extent than those with dim borders. Images of faces involuntarily held attention for a longer duration than images of places. Given these findings, Experiment 3 manipulated the luminance-border and object-type of distracting stimuli, in conjunction with fMRI, to examine the neural correlates of involuntary orienting and hold, respectively.

CHAPTER 4

EXPERIMENT 3: fMRI

The purpose of Experiment 3 was to elucidate the neural correlates of attentional capture, using the factors of luminance-border and object-type to compare enhanced involuntary orienting and hold, respectively. In conjunction with fMRI, we compared the neural regions activated by items that solely enhanced attentional *orienting* versus those that also extended attentional *hold*. By defining the experimental conditions based on their temporal effects on attention, we circumvented the temporal limitations of the fMRI methodology. The experimental paradigm was similar to that of Experiment 2; and thus, we hypothesized that the onset of distractors with a bright gray border would involuntarily orient attention to a greater extent than those with a dim gray border. Further, we predicted that face distractors would involuntarily hold attention longer than place distractors.

As shown by Kim and Hopfinger (2010), distraction at the neural level can manifest as a competitive interaction between distractor and target processing. We predicted that the strength of distractor processing would be inversely related to the strength of target processing. More specifically, when the distractor biases attention, we expected target processing to be reduced as distractor processing increases. Of further interest was if such an interaction would also be reflected in higher-order distractor processing regions such as the FFA and PPA.

In addition, we examined whether activity within attentional processing regions was modulated by the type of distractor. These regions included the TPJ, previously associated with reorienting, and the SPL, previously associated with voluntary attention. Of great interest was if these regions were differentially activated by distractors that involuntarily orient attention versus those that involuntarily orient *and* hold attention. We predicted that activity within the right TPJ and the bilateral SPL would be strongest in conditions leading to attention hold. When attention is involuntarily held, reorienting to the task may be more difficult, necessitating increased activation of the TPJ. Further, successful reorienting might lead to a subsequent increase in parietal activation related to the strengthening of voluntary attentional control back to the target task.

Methods

Participants. Thirty-one right-handed undergraduate students from the University of North Carolina at Chapel Hill were recruited for this study and were paid \$20 per hour. Two participants were removed from the analyses, as their reaction time to at least one of the conditions was more than three standard deviations from the average reaction time for all participants on that condition. Three participants were removed due to excessive movement, and two participants needed to be removed from the scanner before completing the experiment. Each participant was required to have 20/20 or corrected to 20/20 vision, and to be free from neurological and psychiatric disorders. Participants were excluded if they had electrically, magnetically or mechanically activated implants, if they had intracerebral vascular clips, or if they were pregnant. Informed consent was obtained prior to participation in the study, although participants were kept naïve of the experimental hypotheses.

Materials and Procedures

Experimental Runs. Participants completed one fMRI session, during which they performed a continuous performance task, similar to that conducted in Experiments 1 and 2. First, participants completed a practice block outside the scanner. Once inside the scanner, participants were asked to maintain fixation upon a centrally located point, as the target, a red letter 'T', was presented in the periphery. The target randomly changed its orientation every second. Again, participants were instructed to discriminate the orientation of the target, which was continuously presented over a black fixation cross. Using their right hand, participants pressed Button 1 on the response pad if the 'T' was oriented in the horizontal or vertical direction (i.e. 0° , 90° , 180° , or 270°), and pressed Button 2 when the letter was oriented in a diagonal direction (i.e. 45° , 135° , 225° , or 315°). Participants were instructed to respond as quickly as possible without sacrificing accuracy. As in Experiment 2, a task-irrelevant distractor image was presented at fixation. There were four distractor conditions: faces with a dim border, faces with a bright border, places with a dim border, and places with a bright border. Each distractor was presented for four seconds. The disappearance of the distractor lasted either 5, 7, 8, or 16 seconds, pseudo-randomly selected to have equal frequency within a block. Participants were instructed to ignore the central distractor image. Each participant performed six experimental runs. Each run contained 416 target events, and lasted for 496 seconds.

Functional Localizer Run. To identify regions of interest (ROIs) reflecting the visual processing regions of the distractor and the target, we performed a separate functional localizer run. Participants were asked to maintain fixation on a centrally located black cross. One of three possible stimulus events occurred, as participants were shown a blocked series

of: centrally-positioned face images, centrally-presented place images, and a peripherally-presented, rotating ‘T’. These images were identical to those used in the experimental runs. Each image was presented for one second, with no ISI. Each “face” and “place” block lasted for 18 seconds, and each “T” block lasted for 16 seconds. Between blocked events, there were 10 seconds of fixation. The order of the localizer run was: (1) face, (2) fixation only, (3) ‘T’, (4) fixation only, (5) place, (6) fixation only, (7) ‘T’, (8) fixation only; this sequence repeated four times.

Imaging Methods and Analyses

Image Acquisition. Functional images were obtained with a Siemens 3 Tesla Siemens Trio whole-body MRI scanner at the University of North Carolina’s Biomedical Research Imaging Center. Brain volumes were composed of 34 transverse slices (FOV = 243 x 243, matrix = 64 x 64, 3.8 x 3.8 x 3.8 mm resolution) aligned to the AC-PC line, collected interleaved, inferior to superior. Images were acquired using a T2*-weighted EPI sequence (TR = 2000 ms, TE = 30 ms, flip angle = 80°). Participants performed 7 functional runs (i.e. 6 experimental runs and 1 functional localizer run), along with an anatomical scan. The anatomical scan was acquired with a T1-weighted MPRAGE sequence (TR = 1900 ms, TE = 2.32 ms, flip angle = 9°, FOV = 230 x 230, 192 slices, matrix = 256 x 256, 0.90 x 0.90 x 0.90 mm resolution, 266 sec acquisition time). The runs occurred in the following order: anatomical, functional localizer, three experimental runs, resting state, three experimental runs.

fMRI Data Analysis. The functional data was analyzed using the statistical parametric mapping (SPM8) software from the Wellcome Department of Imaging Neuroscience (Queen

Square, London, United Kingdom). Data were slice-time corrected for acquisition order (referenced to the slice acquired in the middle of the time sequence), motion corrected with coregistration without reslicing, spatially normalized (with trilinear interpolation and preserving the intensities of the original images) to the SPM8 EPI template corresponding to the MNI (Montreal Neurological Institute) defined standardized brain space, and spatially smoothed with a Gaussian kernel of 8 mm FWHM. The time series was high pass filtered at 128 seconds.

Statistical Analysis. For each individual, contrast maps for the task runs were estimated, using an event-related hemodynamic response function time-locked to the onset of the central distractor. Random effects analyses were conducted by including these contrast images in one-sample t-tests, in order to make population inferences.

Timecourse and Peak Activation Analysis. ROI analyses were conducted using SPM8 and MarsBar software. The regions were created as spheres with a 6 mm radius around each ROI maxima. Within each ROI, the signal was extracted and averaged. ROIs were created at the center of the maximal response for bilateral FFA and PPA, for attentional processing regions (including the bilateral SPL and TPJ), and for the distractor and target processing regions. All regions were obtained from a random effects analysis of the whole brain.

Behavioral Results

Three-way ANOVAs were performed on the accuracy and reaction times to the targets. Factors included luminance-border (bright or dim), distractor-type (face or place), and target-

position (T1/T2/T3/T4/T5/T-baseline). As in Experiments 1 and 2, T1 represented the targets occurring at the onset of the distractor image. T-baseline included all target positions following T5 and was defined separately for each distractor condition. Responses faster than 150 msec or slower than 1150 msec were removed from the analyses, and only correct responses were included in the analyses of response times.

Reaction Time. (See Figure 9). For reaction time, the ANOVA revealed no main effect of distractor-type [$F(1,22) = 0.297, p = 0.592$; face = 561.136 ms; place = 562.060 ms]. There was a marginally significant main effect of luminance-border [$F(1,22) = 4.200, p = 0.053$; bright = 563.526 ms; dim = 559.670 ms], and a significant main effect of target-position [$F(5,110) = 22.268, p < 0.001$]. In addition, significant interactions between distractor-type and target-position [$F(5,110) = 2.457, p = 0.038$; face: T1 = 588.339 ms, T2 = 558.099 ms, T3 = 552.687 ms, T4 = 552.687 ms, T5 = 560.949 ms, T-baseline = 554.374 ms; place: T1 = 582.882 ms, T2 = 554.507 ms, T3 = 553.065 ms, T4 = 558.912 ms, T5 = 567.635 ms, T-baseline = 555.360 ms], and luminance-border and target-position [$F(5,110) = 2.927, p = 0.016$; bright: T1 = 590.571 ms, T2 = 559.815 ms, T3 = 557.730 ms, T4 = 555.158 ms, T5 = 562.895 ms, T-baseline = 554.989 ms; dim: T1 = 580.650 ms, T2 = 552.792 ms, T3 = 548.022 ms, T4 = 556.125 ms, T5 = 565.688 ms, T-baseline = 554.744 ms] were found. However, no significant interaction was found between distractor-type and luminance [$F(1,22) = 0.589, p = 0.451$; face: bright = 562.374 ms, dim = 559.899 ms; place: bright = 564.679 ms, dim = 559.442 ms], nor between distractor-type, luminance-border, and target-position [$F(5,110) = 1.438, p = 0.216$].

To further explore the data, we conducted paired t-tests in conjunction with the B-H procedure (Benjamini & Hochberg, 1995). As predicted, all four distractor conditions

captured attention (i.e. enhanced attentional orienting), as reaction times for each condition were slower at T1 as compared to at each condition's baseline (FaceBright-T1: $M = 593.503$ ms, $SD = 13.870$; FaceBright-Tbaseline: $M = 552.566$ ms, $SD = 12.619$) [$t(22) = 5.536$, $p < 0.001$]; (FaceDim-T1: $M = 583.174$ ms, $SD = 13.600$; FaceDim-Tbaseline: $M = 556.182$ ms, $SD = 12.472$) [$t(22) = 5.170$, $p < 0.001$]; (PlaceBright-T1: $M = 587.638$ ms, $SD = 15.237$; PlaceBright-Tbaseline: $M = 557.412$ ms, $SD = 13.220$) [$t(22) = 4.078$, $p < 0.001$]; (PlaceDim-T1: $M = 578.126$ ms, $SD = 14.357$; PlaceDim-Tbaseline: $M = 553.307$ ms, $SD = 12.949$) [$t(22) = 4.075$, $p < 0.001$]. At T2, only one distractor-type, faces with a bright gray border, was found to hold attention. Specifically, in the presence of this distractor-type, participants were significantly slower to respond to targets at T2 as compared to T-baseline (FaceBright-T2: $M = 561.456$ ms, $SD = 12.779$; FaceBright-Tbaseline: $M = 552.566$ ms, $SD = 12.619$) [$t(22) = 2.906$, $p = 0.004$]. In contrast, for the other three distractor conditions, participants' performance reached baseline levels by T2, providing strong evidence that participants were able to efficiently disengage from these distractor-types and reorient to the peripheral target location (FaceDim-T2: $M = 554.741$ ms, $SD = 13.286$; FaceDim-Tbaseline: $M = 556.182$ ms, $SD = 12.472$) [$t(22) = -0.458$, $p = 0.326$]; (PlaceBright-T2: $M = 558.174$ ms, $SD = 12.831$; PlaceBright-Tbaseline: $M = 557.412$ ms, $SD = 13.220$) [$t(22) = 0.187$, $p = 0.427$]; (PlaceDim-T2: $M = 550.840$ ms, $SD = 12.152$; PlaceDim-Tbaseline: $M = 553.307$ ms, $SD = 12.949$) [$t(22) = -0.704$, $p = 0.245$]. This finding is different from that of Experiment 2, which revealed that face distractors involuntarily held attention, regardless of the luminance of the gray border. What underlies this difference is unclear (and will be later discussed).

Lastly, at the offset of the distractor image (T5), participants responded more slowly to places with a dim gray border as compared to baseline performance for this condition

(PlaceDim-T5: $M = 570.474$ ms, $SD = 14.062$; PlaceDim-Tbaseline: $M = 553.307$ ms, $SD = 12.949$) [$t(22) = 4.075$, $p < 0.001$]. The driving factor underlying this offset effect is unclear.

Accuracy. For accuracy, there was no main effect of distractor-type [$F(1,22) = 0.111$, $p = 0.742$; face = 87.96%; place = 87.84%], or of luminance-border [$F(1,22) = 0.355$, $p = 0.557$; bright = 88.03%; dim = 87.77%]. There was a significant main effect of target-position [$F(5,110) = 4.356$, $p = 0.001$; T1 = 85.88%; T2 = 89.34%; T3 = 88.99%; T4 = 88.038%; T5 = 87.81%; T-baseline = 87.34%]. No significant interactions were found between distractor-type and luminance border [$F(5,110) = 3.077$, $p < 0.093$], between distractor-type and target-position [$F(5,110) = 1.849$, $p < 0.109$], or between luminance-border and target-position [$F(5,110) = 0.458$, $p < 0.807$]. Additionally, the three-way interaction between distractor-type, luminance-border, and target-position was also not significant [$F(5,110) = 0.943$, $p < 0.456$].

Discussion: Behavioral Data

As predicted, all four distractor conditions captured attention, as reaction times for each condition were slower at T1 as compared to at each condition's baseline. Only one distractor-type, faces with a bright gray border, continued to involuntarily hold attention, prolonging distraction. This latter finding is different from that of Experiment 2, which revealed that face distractors, regardless of the luminance of the gray border, involuntarily held attention. What underlies this difference is not known; however, there were several methodological differences between Experiments 2 and 3. First, Experiment 3 had more target events per block than Experiment 2 (416 vs. 272), and each trial had a longer duration due to the extended ITIs in Experiment 3. Therefore, the blocks in Experiment 3 were 216

seconds longer than those in Experiment 2 (496 sec vs. 280 sec). It is possible that the additional task duration and practice changed participants' strategy for performing the task. Further, across the two experiments, the T-baseline condition contained different numbers of target events. T-baseline was defined by target events occurring after the offset of one distractor, before the onset of a second distractor. Because there were more target events between distractors in Experiment 3 (again, due to the longer ITI), the T-baseline condition in this experiment contained more events (10 additional target trials) and lasted for a longer duration (10 additional seconds) than those in Experiment 2. Therefore, baseline levels of performance were operationally defined slightly differently across the two experiments. Along with differences in timing, the environmental luminance within the scanner versus that in the testing room may have led to variability in the effect of the distractors' luminance-border. In sum, all of these factors may have led to variable effects on task performance across the experiments. For example, participants' response times were faster in Experiment 3 as compared to Experiment 2. Further, compared to baseline performance levels, participants in Experiment 3 were less impaired by distractor onset than participants in Experiment 2. They also showed less variability in their reaction times to distractor onset. Perhaps these findings suggest that participants in Experiment 3 were more motivated, leading to enhanced voluntary control and less susceptibility to involuntary hold. Previous research using ERPs suggests that voluntary attention can be engaged to varying levels, and that increasing the degree of voluntary attention can boost several stages of stimulus processing (e.g. Handy & Mangun, 2000). Perhaps such a boost in voluntary control could leave participants less vulnerable to extended distraction (except for the case of a highly salient distractor- a face with a bright border).

fMRI Results

Distractor Processing Region. Bilateral visual processing regions were identified from the experimental scans. These regions corresponded to the location of the central distractor (from the “FaceBright + FaceDim + PlaceBright + PlaceDim” condition; (FWE, $p < 0.05$)), and were located in the left and right ventral occipital cortex (x, y, z: -27, -91, 1 and 30, -91, -2; Figure 10A-B). In the random effects analyses, we found that this occipital activity was similar across all conditions, as no significant differences were found when contrasting any of the four distractor types (uncorrected, $p < 0.001$). For each distractor type, paired t -tests (with B-H correction) were conducted to examine activity within the distractor processing regions. Figure 10C-D depicts the signal timecourses for each distractor type at the distractor processing regions. These analyses revealed that there were no significant differences between peak activations for any of the four distractor conditions (averaging timepoints 6 and 8), in either hemisphere [Left Hemisphere: FaceBright-FaceDim, $t(22)=-0.896$, $p=0.190$; FaceBright-PlaceBright, $t(22)=-1.575$, $p=0.065$; FaceBright-PlaceDim, $t(22)=-2.190$, $p=0.020$, not significant after B-H correction; FaceDim-PlaceBright, $t(22)=-0.813$, $p=0.213$; FaceDim-PlaceDim, $t(22)=-1.289$, $p=0.105$; PlaceBright-PlaceDim, $t(22)=-0.916$, $p=0.185$; Right Hemisphere: FaceBright-FaceDim, $t(22)=-2.027$, $p=0.027$; FaceBright-PlaceBright, $t(22)=-0.148$, $p=0.442$; FaceBright-PlaceDim, $t(22)=-1.972$, $p=0.031$; FaceDim-PlaceBright, $t(22)=0.817$, $p=0.041$; FaceDim-PlaceDim, $t(22)=-0.707$, $p=0.243$; PlaceBright-PlaceDim, $t(22)=-2.142$, $p=0.123$]. These analyses provided strong evidence that the distractor-processing ROIs were not sensitive to the type of distractor. This

finding is in line with the behavioral measures of orienting, which demonstrated no significant differences in reaction times between distractor conditions at T1 (distractor onset).

FFA. Bilateral “face” processing regions were identified from the experimental scans by the contrast: “Face > Place” (FWE corrected, $p < 0.05$). These regions were located in the left and right ventral temporal cortex (x, y, z: -39, -58, -20 and 39, -61, -14; Figure 11A), and were expected to show enhanced activations for faces versus places. Indeed, in the random effects analyses, we found that activity within the FFA was larger for the face distractors (FaceBright and FaceDim) as compared to that for the place distractors (PlaceBright and PlaceDim) (FWE corrected, $p < 0.05$). Paired *t*-tests (with B-H correction) were conducted within the FFA to compare peak activity to the face distractors versus that of the places distractors (at the 6 sec timepoint). Figure 11B-C depicts the signal timecourses for each distractor type at the FFA. As predicted, the peak FFA response in both hemispheres was significantly greater for distractors comprised of faces than for those comprised of places [Left FFA: FaceBright-PlaceBright, $t(22)=2.860$, $p=0.005$; FaceBright-PlaceDim, $t(22)=5.119$, $p<0.001$; FaceDim-PlaceBright, $t(22)=3.846$, $p<0.001$; FaceDim-PlaceDim, $t(22)=3.008$, $p=0.003$; Right FFA: FaceBright-PlaceBright, $t(22)=4.722$, $p<0.001$; FaceBright-PlaceDim, $t(22)=4.990$, $p<0.001$; FaceDim-PlaceBright, $t(22)=4.286$, $p<0.001$; FaceDim-PlaceDim, $t(22)=3.581$, $p<0.001$].

PPA. Bilateral “place” processing regions were identified from the experimental scans by the contrast: “Place > Face” (FWE corrected, $p < 0.05$). These regions were located in the left and right ventral temporal cortex (x, y, z: -27, -55, -8 and 27, -49, -11; Figure 12A). As expected, greater PPA activity was found in response to places as compared to faces. The random effects analyses revealed that activity within the PPA was larger for the

place distractors (PlaceBright and PlaceDim) as compared to that for the face distractors (FaceBright and FaceDim) (FWE corrected, $p < 0.05$). Paired t-tests, with B-H correction, were conducted within the maximum PPA response to compare peak activity across the distractor types. Figure 12B-C depicts the signal timecourses for each distractor type at the PPA. Indeed, the peak PPA response in both hemispheres was greater for distractors composed of places than for those composed of faces.

SPL. We identified bilateral dorsal parietal regions from the experimental “FaceBright + FaceDim + PlaceBright + PlaceDim” condition; (FWE, $p < 0.05$); (x, y, z: -27, -61, 55 and 24, -64, 55; Figure 13A). In the random effects analyses, activity in the SPL was similar across the four distractor conditions (uncorrected, $p < 0.001$). For each of the four distractor types, paired t-tests (with B-H correction) were conducted within the maximum of the SPL. Figure 13B-C depicts the signal timecourses for each distractor type at the SPL. Similar to the distractor-processing regions, there were no significant differences between SPL peak activations (averaging timepoints 6 and 8) for any of the four distractor conditions, in either hemisphere [Left Hemisphere: FaceBright-FaceDim, $t(22)=0.000$, $p=0.500$; FaceBright-PlaceBright, $t(22)=0.786$, $p=0.220$; FaceBright-PlaceDim, $t(22)=0.616$, $p=0.272$; FaceDim-PlaceBright, $t(22)=-0.713$, $p=0.242$; FaceDim-PlaceDim, $t(22)=0.512$, $p=0.307$; PlaceBright-PlaceDim, $t(22)=1.139$, $p=0.133$; Right Hemisphere: FaceBright-FaceDim, $t(22)=-0.046$, $p=0.482$; FaceBright-PlaceBright, $t(22)=-1.265$, $p=0.110$; FaceBright-PlaceDim, $t(22)=0.268$, $p=0.396$; FaceDim-PlaceBright, $t(22)=-1.083$, $p=0.145$; FaceDim-PlaceDim, $t(22)=0.285$, $p=0.389$; PlaceBright-PlaceDim, $t(22)=1.359$, $p=0.094$]. In sum, these results revealed that activity within the SPL was not modulated by distractor type.

TPJ. The TPJ was defined in two ways (Figure 14): first, by the contrast “FaceBright > FaceDim” (uncorrected, $p < 0.01$); and second, by the contrast “FaceBright > PlaceBright” (uncorrected, $p < 0.01$). In both of these comparisons, the FaceBright condition represents trials in which attention was captured and held by the distractor. The FaceDim/PlaceBright conditions represent trials in which attention was only oriented to, but not held on the distractor. Whether orienting was defined by the FaceDim condition or by the PlaceBright condition, the random effects analyses localized the TPJ to a similar cortical region in both the left and right hemispheres (FaceBright > FaceDim: x, y, z : -45, -55, 16 and 48, -49, 19; FaceBright > PlaceBright: x, y, z : -48, -58, 19 and 48, -58, -19. Figure 15 depicts the signal timecourses for each distractor type at the TPJ as defined by the “FaceBright > FaceDim” contrast (Top), and by the “FaceBright > PlaceBright” contrast (Bottom).

The timecourses of these two contrasts illustrate a similar pattern of activity. In the right TPJ, the timecourses show (1) an initial enhanced activation for the face distractors and (2) an extended activation for the “FaceBright” condition, as compared to the other three conditions (FaceDim, PlaceBright, and PlaceDim). Notably, activity within the right TPJ seemed to remain high for the FaceBright condition, but not for the other conditions. A different pattern of activation was found in the left TPJ (for both the “FaceBright > FaceDim” and the “FaceBright > PlaceBright” contrasts). Specifically, the left TPJ was primarily activated by FaceBright distractors, and not by the other three distractor conditions.

In summary, the timecourse plots suggest that activity in the right TPJ was initially enhanced for all distractor types, and continued to remain high for the FaceBright distractors. The extended activity for the FaceBright distractors may mirror the behavioral hold of attention demonstrated for these distractors. Activity in the left TPJ seemed to show a

different pattern, as activity was enhanced and extended for only the FaceBright condition, and not for the other three distractor types.

Target Processing Region. A visual processing region was identified from the deactivations of the “FaceBright + FaceDim + PlaceBright + PlaceDim” contrast, corresponding to the location of the peripheral target (FWE, $p < 0.05$). This region was located in the left ventral occipital cortex (x, y, z: -6, -82, -8; Figure 16B, bottom), and matched well with the target processing region identified in the localizer run (x, y, z: -9, -82, -11, Figure 16A, top), from the “ $T > (Face + Place)$ ” contrast (uncorrected, $p < 0.001$). In the random effects analyses, the target-related activity was similar across all conditions, as no significant differences were found when comparing the four distractor types (uncorrected, $p < 0.001$). Paired t-tests were also conducted, and Figure 16C depicts the signal timecourses for each distractor type at the target processing region. These analyses revealed deactivations for all distractor types between timepoints 2 and 8 sec; however, these activations were only significantly different from baseline (i.e. zero percent signal change) at timepoint 6 sec [FaceBright6-Baseline: $t(22)=-2.998$, $p=0.003$; FaceDim6-Baseline: $t(22)=-1.966$, $p=0.031$, not significant with B-H correction; PlaceBright6-Baseline: $t(22)=-3.636$, $p<0.001$; PlaceDim6-Baseline: $t(22)=-3.698$, $p<0.001$]. By timepoint 10 sec, the signal for each distractor type was positive, but not significantly different from baseline [FaceBright10-Baseline: $t(22)=2.209$, $p=0.019$, not significant after B-H correction; FaceDim10-Baseline: $t(22)=1.096$, $p=0.142$; PlaceBright10-Baseline: $t(22)=0.963$, $p=0.173$; PlaceDim10-Baseline: $t(22)=-0.057$, $p=0.477$]. In general, these results suggest that deactivations within the target processing region were not modulated by distractor type.

Discussion: fMRI Results

The timecourse plots illustrated a hemispheric asymmetry within the activation of the TPJ, a brain region previously linked to the reorienting of attention (as reviewed in Corbetta et al, 2008). Specifically, the right TPJ seemed to respond to any distractor that oriented attention; and, this activity seemed to be extended when attention continued to be involuntarily held on the distractors. In contrast, the left TPJ was more sensitive to the involuntary hold of attention, activating primarily in response to distractors that held attention (i.e. face distractors with bright borders). These TPJ activations suggest that orienting and hold are related, but maybe partially dissociable processes.

We also found strong activation in distractor processing regions of the visual cortex for all four distractor types. The distractor activations were coupled with a deactivation in target processing regions. These results reveal a competitive relationship between distractor and target processing regions, as was previously demonstrated by Kim & Hopfinger (2010). Of note, however, neither the distractor- nor target- processing regions were modulated by the level of behavioral distraction. Items that held attention did not differentially strengthen distractor processing regions or attenuate target processing regions, as compared to items that solely oriented attention. Beyond visual processing areas, our analyses demonstrated increased activation within bilateral regions in the parietal cortex, specifically in the SPL. Similar to the visual processing regions, the SPL activity was not modulated by differential levels of attentional capture (i.e. orienting vs. orienting and hold). Further interpretation of these neuroimaging results, are presented in the General Discussion, in conjunction with the behavioral results of Experiments 1, 2, 4a, and 4b.

CHAPTER 5

EXPERIMENT 4A: SPATIAL CUING PARADIGM

Experiments 1 and 2 revealed that the image of a face can involuntarily hold attention, leading to distraction. These experiments employed a novel paradigm that is quite different from those traditionally used to study attention, such as spatial cuing task. Additionally, in Experiments 1 and 2, the temporal lag between events was long (with 1000 msec between targets). Thus, the processing level at which the hold occurs is unclear. The hold might reflect an increase in the early sensory processing of faces; or in contrast, might occur at later, higher-order stages of processing. The purpose of Experiment 4a was to investigate if the attentional hold by faces would manifest in a more traditional paradigm designed to isolate relatively early levels of stimulus processing (<400 msec post stimulus onset). To do so, we modified a classic spatial cuing paradigm, manipulating the object-identity of the cue stimulus. Participants were required to detect a lateral target that was preceded by an image of either a face or a place. Each object-type was equally likely to occur; and importantly, its location did not predict that of the upcoming target. Participants were instructed to ignore the non-predictive cues. The cues and targets were separated by either an SOA of 100-200 msec or 300-400 msec. Given this temporal sequence and given that the cues were non-informative, any attention directed to these cues would reflect relatively early involuntary effects. If faces are not found to hold attention here, this would suggest that the hold shown in Experiments 1 and 2 likely affects a later, higher-order stage

of processing (>400 msec post stimulus onset). Though not a direct comparison, Experiment 4a acts as a first step in evaluating the processing stage at which attentional hold by faces occurs. This information can then be used to help interpret the neuroimaging results of Experiment 3.

In Experiment 4a, we expected to find traditional cuing effects (faster responses to cued vs. uncued targets) at the short SOA. Given this, facilitated *orienting* by face cues would be evidenced by the speeding of responses on valid trials containing these cues as compared to valid trials containing place cues. This validity effect would reflect enhanced spatial engagement of involuntary attention to the face cues. Attentional *hold* by face cues would be evidenced by the slowing of responses on invalid trials containing those cues as compared to invalid trials containing place cues. On invalid trials, attention must be disengaged and reoriented to the target location. The longer that attention is held on an invalid cue, the worse performance will be on the subsequent target task. Thus, differences in performance on invalid face versus place trials represent differences in the hold of attention, and more specifically, in the spatial transfer (i.e. disengagement and reorienting) of attention. Lastly, at the long SOA, it was unclear whether typical cuing effects would be found, or whether IOR would begin to initiate.

Methods

Participants. Thirteen right-handed undergraduate students from the University of North Carolina at Chapel Hill were recruited for this study and were compensated with course credit in their Introduction to Psychology course. Each participant was required to

have 20/20 or corrected to 20/20 vision, and to be free from neurological and psychiatric disorders. Informed consent was obtained prior to participation in the study, although participants were kept naïve of the experimental hypotheses.

Materials and Procedure. In a sound attenuated room, a commercial software package (“Presentation”; Neurobehavioral Systems; San Francisco, CA) was used to present stimuli and record responses on a 17-inch computer monitor. As in the previous experiments, participants began the experiment with a passive viewing of the stimuli. During this block, each image was displayed one at a time and in a random order for 2000 msec, separated by a 1000 msec ISI. No task was required, besides maintaining attention on a central fixation point.

Across twelve experimental blocks, participants performed a manipulated version of Posner’s classic cuing paradigm consisting of peripheral cue and target presentation (Posner, 1980) (See Figure 17). The background display consisted of a central fixation cross and two light gray square outline boxes, one located in the upper left visual field, and the other located in the upper right visual field. Participants were required to maintain fixation upon a central cross throughout each block. The cue stimuli were grayscale photographic images, identical to those used in the previous experiment. Half were images of a place, and the other half were images of a face with a neutral expression. The target stimuli was a blue rectangle (RGB “0, 0, 255”) that was either oriented vertically or horizontally.

Each cue stimulus was equally likely to appear in one of the two peripheral outline boxes, for a duration of 75 msec. Its location did not predict the location of the upcoming target, which was also equally likely to appear in either peripheral outline box. The target was presented for 50 msec, centered within one of the peripheral outline boxes. The stimulus

onset asynchrony (SOA) between the cues and targets varied randomly between 100-200 msec (short SOA) and 300-400 msec (long SOA). The task was to discriminate the orientation of the blue target. With their right hand, participants pressed Button 1 on a video controller if the bar was vertical or Button 2 if the bar was horizontal. Participants were instructed to respond to the target as quickly as possible without sacrificing accuracy, while maintaining central fixation. A new trial began after an inter-trial-interval (ITI) of 1200-1500 msec. Before the experimental blocks, participants completed a practice block, containing 64 trials. Each experimental block contained 64 trials, for a total of 768 trials across the experiment. There were an equal number of trials for each condition.

Results

Reaction Time Data Analysis. (See Figure 18). A four-way ANOVA was performed on the reaction times to the targets, with factors of target-side (left or right), cue-to-target SOA (short or long), object-type (face or place), and validity (cued or uncued). Responses faster than 150 msec or slower than 1150 msec were removed from the analyses. The ANOVA revealed a significant main effect of side [left: 440.839 msec; right: 433.307 msec; $F(1,12)=8.847, p=0.012$], such that participants responded faster when the location of the target stimulus was in the same relative location as the response (i.e. *right* target requiring a button press with the *right* hand). This phenomenon is termed the “Simon effect,” and is believed to reflect difficulty in the response-selection stage of decision making (e.g. Simon & Wolf, 1963). A significant main effect of SOA was also found [short: 450.185 msec; long: 423.961 msec; $F(1,12)=117.259, p<0.001$], as participants were *slower* to respond at the short SOA as compared to the long SOA. There was no significant main effect of object-

type $F(1,12)=0.701, p=0.419$], or validity $F(1,12)=2.318, p=0.154$]. None of the two-way interactions were significant; however, we found a significant three-way interaction between SOA, object-type, and validity [$F(1,12)=68.668, p=0.012$]. To explore this interaction, we conducted paired t-tests using the Benjamini-Hochberg (1995) procedure to correct for multiple comparisons. We first observed whether there were significant cuing effects within each condition (cued vs. uncued). Next, we examined whether object-type affected the orienting and/or hold of attention, at the cued and uncued locations, respectively.

For the interaction of SOA, object-type, and validity, significant cuing effects were *not* found for any condition including: places at the short (cued: $M=454.147$ msec; uncued: $M=450.277$ msec) ($t(12)=1.218, p=0.123$), place at the long SOA (cued: $M=419.814$ msec; uncued: $M=428.739$ msec) ($t(12)=-1.474, p=0.083$), faces at the short SOA (cued: $M=445.820$ msec; uncued: $M=450.498$ msec) ($t(12)=-1.615, p=0.066$), and faces at the long SOA (cued: $M=423.129$ msec; uncued: $M=426.160$ msec) ($t(12)=-1.136, p=0.139$). In all cases, participants did not respond to cued trials significantly faster than to uncued trials. Thus, the cue did not effectively orient attention. This result was unexpected, and may suggest that the cues here acted as visual masks, *reducing* the visibility of the target.

While we did not find typical cuing effects, we were still interested in examining attentional capture effects for face and place cues. First, we compared reaction times for trials containing faces versus places at the *cued* location. No significant effects were found for any comparison. Specifically, at the short SOA, no differences were found between the reactions times to cued targets following faces as compared to those following places (face: $M=445.820$ msec; place: $M=454.147$ msec) ($t(12)=-2.840, p=0.007$, not significant after B-H correction). The same pattern was found for cued targets at the long SOA (face: $M=423.129$

msec; place: $M=419.814$ msec) ($t(12)=0.961$, $p=0.178$). These results suggest that faces did not differentially orient attention here. Next, we investigated whether faces involuntarily held attention, comparing reaction times for trials containing faces versus places at the *uncued* location. At both the short and long SOA, no significant differences were found between the reactions times to uncued targets following faces as compared to those following places [Short SOA: face: $M=450.498$ msec; place: $M=450.277$ msec; ($t(12)=-0.062$, $p=0.476$); Long SOA: face: $M=426.160$ msec; place: $M=428.739$ msec; ($t(12)=-0.158$, $p=0.0438$). In sum, the interaction between SOA, object-type, and validity revealed no significant differences between orienting or hold to faces versus places.

To further explore the interaction of SOA, object-type, and validity, we conducted two-way ANOVAs on trials with short SOAs and with long SOAs, respectively. For the short SOA trials, we found no significant main effect of validity [$F(1,12)=0.411$, $p=0.531$], or of object-type [$F(1,12)=1.846$, $p=0.194$]. In addition, the interaction between validity and object-type was not significant [$F(1,12)=0.331$, $p=0.573$]. Similar patterns were found for the long SOA trials, a we found no significant main effect of validity [$F(1,12)=2.734$, $p=0.124$], or of object-type [$F(1,12)=0.263$, $p=0.617$]. The interaction between validity and object-type was also not significant [$F(1,12)=0.686$, $p=0.424$].

Accuracy Data Analysis. A four-way ANOVA was performed on accuracy to the target, with factors of target-side (left or right), cue-to-target SOA (short or long), object-type (face or place), and validity (cued or uncued). Responses faster than 150 msec or slower than 1150 msec were removed from the analyses. Throughout the experiment, accuracy was quite high at 96.55%. There were no significant main effects of distractor-type [$F(1,12)=0.147$, $p=0.708$; face = 96.64%; place = 96.47%], of target-side [$F(1,12)=2.824$, $p=0.119$; Left =

96.15%; Right = 96.96%], of SOA [$F(1,12) = 0.715$, $p = 0.414$; Short = 96.39%; Long = 96.72%], or of cuing [$F(1,12) = 2.233$, $p = 0.161$; Cued = 96.88%; Uncued = 96.23%].

Further, no significant two-, three-, or four- way interactions were found between any factors.

Discussion

The goal of Experiment 4a was to examine if the attentional hold found in previous experiments would manifest in a more common attentional paradigm designed to highlight early attention effects. To accomplish this, we used a classic, non-predictive spatial cuing paradigm with relatively short cue-to-target SOAs. We manipulated the object-identity of the cue stimulus, as either an image of a neutral face or of a place. Enhanced *orienting* to face cues was defined by the speeding of responses on valid trials containing these cues as compared to valid trials containing place cues. Enhanced attentional *hold* by face cues was defined by the slowing of responses on invalid trials containing those cues as compared to invalid trials containing place cues.

Overall, Experiment 4a provided no evidence that faces orient or hold attention to a greater extent than places. However, these findings are difficult to interpret given that neither cue was found to capture attention, as responses on cued trials were not significantly different from those on uncued trials. Why cuing effects were not found is unclear, although is likely related to the timing parameters used here. First, it is possible that the timing, especially at the short SOA, led to visual masking of the targets. In general, masking occurs when the visibility of an object (e.g. the target) is reduced by the presentation of a second object nearby in space or time (for review see Enns and Di Lollo, 2000). The cues here may have masked the subsequently appearing targets, which occurred nearby in time (and in space

for cued trials). While involuntary attention can act quickly, facilitating responses to items at cued locations for the first few hundred msec, it is possible that the complex nature of the cues used here blocked this facilitation. Participants may have simply required more time to process these complex cues. In addition, the use of two distinct cue-to-target SOAs may have attenuated the typical cuing effect. Lamy (2010) suggests that participants' temporal expectations can alter their ability to overcome attentional capture. When the time interval between cue and target is unpredictable (i.e. when there are two time bins, or SOAs, between events), capture can be overridden (Lamy, 2010).

Given these concerns, we chose to conduct a second cuing experiment in an attempt to better isolate typical cuing effects. This experiment was similar to Experiment 4a, except for a few methodological changes. First, the short SOA was increased from 100-200 msec to 200-300 msec, allowing for more stimulus processing time between cue and target. This delayed SOA left no time interval between the short (200-300 msec) and long (300-400 msec) SOAs. By making the cue-to-target interval more predictable (i.e. within one time bin), we hoped to prevent any attentional capture effects from being overridden. Finally, the task was changed from a discrimination judgment to a detection judgment in order to decrease task difficulty and the extent of target processing.

CHAPTER 6

EXPERIMENT 4B: SPATIAL CUING PARADIGM

Experiment 4b used similar stimuli and procedures to Experiment 4a, except for the following changes: the short SOA was changed from 100-200 msec to 200-300 msec; and the task was changed from a discrimination judgment to a detection judgment.

Methods

Participants. Thirteen right-handed undergraduate students from the University of North Carolina at Chapel Hill were recruited for this study and were compensated with course credit in their Introduction to Psychology course. Each participant was required to have 20/20 or corrected to 20/20 vision, and to be free from neurological and psychiatric disorders. Informed consent was obtained prior to participation in the study, although participants were kept naïve of the experimental hypotheses.

Materials and Procedure. In a sound attenuated room, a commercial software package ("Presentation"; Neurobehavioral Systems; San Francisco, CA) was used to present stimuli and record responses on a 17-inch computer monitor. As in the previous experiments, participants began the experiment with a passive viewing of the stimuli. During this block, each image was displayed one at a time and in a random order for 2000 msec, separated by a 1000 msec ISI. No task was required, other than to maintain attention on a central fixation point.

Across twelve experimental blocks, participants performed a manipulated spatial cuing paradigm (Posner, 1980). The background display consisted of a central fixation cross and two light gray square outline boxes, one located in the upper left visual field, and the other located in the upper right visual field. Participants were required to maintain fixation upon a central cross throughout each block. The cues were grayscale photographic images, identical to those used in the previous experiment. Half were images of a place, and the other half were images of a face with a neutral expression. The target stimuli was a small blue square (RGB “0, 0, 255”).

Each cue stimulus was equally likely to appear in one of the two peripheral outline boxes, for a duration of 75 msec. Its location did not predict the location of the upcoming target, which was also equally likely to appear in either peripheral outline box. The target was presented for 50 msec, centered within one of the peripheral outline boxes. The SOA between the cue and target varied randomly between 200-300 msec (short SOA) and 300-400 msec (long SOA). The task was to detect the blue target by pressing Button 1 on a video controller. Participants were instructed to respond to the target as quickly as possible without sacrificing accuracy, while maintaining central fixation. A new trial began after an ITI of 1200-1500 msec. Before the experimental blocks, participants completed a practice block, containing 64 trials.

Each of the experimental blocks contained 64 trials, for a total of 768 trials across the experiment. Eighty-percent of the trials contained both a cue and target stimulus, and there were an equal number of each condition. The remaining twenty-percent of the trials were “catch trials,” and did not contain a target stimulus. In these trials, participants were instructed to continue to maintain fixation without responding, until the next trial occurred.

These catch trials were included to enhance participant motivation and to ensure that participants were responding to the target and not to the cue.

Results

Reaction Time Data Analysis. (See Figures 19 & 20). A four-way ANOVA was performed on the reaction time to the targets, with factors of target-side (left or right), cue-to-target SOA (short or long), object-type (face or place), and validity (cued or uncued). Responses faster than 150 msec or slower than 1150 msec were removed from the analyses. The ANOVA revealed a significant main effect of side [left: 295.708 msec; right: 288.387 msec; $F(1,12)=17.968, p<0.001$], such that participants responded faster when the location of the target was in the same relative location as the response. This pattern was also found in Experiment 4a, and likely reflects the “Simon effect.” A significant main effect of validity was also found [cued: 300.206 msec; uncued: 283.889 msec; $F(1,12)=16.769, p=0.001$], as participants were *slower* to respond to cued targets as compared to uncued targets. This result was unexpected given the short cue-to-target SOA used here, and will be further discussed below. The main effects of SOA [$F(1,12)=0.209, p=0.656$] and object-type [$F(1,12)=0.515, p=0.487$] were not significant. None of the two-way interactions were significant, however, we found a significant three-way interaction between SOA, object-type, and validity [$F(1,12)=6.985, p=0.021$]. To explore this interaction, we conducted paired t-tests using the Benjamini-Hochberg (1995) procedure to correct for multiple comparisons. We first observed whether there were significant cuing effects within each condition (cued vs. uncued). Next, we examined whether object-type affected the orienting and/or hold of attention, at the cued and uncued locations, respectively.

For the interaction of SOA, object-type, and validity, *reversed* cuing effects were present for all four conditions. Specifically, we found significant reversed cuing effects for places at the short (cued: $M=299.245$ msec; uncued: $M=283.788$ msec) ($t(12)=15.457$, $p=0.001$) and the long SOA (cued: $M=302.494$ msec; uncued: $M=280.710$ msec) ($t(12)=21.784$, $p<0.001$), and for faces at the short SOA (cued: $M=303.585$ msec; uncued: $M=285.538$ msec) ($t(12)=18.047$, $p=0.005$), and marginally significant at the long SOA (cued: $M=295.502$ msec; uncued: $M=285.502$ msec) ($t(12)=9.982$, $p=0.033$, not significant after B-H correction). These results may indicate the influence of visual masking between cues and targets, or instead, may reflect an early IOR-like effect.

To explore whether faces involuntarily held attention, we compared reaction times for trials containing faces versus places at the *uncued* location. At both the short and long SOA, no significant differences were found between the reactions times to uncued targets following faces as compared to those following places [Short SOA: face: $M=285.538$ msec; place: $M=283.788$ msec; ($t(12)=0.973$, $p=0.175$); Long SOA: face: $M=285.519$ msec; place: $M=280.710$ msec; ($t(12)=1.357$, $p=0.099$)]. Next, we investigated whether faces enhanced the orienting of involuntary attention, comparing reaction times for trials containing faces versus places at the *cued* location. At the short SOA, no differences were found between the reactions times to cued targets following faces as compared to those following places (face: $M=303.585$ msec; place: $M=299.245$ msec) ($t(12)=1.264$, $p=0.115$). However, at the long SOA participants were significantly faster to respond to cued targets preceded by faces than to those preceded by places (face: $M=295.502$ msec; place: $M=302.494$ msec) ($t(12)=-3.545$, $p=0.002$). In sum, the interaction between SOA, object-type, and validity revealed that at the long SOA, faces, as compared to places, reduced the IOR-like effect at cued target locations.

Again, the two-way interactions between SOA and object type $F(1,12)=2.219, p=0.162$], SOA and validity $F(1,12)=0.078, p=0.785$], and object-type and validity were not significant [$F(1,12)=2.367, p=0.150$].

Accuracy Data Analysis. A four-way ANOVA was performed on accuracy to the target, with factors of target-side (left or right), cue-to-target SOA (short or long), object-type (face or place), and validity (cued or uncued). Responses faster than 150 msec or slower than 1150 msec were removed from the analyses. Throughout the experiment, accuracy was quite high with overall at 98.05%. There were no significant main effects of distractor-type [$F(1,12) = 0.281, p = 0.606$; face = 98.12%; place = 97.98%], of target-side [$F(1,12) = 0.003, p = 0.955$; Left = 98.04%; Right = 98.06%], of SOA [$F(1,12) = 3.136, p = 0.102$; Short = 98.82%; Long = 97.28%], or of cuing [$F(1,12) = 1.022, p = 0.470$; Cued = 97.98%; Uncued = 98.12%]. Further, no significant two-, three-, or four- way interactions were found between factors.

Discussion

The goal of Experiment 4b was to examine if the attentional hold by faces found in Experiments 1 and 2 would manifest in a more common attentional paradigm designed to highlight early attention effects. To accomplish this, we used a classic, non-predictive spatial cuing paradigm with short cue-to-target SOAs, in conjunction with a simple detection task. As in Experiment 4a, we manipulated the object-identity of the cue stimulus, as either an image of a neutral face or of a place. We expected to find typical cuing effects in which participants respond faster to cued versus uncued targets. Of interest was if we could find enhanced orienting and/or hold to the face cues. Enhanced *orienting* to face cues was

defined as by the speeding of responses on valid trials containing these cues as compared to valid trials containing place cues. Enhanced attentional *hold* by face cues was defined as the slowing of responses on invalid trials containing those cues as compared to invalid trials containing place cues.

Unexpectedly, we found IOR-like effects for both face and place cues, in which participants responded faster to *uncued* trials as compared to *cued* trials. We had not predicted this effect given several design parameters within our paradigm. First, the effects of IOR typically arise 300-500 msec after the onset of a simple cue stimulus (e.g. a brief flash). In our paradigm, however, we used a complex object cue that preceded the target by 200-400 msec. Two previous studies have demonstrated IOR using spatial cuing paradigms with schematic face cues (Fox, Russo, & Dutton, 2002; Taylor & Therrien, 2005). In both of these studies, however, the cue-to-target SOA was greater than 960 msec, and an additional event occurred between the cue and target. While further research is needed to determine what factors produced the IOR-like effect here, we note that our task was not difficult. Participants demonstrated both fast and accurate responses when detecting the target. Importantly, the onset of IOR has been shown to be affected by task difficulty (as reviewed in Klein, 2000). The easier the task, the earlier that IOR manifests. Further, Lupiáñez and colleagues showed that IOR occurs earlier for detection tasks than for localization or discrimination tasks (Lupiáñez, Milan, Tornay, Madrid, & Tudela, 2001). Thus, it is possible that the ease and nature of the task used here led to strong and early IOR effects. Alternatively, more recent work suggests that “high-value” distractors, as defined by monetary reward, draw spatial attention, and that disengagement from these distractors might leave an inhibitory trace at their location, similar to IOR (Anderson, Laurent, & Yantis,

2011). Perhaps the face and places distractors used here were processed as “high-value” stimuli, leading to IOR-like effects. Lastly, it is also possible that the cues masked the targets, reducing task performance on cued target trials (Enns & Di Lollo, 2000).

Thus, while we provided some evidence that participants respond faster to cued faces as compared to places, these results are difficult to interpret given the lack of typical attentional cuing effects. If the reversed cuing reflected an IOR-like effect, then our results weakly support previous evidence that faces reduce the magnitude of IOR (Fox, et al, 2002; Taylor & Therrien, 2005). On the other hand, if the reversed cuing reflected visual masking, then our results suggest that faces serve as less effective visual masks than places. In either case, these findings are in line with the notion that faces are uniquely prioritized and processed within the human brain.

Whatever the mechanism, the limited nature of these findings might suggest that the strong hold of attention found in Experiments 1 and 2 occurs at later stages of processing (>400 msec after face onset) than those examined here. This notion is also supported by the neuroimaging results of Experiment 3, which revealed that the bilateral TPJ, and not early visual processing regions, were differentially modulated by the orienting versus hold of attention. Alternatively, the attentional hold by faces might be dependent on the continuous presence of the face stimuli, as was the design in Experiments 1 and 2. Perhaps the abrupt offset of faces in Experiments 4a and 4b re-captured attention, countering the initial hold effect. Further research is required to disentangle these possibilities.

CHAPTER 7

GENERAL DISCUSSION

In this study, we investigated the neural underpinnings of distraction by isolating two stages of involuntary capture: attentional orienting and hold. While previous work on attentional capture focused on how stimuli initially draw attention, new evidence suggests that the subsequent time during which attention is involuntarily *held* on the captured items may be equally, if not more, important. Yet, no study to our knowledge has attempted to examine the neural mechanisms underlying these stages of attentional capture. Several neuroimaging studies have examined *voluntary* attention, revealing an associated network within the *dorsal* frontal and parietal cortices (Brefczynski & De Yoe, 1999; Corbetta & Shulman, 2002; Gandhi, et al, 1999; Ress, et al, 2000; Giesbrecht, et al, 2003; Hopfinger, et al, 2000; Kastner, et al, 1999; Kastner & Ungerleider, 2000; Somers, et al, 1999). In addition, a second network, the *ventral* fronto-parietal network, has been associated with the detection of physically salient items within the environment. One region within this network, the *right* TPJ, is recruited during attentional reorienting in response to an unexpected stimulus. Here, we sought to understand how the dorsal and ventral networks interact when attention is involuntarily held on a distracting stimulus and must be voluntarily reoriented back to a task. Of critical interest was exploring if the neural correlates of involuntary hold are dissociable from those of involuntary orienting.

fMRI timecourse plots suggested a hemispheric asymmetry in brain regions involved in the reorienting of attention. Activity in the *right* TPJ was enhanced for distractors that orient attention; and critically, this activity seemed to extend when attention continued to be involuntarily held on the distractors. Additionally, the *left* TPJ was primarily sensitive to the involuntary hold of attention, activating only in response to distractors that held attention (i.e. face distractors with bright borders). The TPJ activations may have led to the attentional hold effects seen in behavioral performance and suggest that orienting and hold are related, but partially dissociable processes. Both mechanisms were associated with activations in the right TPJ (with hold to a greater extent), but only increased attentional hold was associated with activations in the left TPJ. It is possible that the distractors that only oriented attention simply did not activate the left TPJ to an above-threshold level. However, given the strong behavioral orienting effects seen for all distractors, this seems less likely.

The orienting effect here is considered to reflect the heightened engagement of attention. Given the temporal limitations of fMRI, however, the mechanisms underlying the involuntary hold of attention are less clear. Increased hold might result from extended dwell time on a distractor. Yet, this seems unlikely here, as we did not find enhanced activation in visual distractor processing regions for items that held attention. Alternatively, it is possible that the hold of attention is due to slowed or more effortful disengagement from distractors that hold attention. Lastly, items that involuntarily held attention may require more effortful reorienting from the distractor back to the target. Of final note, in the current analyses, we were able to highlight isolated regions of activation. However, involuntary attentional hold may depend on differential connection strengths between cortical regions of interest. For example, enhanced activation within the TPJ might result in weaker connections between the

TPJ and visual target processing region, or between the TPJ and parietal regions involved in voluntary control. Either case might lead to increased behavioral distraction.

Whatever the mechanism, we provided novel evidence of a hemispheric asymmetry in brain regions previously linked to attentional reorienting. While the TPJ is typically discussed as a right lateralized network (Corbetta & Shulman, 2002), a few attention studies have reported activation within the left TPJ (Kincade, Abrams, Astafiev, Shulman, & Corbetta, 2005; Weidner, Krummenacher, Reimann, Muller, & Fink, 2009; Marois, Leung, & Gore, 2000). While none of these studies directly examined involuntary attentional hold, Weidner and colleagues (2009) suggest that the left TPJ might be related to non-spatial attentional reorienting. Perhaps the centrally-presented distractors in the current study draw non-spatial, as opposed to spatial, attention resources (as will be further discussed later). Regardless, the current results add to previous studies of reorienting in which TPJ activation was limited to the right hemisphere (as reviewed in Corbetta et al, 2008). We suggest that the right hemispheric bias demonstrated in previous studies of attentional reorienting may reflect the fact that these studies did not elicit involuntary attentional hold. More specifically, reorienting has often been studied using attentional cuing paradigms in which right TPJ activation is uniquely associated with trials that require the re-directing of attention from an invalid cue to a target (e.g. Corbetta & Shulman, 2002). In these studies, the cue is typically a simple stimulus such as a square or circle. We propose that the lack of left TPJ activation in these studies is due to the fact that the simple cues do not hold attention to the extent required to elicit left TPJ activation. The absence of hold may have led to the observed right-dominant activity. However, we note that the left TPJ is not likely *uniquely* sensitive to the hold of attention, as a previous study revealed that both the left and right TPJs

are also associated with the selective processing of mental states, whether the content of the mental states is expected or unexpected (Young, Dodell-Feder, & Saxe, 2010). However, in that study, the stimuli were written sentences, and expectancy was defined by the likelihood of the sentence's content occurring. For example, an unexpected event might read, "The water from the tap tastes like chocolate milk." In contrast, the stimuli in our experiment were defined by a non-verbal event requiring *spatial* reorienting from an unexpected event; therefore, it is unlikely that these two studies isolate the same type of expectancy. Additionally the TPJ regions defined by Saxe and colleagues are more lateral than those defined here, suggesting that their study and our own are highlighting different regions within the temporo-parietal junction.

Beyond the TPJ, we found that task-irrelevant stimuli produced strong activation in distractor processing regions of the visual cortex, while also attenuating activity in target processing regions. These results reveal a competitive relationship between distractor and target processing regions, and were apparent even though the distractors did not match the attentional set of the target stimulus. These findings replicate the results of Kim and Hopfinger (2010), which demonstrated that new objects capture attention despite the fact that participants knew the locations of the targets and distractors. As discussed by Kim and Hopfinger, this finding is not in line with previous results demonstrating that attentional capture to peripheral onsets can be avoided when participants can anticipate the location of a target (Theeuwes, 1991). What underlies this discrepancy is unclear, but is likely related to differences in experimental design. Our study used a continuous performance task with simultaneously presented distractors, while Theeuwes (1991) used a visual search paradigm

in which a target location was precued by a central arrow. Future research is needed to evaluate the effect of these design inconsistencies.

Of additional note, the distractor and target processing regions were not modulated by the level of behavioral distraction. Items that solely oriented attention versus those that oriented and held attention, did not differentially activate distractor processing regions (including lower-order visual processing in V1 and higher-order processing in FFA/PPA). This pattern was also mirrored in target processing region, as the visual response to the target was equivalent for all distractor conditions. These results may suggest that the involuntary hold of attention found here (in Experiments 1-3) reflects an extension of higher-order, and not lower-order, processing. This is in line with the cuing results of Experiment 4a and 4b, which found no attentional hold effects during times when lower-order visual processing takes place (<400 msec post stimulus onset). This may suggest that attentional hold is due to changes in the *connections* between regions, rather than to changes in the regional activations themselves.

Beyond visual processing areas, our analyses also revealed that regions in the parietal lobe, specifically the bilateral SPL, were activated by the appearance of a distractor. Once more, this activity was not modulated by whether the distractor merely oriented or also held attention. This effect was unexpected given recent evidence that the left superior parietal cortex plays a role in reducing distraction. Disrupting this region with transcranial magnetic stimulation (TMS) was found to increase susceptibility to distraction (Kanai, Yuan Dong, Bahrami, & Rees, 2011). The inconsistency between this study and our own may suggest that the parietal cortex helps to prevent attentional capture, but once capture has occurred, cannot reduce the degree of attentional orienting and/or hold.

Lastly, we did not find activations within other more ventral regions known to be important for the detection of physically salient stimuli, such as the inferior frontal gyrus (IFG). This was somewhat surprising, as this region has been shown to have both structural (Umarova, Saur, Schnell, Kaller, Vry, Glauche, Rijntjes, Hennig, Kiselev, & Weiller, 2010) and functional (e.g. Corbetta & Shulman, 2002) connections with the temporoparietal cortex. However, in a recent neuroimaging study, inferior frontal activity was found in response to novel stimuli, even when those stimuli did not elicit a conscious shift in attention (van Schouwenburg, den Ouden, & Cools, 2010). In other words, the IFG was linked to novelty detection, rather than to attentional switching. Perhaps we did not find inferior frontal activity here because our distractor stimuli were not novel, as all were previously viewed prior to the experimental session. Alternatively, Shulman and colleagues (2009) suggest that the ventral frontal cortex is primarily activated when reorienting is unexpected. Here, participants were aware of the presence and location of the distractors; and thus, were likely to expect the need to reorient attention from the distractor to the target.

Thus far, we have suggested that the involuntary hold of attention is associated with enhanced processing in the left TPJ, and enhanced and extended processing in the right TPJ. However, it is possible that the latter finding (in the right TPJ) does not reflect a boost in activation, but rather reflects an interference with the inhibition of distractors. Previous research has shown that people intentionally prioritize newly appearing stimuli and ignore distracting, pre-existing stimuli. In a visual search task, Watson and Humphreys (1997) found that when distractors are presented in a preview, participants can suppress the processing of these items. In the current study, participants likely intentionally ignored the spatial window corresponding to the distractors, as their location was predetermined and

unchanging. Nevertheless, the onset of all distractor types drew attention, impairing task performance at T1. This finding suggests that there was an initial boost in the processing of these objects despite (possible) intentional inhibition. After T1, however, the distractors may have been categorized as pre-existing objects that could be intentionally ignored in some cases (e.g. distractors that orient attention), but not in others (e.g. distractors that involuntarily orient and hold attention). Further research is required to determine whether attentional hold reflects an extension of activity related to the initial distraction, or the blockage of inhibitory mechanisms to pre-existing distractors.

Although the current study is couched in terms of isolating involuntary orienting versus hold, it is important to note that the capture mechanisms described here may be somewhat different from those described in more typical spatial cuing paradigms. For example, the distractors in our continuous performance task were complex object-stimuli that were centrally-located at fixation. Thus, the initial orienting of attention to these distractors may have reflected a non-spatial engagement of attention, such as the allocation of attentional resources to a specific feature or object, rather than to a spatial location. This might explain why we did not find frontal (e.g. frontal eye fields) activation, which is typically associated with the voluntary shift of spatial attention (e.g. Corbetta & Shulman, 2002). Second, in the continuous performance task used here, the distractors were completely task-irrelevant and their location was pre-set and unchanging. In contrast, while the cues in a non-predictive spatial cuing paradigm are also task-irrelevant, they occur in possible target locations and are temporally linked to the target. Capture across these two cases may therefore elicit unique forms of distraction. Lastly, it is difficult to isolate the mechanisms that underlie the involuntary hold of attention found here. The mechanisms

might include the extension of attentional dwell time on the distracting item, the slowed/more effortful disengagement of attentional resources from the distractor, or the slowed/more effortful reorienting of attention back to the target task (or some combination of these). Because distractor-related activations in the visual cortex were similar for all distractor types, it is unlikely that the hold of attention here reflects increased dwell time on the distractor. Whether the hold reflects changes in disengagement or reorienting mechanisms is not yet known.

In all, this study provides new evidence that the involuntary hold of attention on distracting stimuli involves enhanced activity in the TPJ. Our findings illustrate a hemispheric asymmetry in this region. Specifically, activity in the right TPJ was enhanced by distractors that oriented attention, and this activity seemed to be extended when attention continued to be held on the distractors. Conversely, the left TPJ was primarily responsive to the involuntary hold of attention, activating only in response to distractors that held attention. Our data may help to explain why previous studies of attentional reorienting did not find activity in the left TPJ. We suggest that, in these studies, stimuli oriented but did not hold attention, and that the lack of attentional hold may have led to the right-bias in activity. Finally, both our behavioral and neuroimaging results suggest that the hold of attention described here reflects changes not in lower-order visual processing, but rather in higher-order processing. Overall, involuntary orienting and hold were associated with different neural signatures, providing novel evidence that these two processes reflect partially distinct mechanisms. Future research aims to examine how involuntary attentional capture mechanisms vary across individuals who are more or less able to resist distraction, and to explore the effective connectivity between brain regions involved in distraction.

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FIGURES

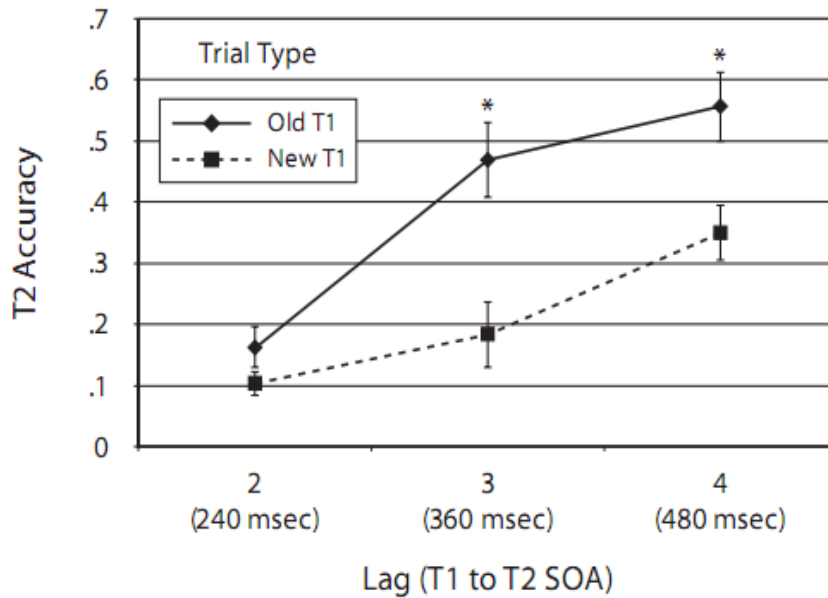


Figure 1: The duration of the AB was extended when the memory-status of T1 was different from the memory context (i.e. for a “new” T1 among “old” distractors). A parallel effect was found for an “old” T1 among “new” distractors. Adapted from Parks & Hopfinger (2008).

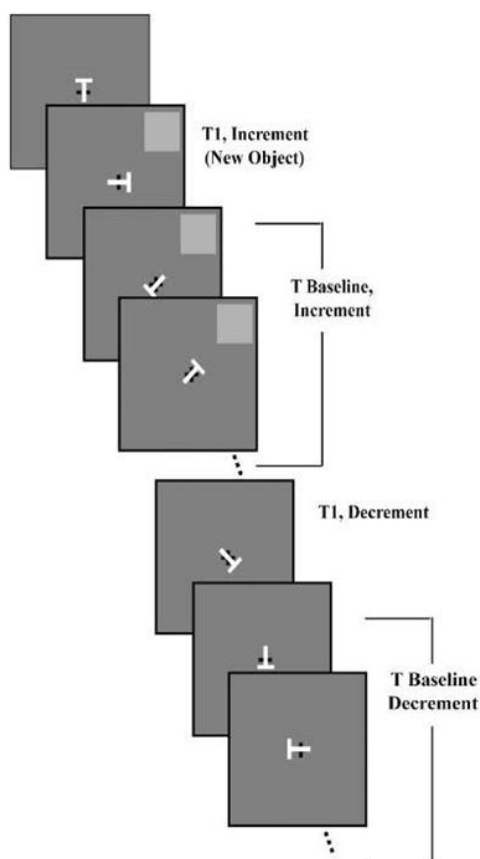


Figure 2: Trial sequence in continuous performance task, for a “new object” trial. Each screen is present for 1 second, and the target letter “T” changes orientation between each screen. “T1” is the target occurring simultaneously with the distractor. “T Baseline” refers to all other targets. “T1” and “T Baseline” are separated for each luminance type (“Increment” and “Decrement”). The duration between each luminant event was 5, 6, 7, 8, or 16 seconds. Adapted from Kim & Hopfinger (2010).

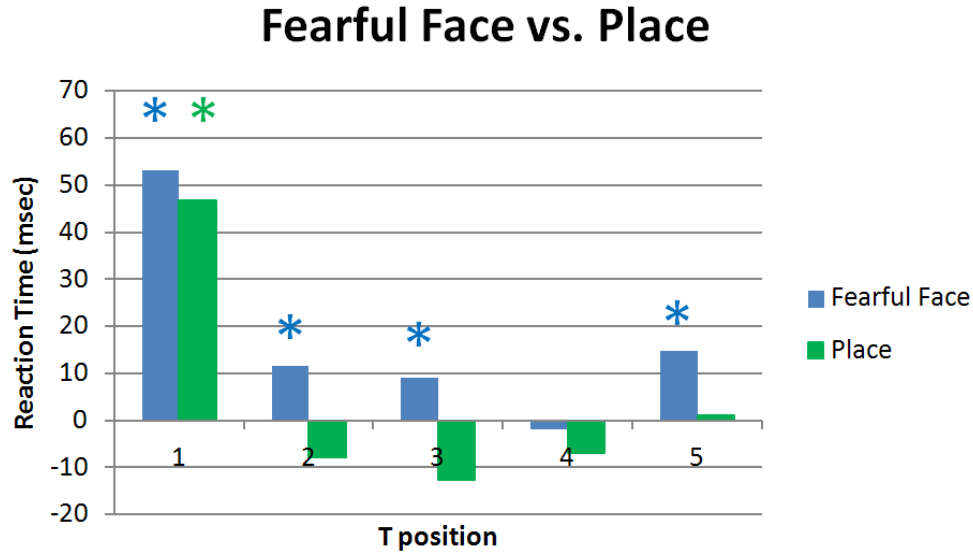


Figure 3: Reaction time depending on the type of distractor (fearful face or place). “T1” is the first target following the appearance of the distractor. “T2” and “T3” are the second and third targets after the appearance of the distractor. For each condition, reaction times reflect performance beyond the average baseline performance for that condition. Asterisks indicate significant difference from baseline for each condition ($p < 0.05$, B-H corrected). Adapted from Parks, Kim, & Hopfinger, in prep.

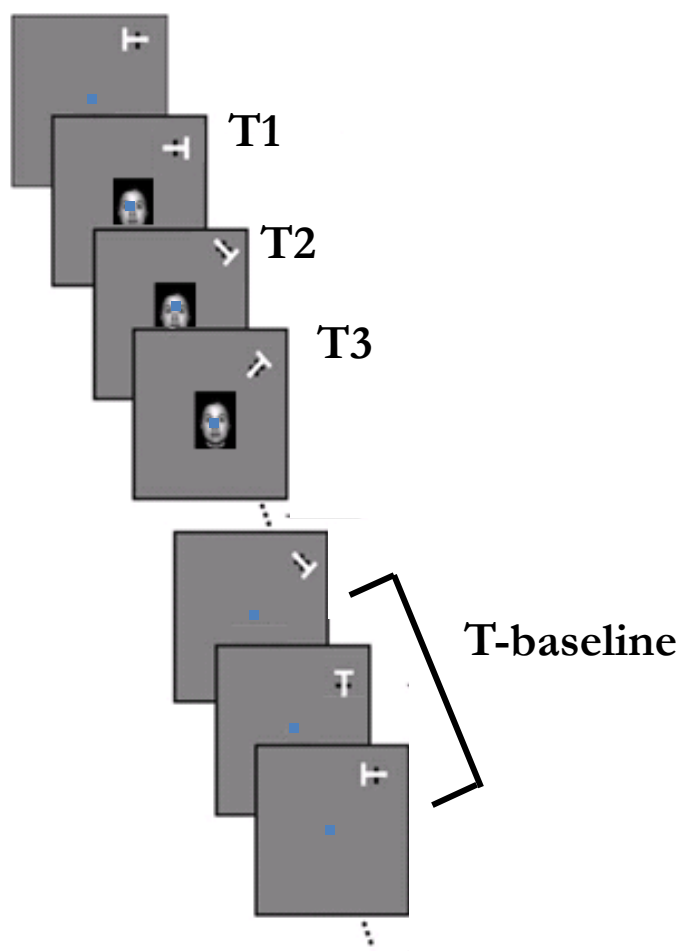


Figure 4: Trial sequence for Experiment 1. Depicted is a trial with a neutral face cue.

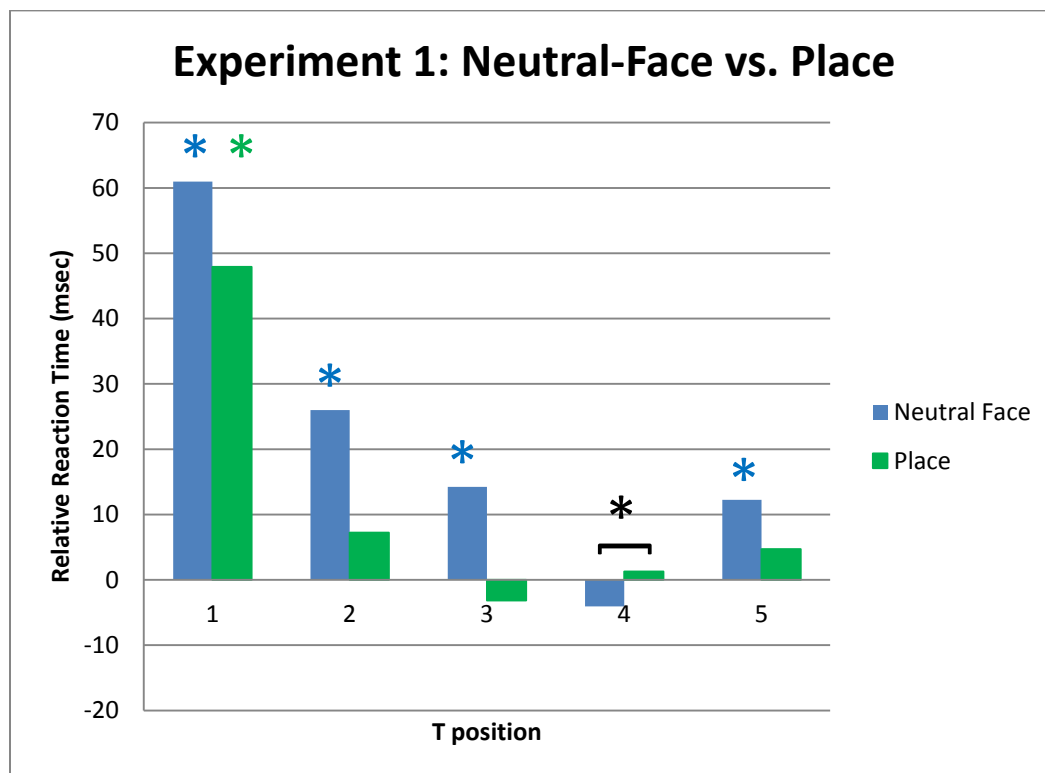


Figure 5: Reaction time depending on the type of distractor (neutral-face or place). For each condition (“object-type” x “T-position”), reaction time reflects performance beyond the average baseline performance for that condition. Asterisks indicate significant difference from baseline for each condition ($p < 0.05$, B-H corrected).



Figure 6: Sample distractors used in Experiments 2 and 3. Distractors varied in their object-type (face vs. place) and their border-luminance (dim vs. bright).

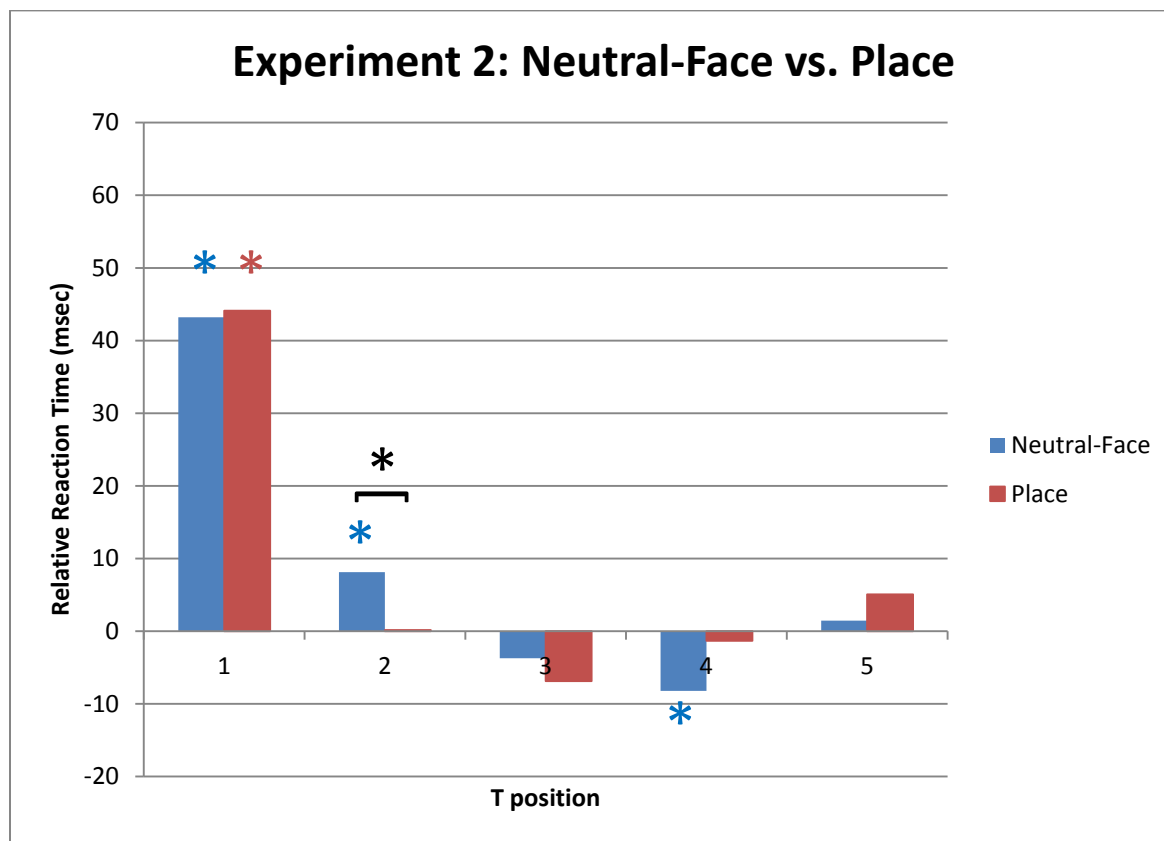


Figure 7: Reaction time depending on the type of distractor (neutral-face or place), collapsed across luminance-border. For each condition, reaction time reflects performance beyond the average baseline performance for that condition. Asterisks indicate significant difference from baseline for each condition ($p < 0.05$, B-H corrected).

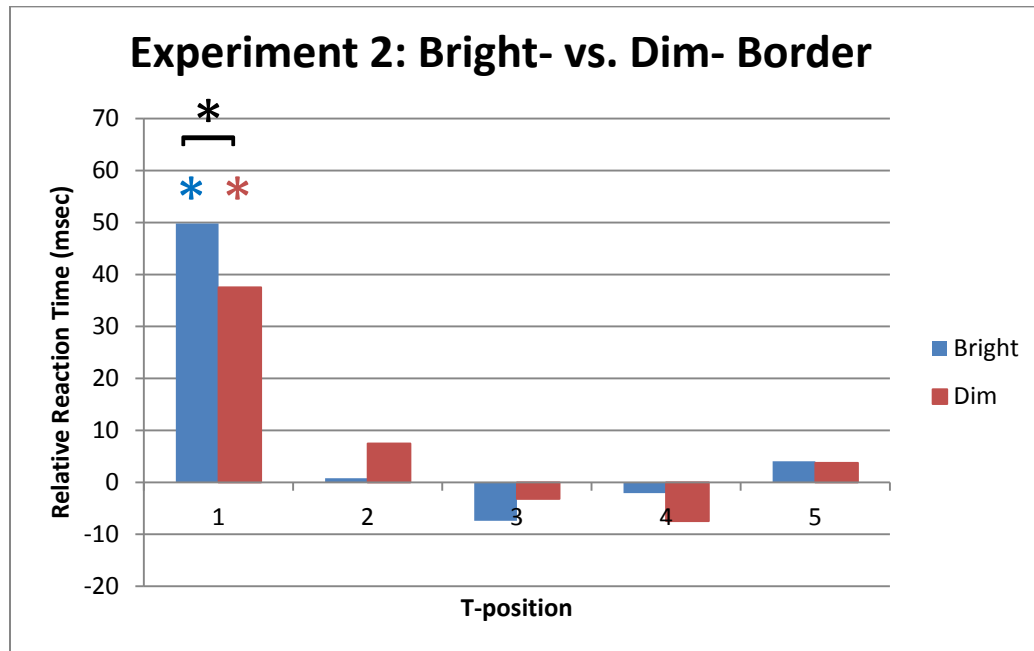


Figure 8: Reaction time depending on the type of distractor (bright- vs. dim-luminance border), collapsed across object-type. For each condition, reaction time reflects performance beyond the average baseline performance for that condition. Asterisks indicate significant difference from baseline for each condition ($p < 0.05$, B-H corrected).

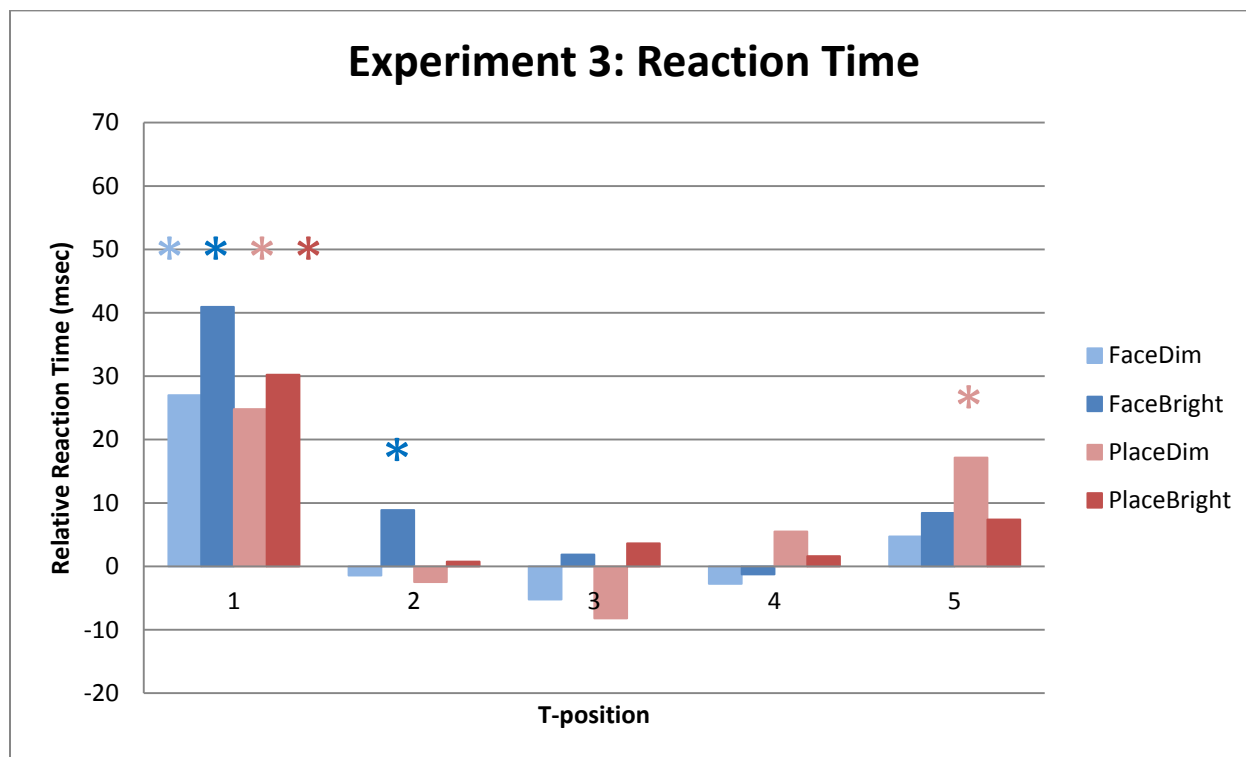


Figure 9: Reaction time depending on the type of distractor. For each condition, reaction time reflects performance beyond the average baseline performance for that condition. Asterisks indicate significant difference from baseline for each condition ($p < 0.05$, B-H corrected).

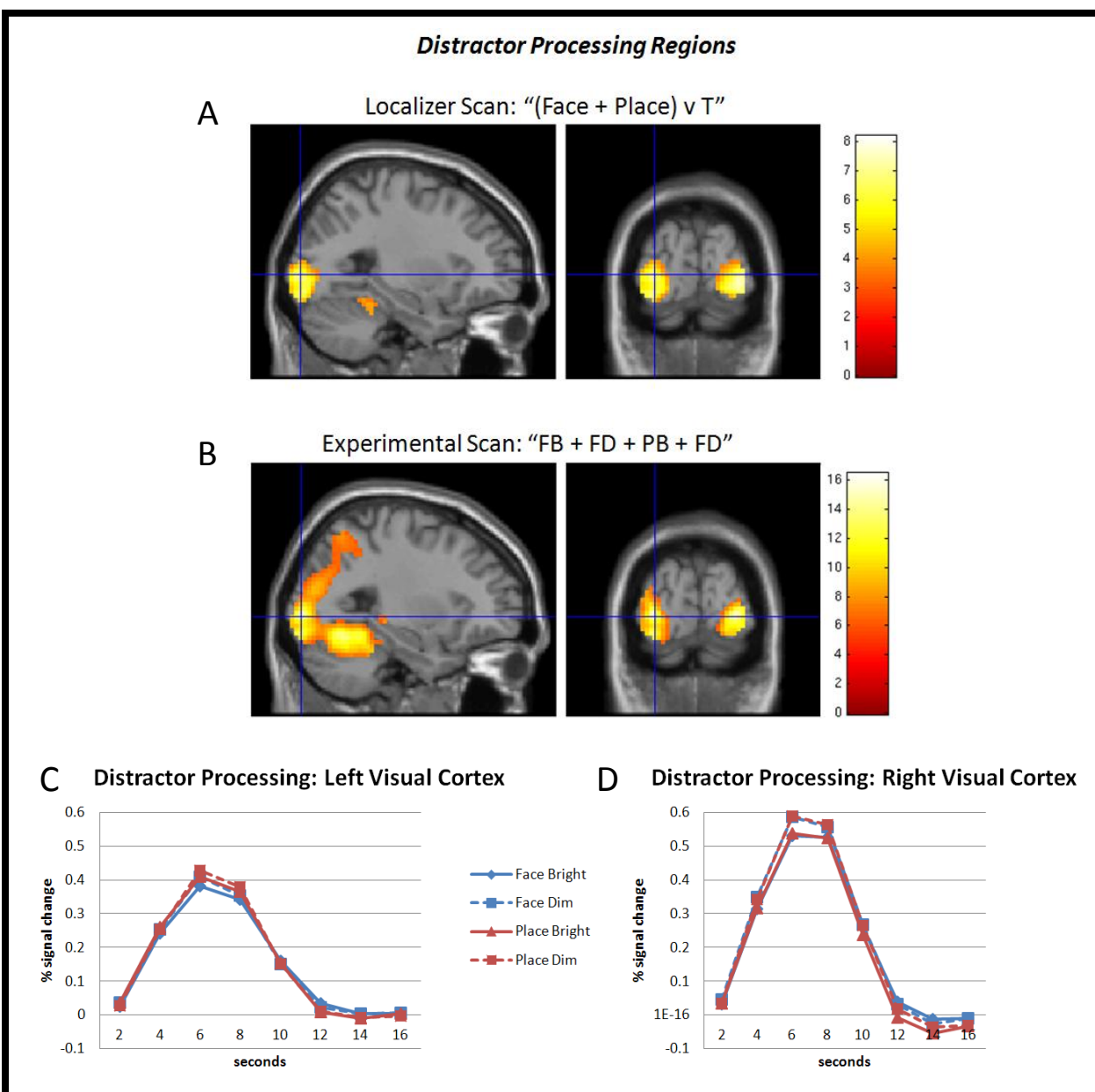


Figure 10: Distractor Processing Region

(A) Distractor processing areas in the left and right visual cortex as defined by the localizer run for “(Face + Place) v T”. Lingual gyrus, MNI (x, y, z) = -27, -91, 1 and 24, -97, -8, $p < 0.001$, uncorrected for whole-brain analysis.

(B) Distractor processing areas in the left and right visual cortex as defined by the experimental run for “(FaceBright + FaceDim + PlaceBright + PlaceDim)”. Lingual gyrus, MNI (x, y, z) = -27, -91, 1 and 30, -91, -2, $p < 0.001$, uncorrected for whole-brain analysis.

(C-D) BOLD signal time courses for the left and right visual processing regions, as defined by the contrast “(FaceBright + FaceDim + PlaceBright + PlaceDim)”.

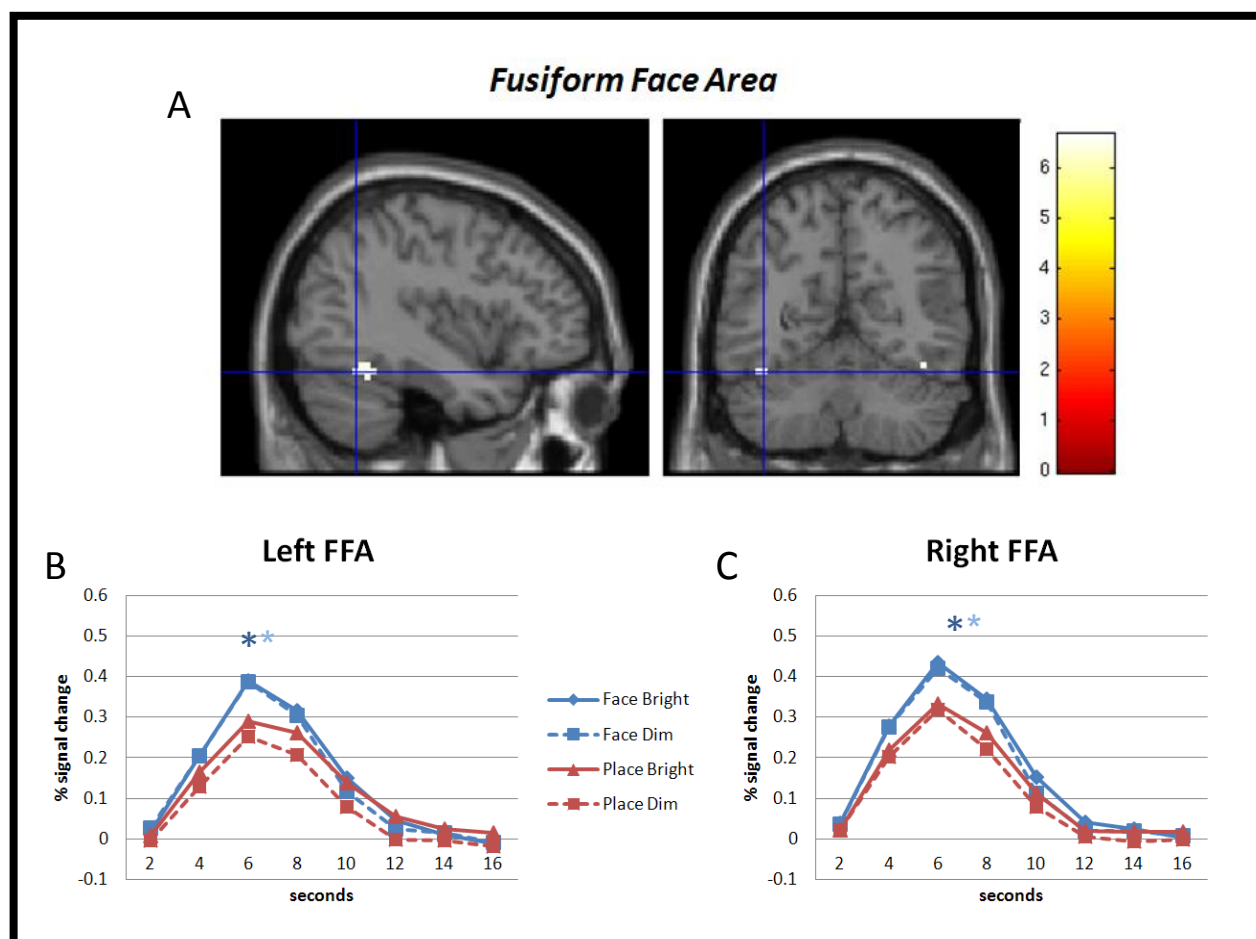


Figure 11: Fusiform Face Area.

(A) Activity in the left and right ventral occipital cortex as defined by the experimental run for “(Face > Place)”. MNI (x, y, z) = -39, 58, -20 and 39, -61, -14, $p < 0.05$, FWE-corrected for whole-brain analysis.

(B-C) BOLD signal time courses for the left and right FFA, as defined by the contrast “Face > Place.”

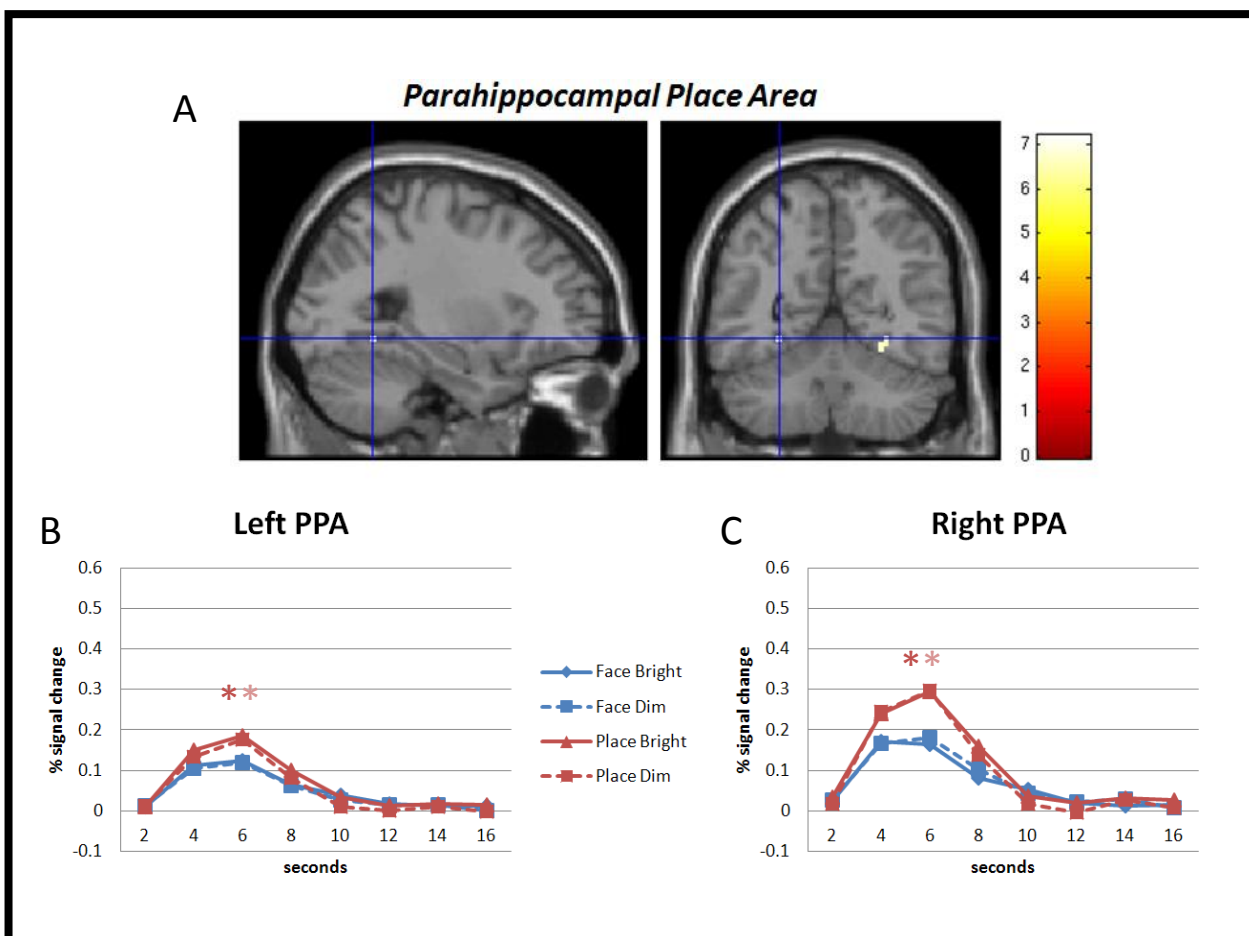


Figure 12: Parahippocampal Place Area.

(A) Activity in the left and right ventral occipital cortex as defined by the experimental run for “(Place > Face)”. MNI (x, y, z) = -27, -55, -8 and 27, -49, -11, $p < 0.05$, FWE-corrected for whole-brain analysis.

(B-C) BOLD signal time courses for the left and right PPA, as defined by the contrast “Place > Face.”

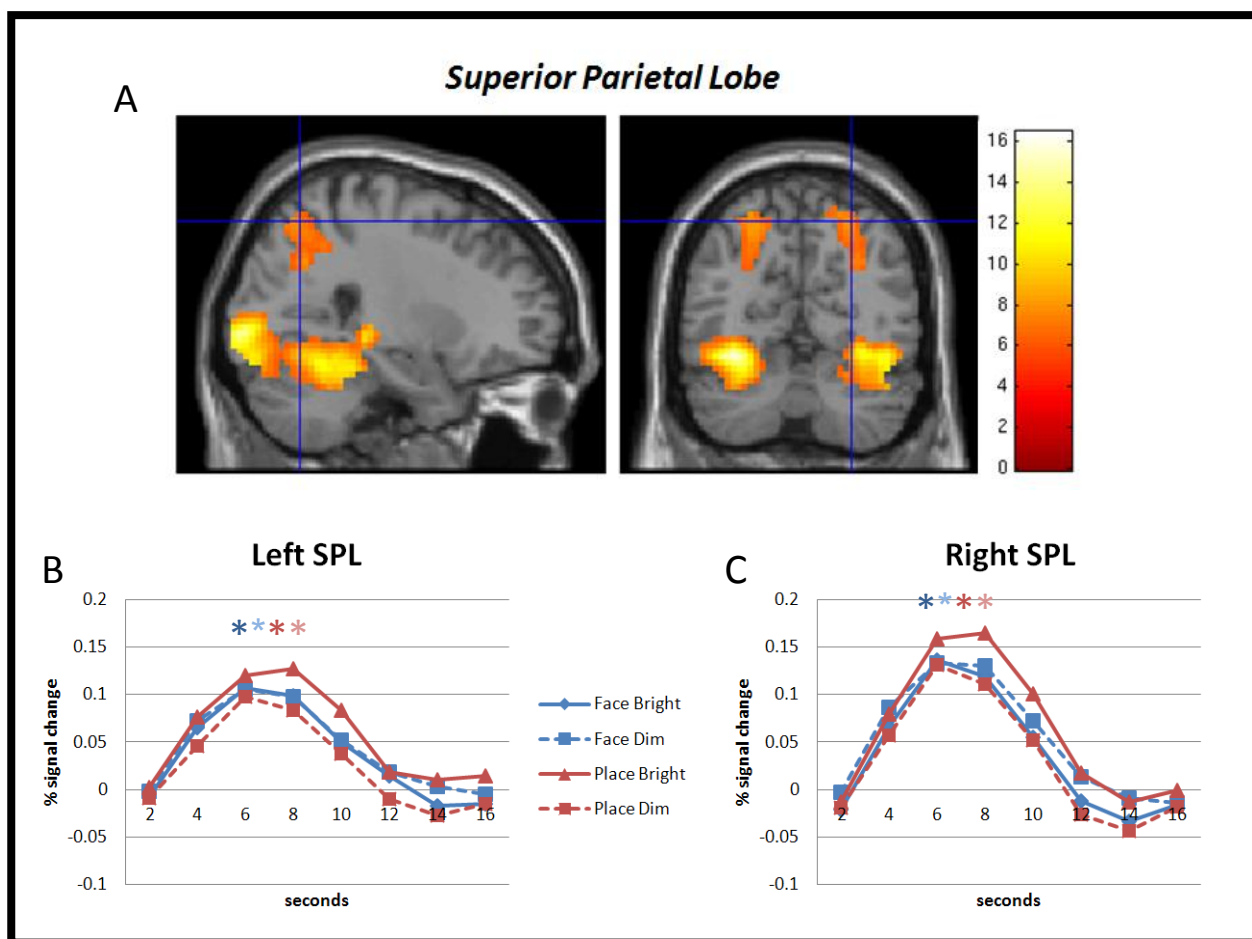


Figure 13: Superior Parietal Lobule.

(A) Activity in the left and right parietal cortex as defined by the experimental run for “(FaceBright + FaceDim + PlaceBright + PlaceDim)”. MNI (x, y, z) = -27, -61, 55 and 24, -64, 55, $p < 0.05$, FWE-corrected for whole-brain analysis.

(B-C) BOLD signal time courses for the left and right SPL, as defined by the contrast “(FaceBright + FaceDim + PlaceBright + PlaceDim)”.

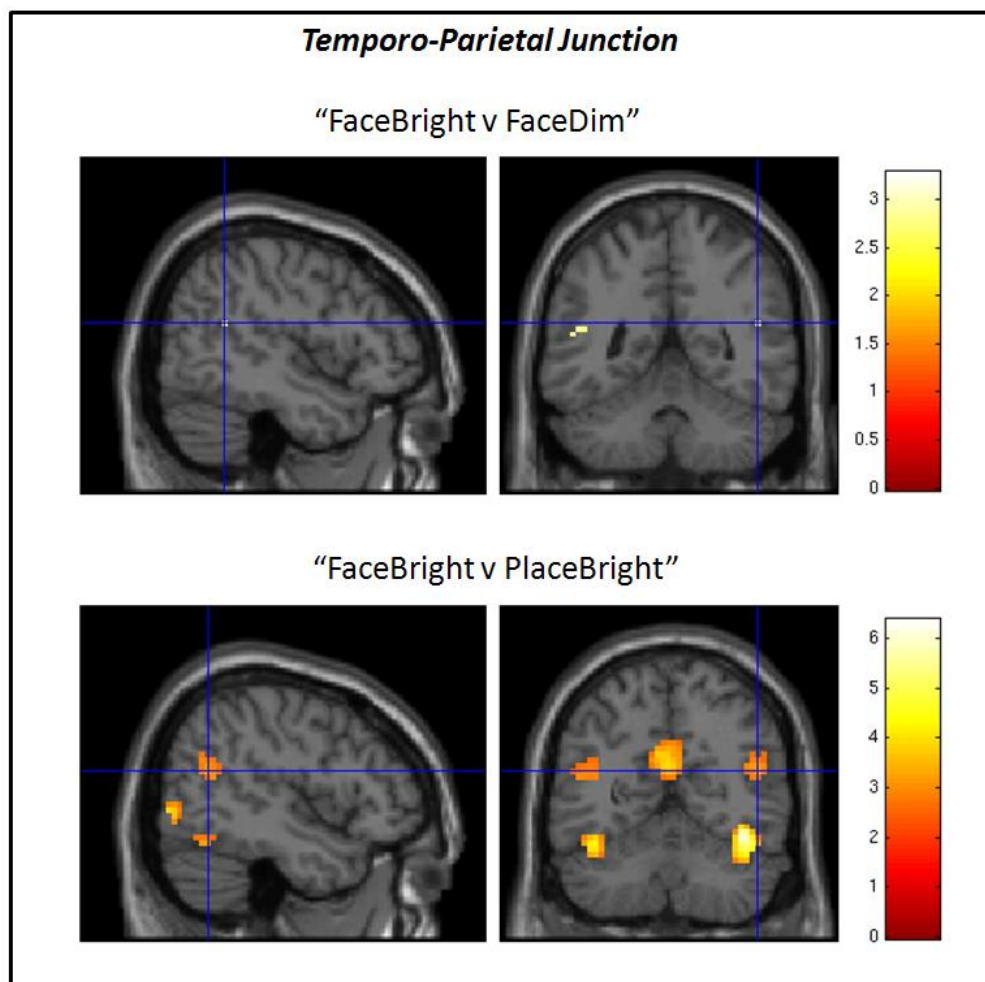


Figure 14: Temporo-Parietal Junction. (Top) Activity defined by the experimental run for “(FaceBright > FaceDim)”. MNI (x, y, z) = -45, -55, 16 and 48, -49, 19, $p < 0.01$, uncorrected for whole-brain analysis. (Bottom) Activity defined by the experimental run for “(FaceBright > PlaceBright)”. MNI (x, y, z) = -45, -58, 19 and 48, -58, 19, $p < 0.01$, uncorrected for whole-brain analysis.

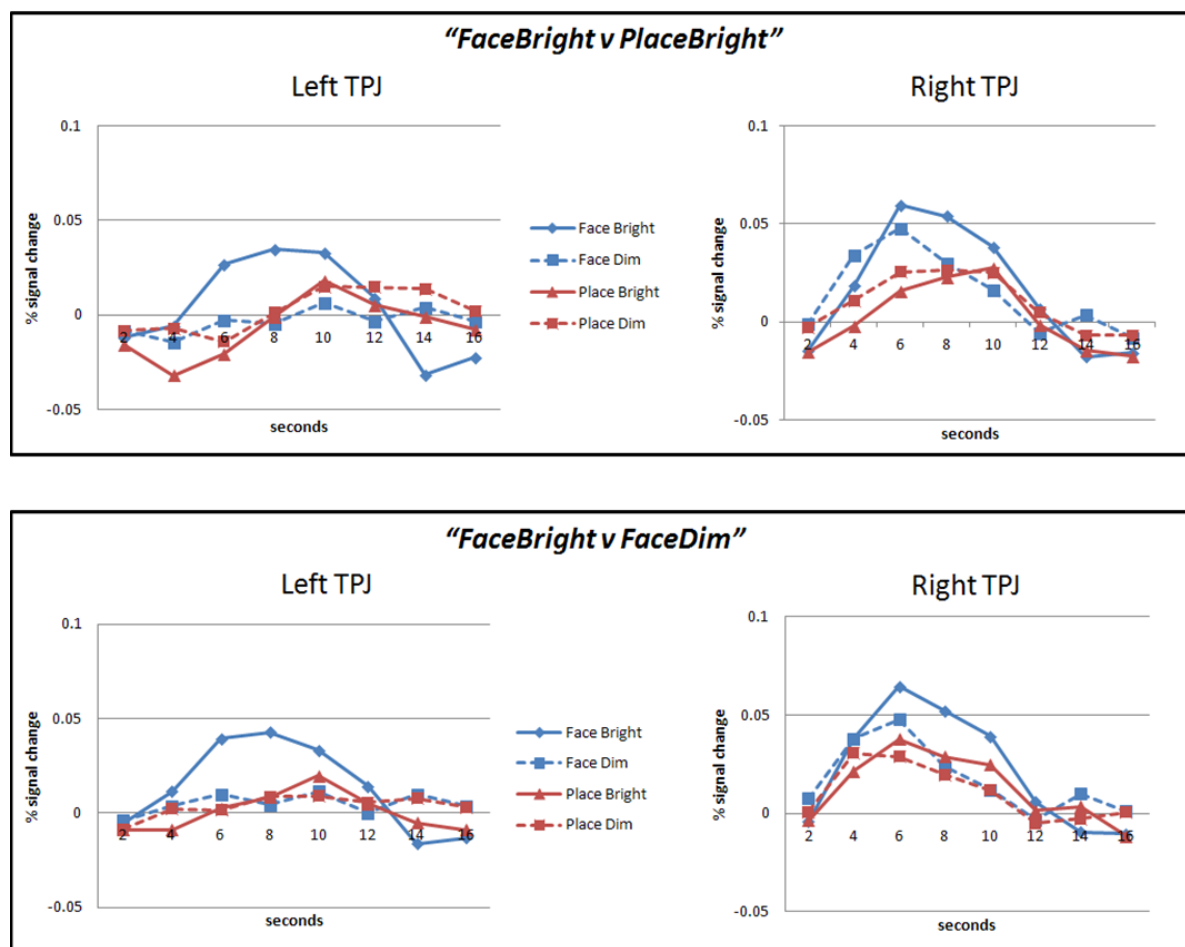


Figure 15: BOLD signal time courses for the left and right TPJ. (Top) as defined by the contrast “(FaceBright > FaceDim)”; and (Bottom) as defined by the contrast “(FaceBright > PlaceBright).”

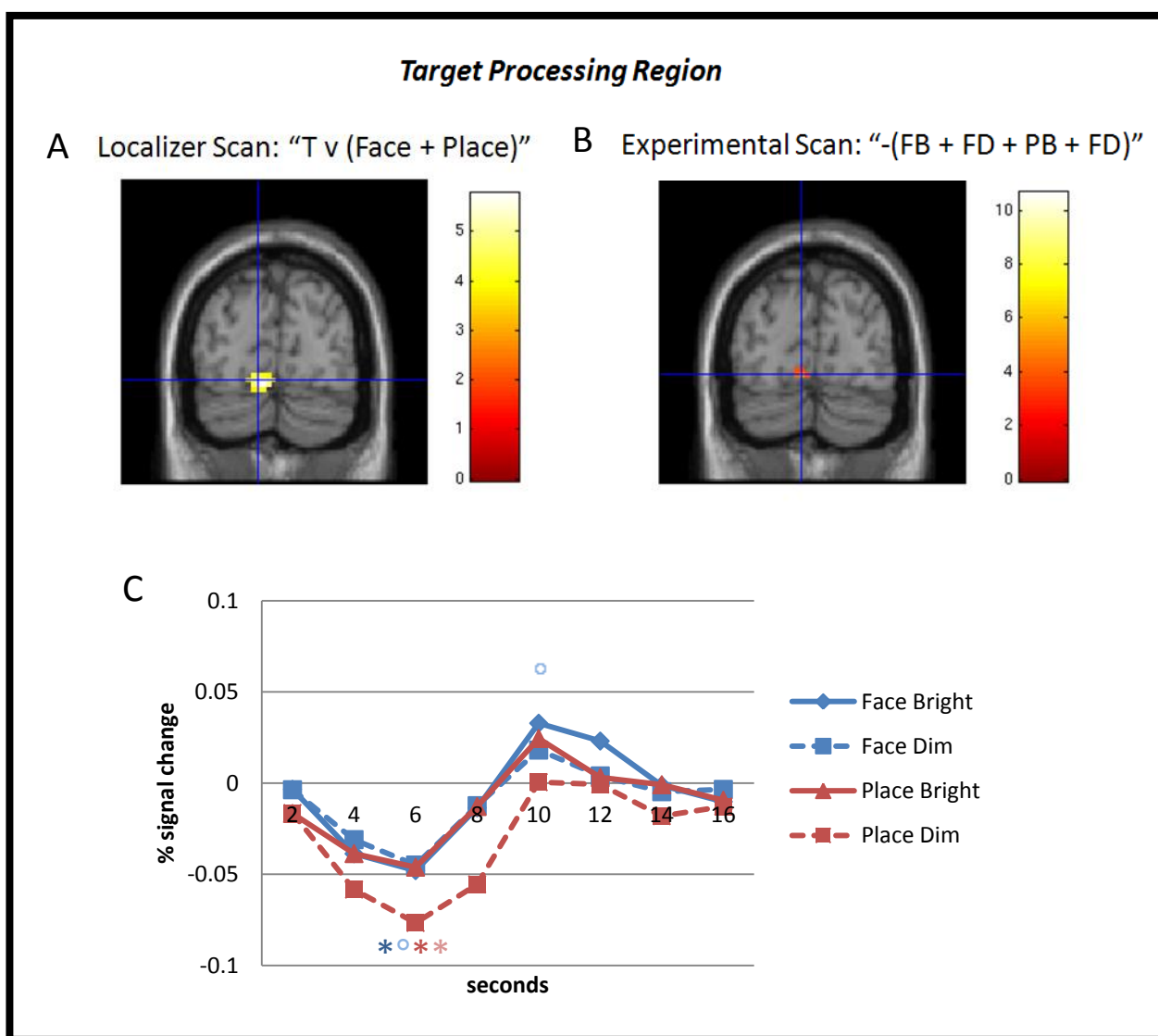


Figure 16: Target Processing Region

(A) Target processing area in the left visual cortex as defined by the localizer run for “T v (Face + Place)”. MNI (x, y, z) = -9, -82, -11, $p < 0.001$, uncorrected for whole-brain analysis.

(B) Target processing area in the left visual cortex as defined by the experimental run for “-(FaceBright + FaceDim + PlaceBright + PlaceDim)”. MNI (x, y, z) = -6, -82, -8, $p < 0.001$, uncorrected for whole-brain analysis.

(C) BOLD signal time courses for the Target processing region, as defined by the contrast “-(FaceBright + FaceDim + PlaceBright + PlaceDim)”.

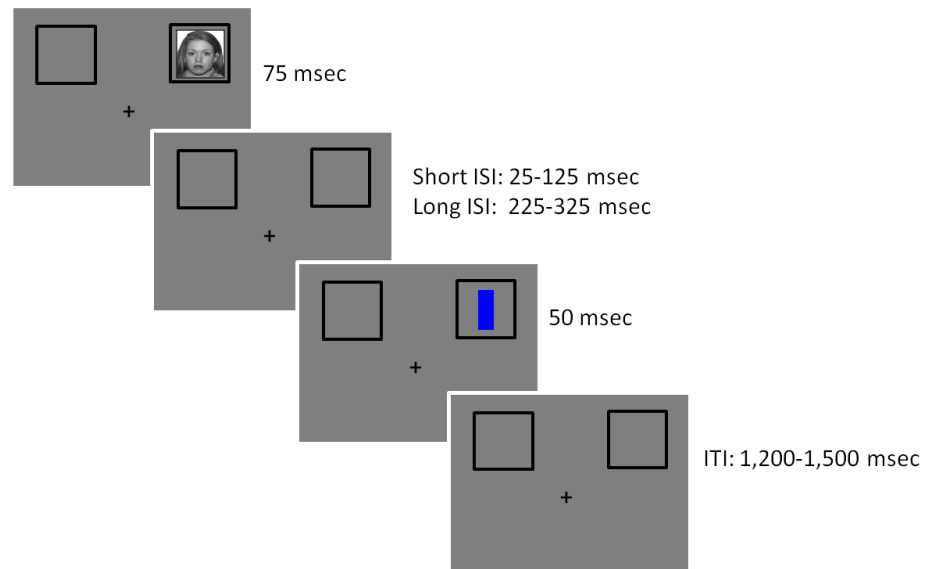


Figure 17: Trial Sequence for Experiment 4a. Depicted is a trial with a valid face cue.

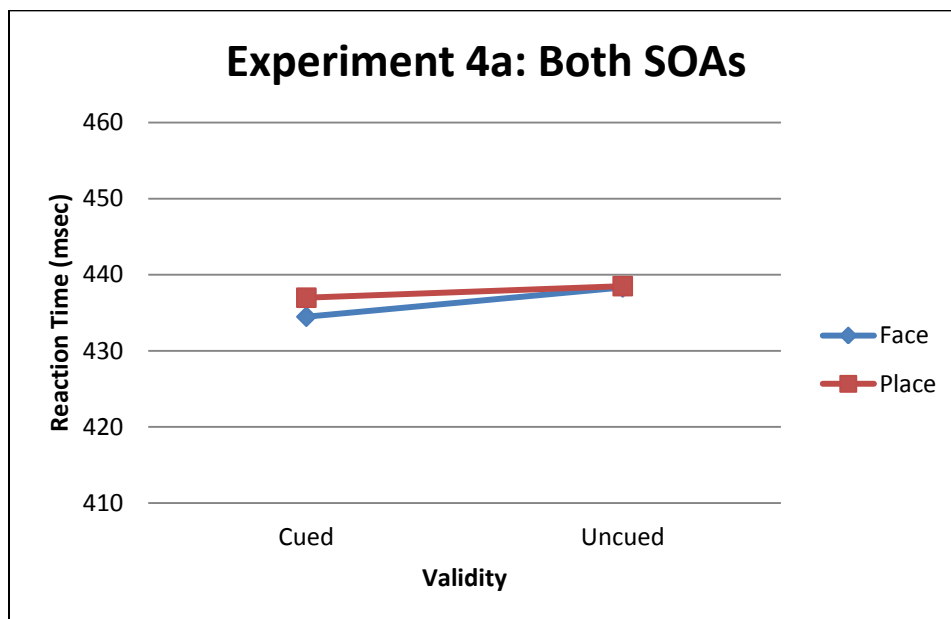


Figure 18: Reaction time depending on the type of cue for both SOA trials, collapsed across target-side. Asterisks indicate significant differences between object-types ($p < 0.05$, B-H corrected).

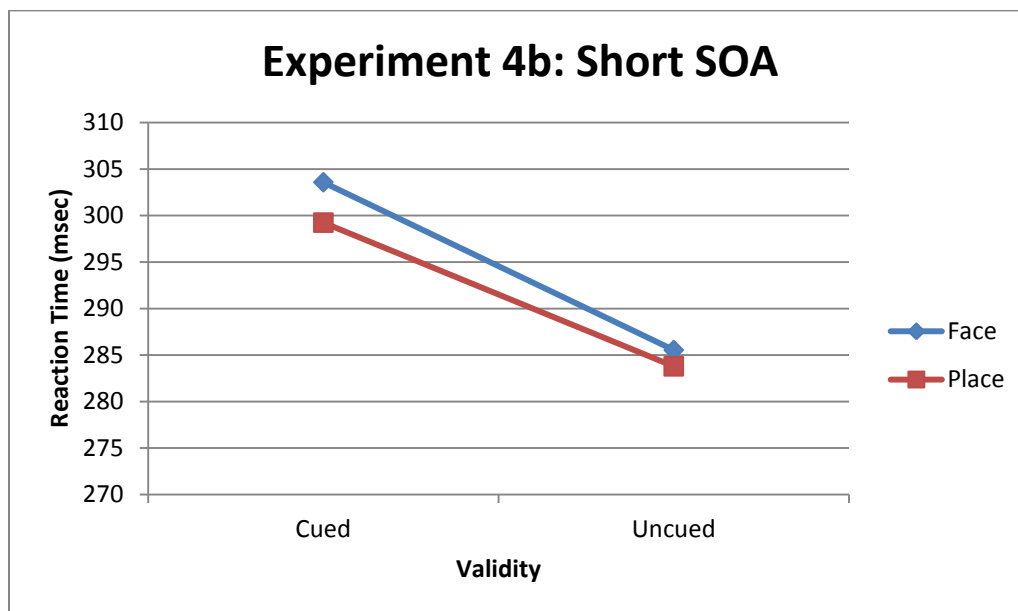


Figure 19: Reaction time depending on the type of cue for Short SOA trials, collapsed across target-side. Asterisks indicate significant differences between object-types ($p < 0.05$, B-H corrected).

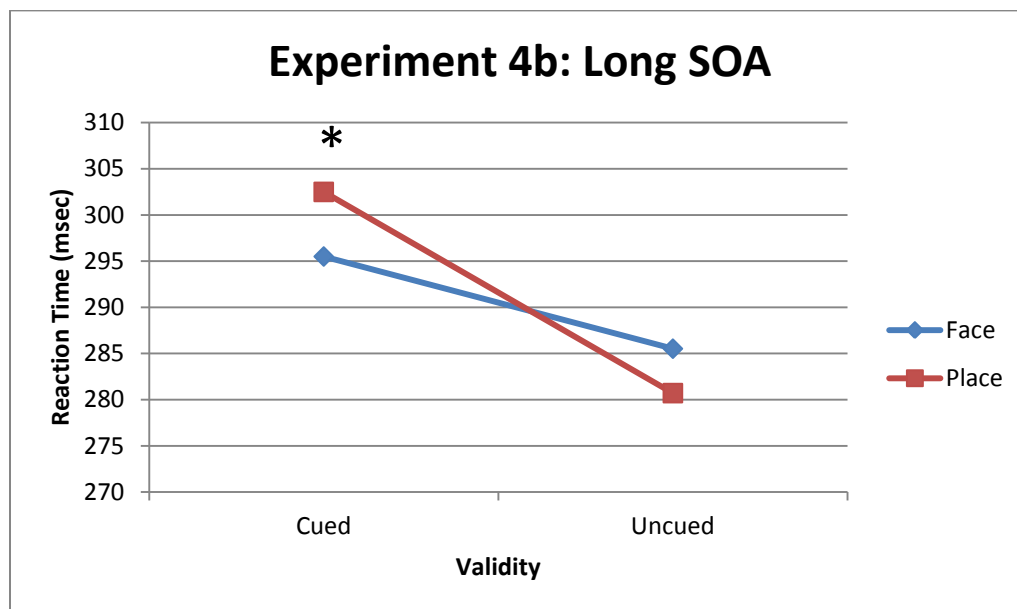


Figure 20: Reaction time depending on the type of cue for Long SOA trials, collapsed across target-side. Asterisks indicate significant differences between object-types ($p < 0.05$, B-H corrected).