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Resolving Visual Interference During Covert Spatial Orienting: Online Attentional Control Through Static Records of Prior Visual Experience

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Models of attentional control usually describe online shifts in control settings that accommodate changing task demands. The current studies suggest that online control over distractor exclusion—a core component of visual selection—can be accomplished without online shifts in top-down settings. Measurements of target discrimination accuracy suggested that the degree of distractor exclusion was guided by retinotopic maps of the prior probability of distractor interference at the attended locations. These probability maps can be retrieved via object-based cues, and they interact with shifts of attention to elicit increased levels of distractor exclusion when it is most needed. Thus, static probability maps can provide an internal template that guides the resolution of visual interference as spatial attention traverses the visual field.

In many contexts, thought and action can be guided primarily by well-learned associations between specific environmental inputs and the appropriate responses. In these cases, the need for top-down intervention is minimal. For example, one's morning drive to work might be such an ingrained routine that the trip passes by with little attention to the details of driving or navigating. However, in other contexts a specific bottom-up input may be associated with multiple responses, only some of which are relevant to the current processing goals. For example, consider the case of the distracted driver who intends to make his way to the grocery store, only to find that he has accidentally taken that well-worn path to work! Fortunately, such planning failures are rare, but they serve to emphasize how even simple behavioral routines can go awry when prepotent responses conflict with current processing goals. In these cases, attentional control is necessary to bias cognitive processing toward the representations that are relevant for goal-driven behavior. The need for attentional control cuts across a broad array of cognitive processes, enabling one's ability to retrieve a specific memory from among a host of others, select the appropriate action from multiple response associations, or encode a specific aspect of an otherwise overwhelming array of perceptual information. In each of these cases, successful goal-driven processing depends on the resolution of interference between relevant and irrelevant mental representations. Thus, the goal of the current research is to provide further insight into how mechanisms for attentional control can aid in managing the cognitive system's response to ambiguous bottom-up inputs.

We use visual selective attention as a model system for examining attentional control. In this case, the higher order processing goal is the accurate encoding of visually presented targets, and the relevant inputs are cued by their spatial positions. A wide variety of research has shown how selective attention can facilitate perception by biasing processing toward the relevant aspects of a visual scene. Attended stimuli are processed with greater accuracy and efficiency, and these effects can be observed during multiple stages of processing, including early sensory encoding (e.g., Mangun, Hillyard, & Luck, 1993), memory consolidation (e.g., Vogel, Luck, & Shapiro, 1998), and decision making (e.g., Palmer, Ames, & Lindsey, 1993). However, whereas we have developed a relatively detailed understanding of the consequences of attentional selection, less is known about how this process is controlled internally. In the present research, we used a procedure that isolates a distractor exclusion component of visual selection (Awh, Matsukura, & Serences, 2003; Serences, Yantis, Culberson, & Awh, 2004), with the goal of examining how internal control is implemented for this process.

In these experiments, observers were asked to report the identity of target digits that were presented in a perceptually challenging visual display (see Figure 1 for an example). The observers fixated a central location and were cued to direct their attention toward specific locations in the periphery. By manipulating whether the targets were presented in the cued locations or not, we were able to measure relative benefits for target processing at attended relative to unattended locations. In addition, the target digits were presented in one of two kinds of display. In the *distractor present* displays, the targets were embedded in a dense array of irrelevant letter stimuli that produced high levels of distractor interference. By contrast, in the *distractor absent* displays, the targets were presented alone in the visual field. Finally, a crucial manipulation in these experiments related to the probability that distractor present and distractor absent displays would be presented. In *distractor probable* conditions, there was an 80% chance that a distractor present display would be presented. In *distractor improbable* conditions, there was only a 20% chance of a distractor present display. As we review below, this probability manipulation had a selective influence on the resolution of interference from distractors, with greater levels of distractor exclusion associated with a high probability of interference. This paradigm therefore provides a clear example of a case in which top-down attentional

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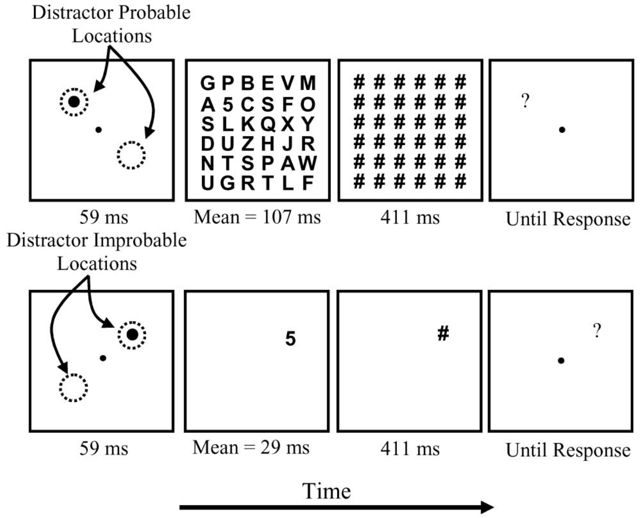

Figure 1. Schematic of the events in a single trial of Experiment 1 with distractors present (top row) or distractors absent (bottom row). The peripheral cue appeared in the correct target location with a probability of .50. When the target location did not match the cued location (unattended trials), the target always appeared in the location that had the same probability of distractors (i.e., the diagonally opposed location). The exposure duration indicated for the target grid represents the mean value achieved by the observers in this experiment.

control determines how the cognitive system responds to identical bottom-up inputs. In this case, top-down settings for distractor exclusion are adjusted to take into account the prior probability of interference within a given context.

The goal of the present research is to characterize the processes for internal control over distractor exclusion. We examine two basic issues. First, we address the temporal dynamics of control over distractor exclusion. When the degree of distractor exclusion is changed on a trial-to-trial basis, what is the time course underlying these changes in visual selection? We propose that multiple settings for distractor exclusion can be maintained in parallel, with distinct settings associated with each position in the visual field. Thus, whereas many instances of attentional control require active shifts in top-down settings to accommodate changing task demands (e.g., shifts of spatial attention or task set shifting), the current studies emphasize the role of interactions with static maps that maintain multiple settings for distractor exclusion in parallel. Second, Experiments 4 and 5 provide insight into the format and retrieval mechanisms for these control representations. Specifically, these experiments suggest that the static maps are retinotopically organized and can be retrieved via object-based cues. In the remaining sections of the introduction, we provide a more detailed account of how the present paradigm isolates a distractor exclusion component of selection, and a preview of the overall findings.

Distractor Exclusion Versus Signal Enhancement

Visual selective attention improves the signal-to-noise ratio associated with relevant perceptual events. Although this benefit of attention is uncontroversial, it is often ambiguous whether attention improves the signal-to-noise ratio by amplifying target signals or by suppressing the irrelevant noise. The biased competition perspective (Desimone & Duncan, 1995) emphasizes noise suppression as a key component of attentional selection. According to this view, attention facilitates visual perception by biasing competitive interactions between multiple stimuli in favor of the attended aspects of the scene. In line with this view, psychophysical and neuroimaging studies in humans have demonstrated much larger processing benefits at attended locations when distractor interference is prevalent (Awh et al., 2003; Dosher & Lu, 2000; Kastner, De Weerd, Desimone, & Ungerleider, 1998; Shiu & Pashler, 1994). Because the benefits of resolving interference should manifest themselves when there is significant interference to resolve, this result provides evidence for spatial selection via distractor exclusion. Nevertheless, there is also evidence that the signal associated with attended stimuli is enhanced. Multiple investigators have documented reliable benefits at attended locations in the absence of any significant interference from distractors (e.g., Cheal & Gregory, 1997; Eriksen & Hoffman, 1974; Henderson, 1996; Luck, Hillyard, Mouloua, & Hawkins, 1996). These effects suggest that attention can facilitate target processing through a process like signal enhancement (Hillyard, Vogel, & Luck, 1998). Thus, it is necessary to disentangle these two components of selection if we are to develop a complete model of visual selective attention. In the present studies, we attempted to gain a clearer understanding of attentional control over distractor exclusion by using a procedure that isolates this component of visual selection.

Parameters of Attentional Control

Developing models of attentional control requires a clear taxonomy of which aspects of selection are subject to control. In the current research, we argue for a distinction between two parameters of attentional control during spatial selection: one that determines where attention is directed and another that determines how visual processing will be affected at the attended locations. Awh et al. (2003) provided support for this distinction by manipulating the probability that the attended stimuli would compete with strong interference from distractors. In these experiments, observers reported the identity of target digits that were either presented alone in the visual field (distractor absent trials) or surrounded by a dense array of irrelevant letter distractors (distractor present trials). When there was a high probability of distractor interference (distractor probable trials), the processing advantage at the attended locations was significantly larger than when distractors were unlikely (distractor improbable trials). Moreover, these probability effects were observed only in the distractor present trials. Although reliable spatial attention effects were also observed in the distractor absent trials, these effects were identical in the distractor probable and distractor improbable conditions.

The absence of probability effects with the distractor absent displays suggests that distractor probability did not influence the spatial distribution of attention; changes in where attention was oriented should have affected performance with both the distractor present and distractor absent displays. (Recall that reliable spatial attention effects with the distractor absent displays showed that this procedure was sensitive to changes in the spatial distribution of attention even when no interference was present.) By contrast, changes in distractor exclusion as a function of distractor probability provided a consistent explanation of why performance was influenced only when there was significant interference in the target display. By this view, an increased probability of distractor interference produced increased levels of distractor exclusion without any concurrent change in the locations that were selected. Moreover, changes in the degree of distractor exclusion would not be expected to influence performance with the distractor absent displays, consistent with the observed data. The current studies use the same method to manipulate the degree of distractor exclusion, allowing a clearer characterization of the mechanisms for attentional control over this parameter of selection.

Temporal Dynamics of Attentional Control

Awh et al. (2003) demonstrated that the degree of distractor exclusion at the attended locations could change on a trial-to-trial basis. This effect was observed in a task that included a strong association between the specific locations that were attended and the probability of distractor interference. When the observers directed attention toward distractor probable locations, increased levels of distractor exclusion were observed as compared with when attention was directed toward distractor improbable locations. An attractive conclusion is that there was a global setting for distractor exclusion that was adjusted during the time between the onset of the cues that directed attention and the presentation of the targets (1,528 ms). Indeed, most accounts of attentional control refer to online shifts in internal settings that accommodate changing task demands. For example, it is clear that observers can exert moment-to-moment control over where spatial attention is focused or which object properties are relevant for guiding behavior (e.g., Yantis & Serences, 2003). In the current experiments, however, we seek to provide a clear example of control through interactions with static representations rather than through active changes in top-down settings. In other words, attentional control over distractor exclusion may not require online shifts in a global setting for distractor exclusion.

The first experiment reported here provides suggestive evidence for this assertion by replicating the procedure from Awh et al. (2003) with a 59-ms stimulus onset asynchrony (SOA) between the cue and the target. In line with the previous evidence, we observed amplified spatial attention effects when the observers directed attention toward locations that were associated with a high probability of distractor interference. Once again, this interaction between distractor probability and spatial attention was expressed only when the targets were surrounded by distractors, suggesting that distractor probability influenced the degree of distractor exclusion rather than the degree of signal enhancement. Experiment 1 therefore replicated the key results from the Awh et al. (2003) studies. In addition, because the probability of interference in a given trial could not be determined until after the presentation of the cue, the 59-ms cue–target SOA indicated a surprisingly low upper bound for the time that would be required for active shifts in the degree of distractor exclusion.

We therefore considered alternatives to the hypothesis that a global setting for distractor exclusion was changing during the 59 ms that separated the cue and target. Specifically, we suggest that distinct settings for distractor exclusion can be maintained in parallel for each location in the visual field. Experiment 3 provided some direct evidence for this claim by demonstrating that both high and low levels of distractor exclusion can be observed within a single trial, when one target appears in a distractor probable location and another target appears in a distractor improbable location. On the basis of these data, our working hypothesis was that separate settings for distractor exclusion can be maintained within long-term maps that record the prior probability of interference at different target locations. These maps interact with online shifts of attention to determine the degree of distractor exclusion at each attended location, with interference resolution becoming more effective when there is a high probability of interference. Because different settings are maintained in parallel for each location, there would be no need for active shifts in top-down settings for distractor exclusion when attention moves from one location to another. Thus, although many contexts may demand active changes in control settings in response to changing task demands, the present work suggests that online control over a key parameter of visual selection can be guided through interactions with static representations.

Experiment 1

Observers fixated a central point, and a brief peripheral cue elicited a stimulus-driven shift of attention to one of four potential target locations. The observers made unspeeded reports of the identity of a subsequent target digit. A cue in one of two distractor probable target locations was associated with an 80% probability that the subsequent target would be surrounded by a dense array of irrelevant letter distractors. By contrast, a cue in one of the two distractor improbable target locations was associated with a 20% probability of distractor interference. This design enabled measurements of spatial attention effects when the displays were held constant and the attentional control settings for distractor exclusion varied.

Method

Observers. Twenty volunteers from the University of Oregon community were paid for their participation in a 2-hr session. All observers had normal or corrected-to-normal vision.

Stimuli. Figure 1 shows the sequence of events in distractor present and distractor absent trials. The stimuli were presented within a 6 × 6 grid that subtended 5.7° on each side. The center-to-center distance between stimuli was 1°. The height and width of the target stimuli (in Arial font) were 0.7° and 0.5°, respectively. There were four potential target positions (two distractor probable and two distractor improbable) located on the corners of the 4 × 4 array in the center of the larger grid. The distractor probable locations were assigned to one diagonal (i.e., either the upper left and lower right target positions or the upper right and lower left target positions), and the distractor improbable locations were assigned to the other diagonal. The diagonal assigned to the distractor probable and distractor improbable conditions was counterbalanced across observers. When distractors were present, all letters of the alphabet (except for *I*) were placed in random order within the target array, with no letter appearing more than twice.

Design and procedure. The following events occurred during each trial: (a) A fixation point subtending 0.2° in diameter appeared in the center of the screen for 1,528 ms. (b) A single peripheral cue subtending 0.1° in diameter appeared just adjacent to a distractor probable or distractor improbable target location (each of the four locations was cued with equal probability) for 59 ms; in relation to an imaginary square surrounding the target location, the cue appeared on the corner of the square closest to the fixation point. (c) The target array appeared immediately after the offset of the peripheral cue. The center of the target digit (randomly selected from 1 to 9) was 1.5° away from fixation. Exposure duration for the target array was determined on a within-subject basis, separately for distractor present (mean duration = 107 ms) and distractor absent (mean duration = 29 ms) trials using a staircase timing procedure (see timing procedure below). (d) Masks were presented for 411 ms immediately after target offset. Distractor present displays were followed by a full-field mask. Distractor absent displays had masks only over the target location. After the offset of the masking display, a *?* symbol marked the location where the target had appeared, and the observers indicated the identity of the digit that had been presented with an unspeeded keypress. Observers were free to correct responses in the event that the wrong key was pressed. Visual feedback regarding response accuracy was provided at the end of each trial. Each observer participated in 16 blocks of 40 trials. Within each block there were 20 distractor probable trials and 20 distractor improbable trials. Within each probability condition, 80% of the trials were in the dominant category. Within the dominant and nondominant trial types, half were validly cued and half were invalidly cued. When a target was invalidly cued, the target and cue appeared in a different location that was associated with the same probability of distractor interference (i.e., the opposite side of the same diagonal). The order of these trials was randomized within each block.

Timing procedure. There is considerable between-subjects variability in the time needed to encode these target digits. To ensure an appropriate degree of difficulty for each observer and equate the difficulty of discrimination in the distractor present and distractor absent displays, we tailored exposure durations to the abilities of each observer using a staircase timing procedure. Each observer performed 12 blocks of 30 trials in the timing procedure. These trials followed the same sequence of events as in the experimental trials described above, except that only distractor present displays were presented following cues in the distractor probable locations and only distractor absent displays were presented following cues in the distractor improbable locations. This procedure therefore served to adapt each observer to the contingencies between locations and distractor interference that would be in place during the experimental procedure, in which distractor probable cues were followed by distractor present displays with probability .80 and distractor improbable trials were followed by distractor absent displays with probability .80. All trials during this timing procedure were validly cued. Exposure duration was adjusted (separately for distractor present and distractor absent displays) on a trial-by-trial basis as follows: If the target was reported accurately, the exposure duration was reduced by 11.8 ms (one monitor vertical refresh cycle, at 85 Hz). If the target was reported inaccurately, the exposure duration was raised by 23.5 ms (two refresh cycles). The average exposure duration over the final two blocks (after observers had reached asymptote with each display type) determined the exposure duration used during the experimental trials.

Results and Discussion

Figure 2 illustrates the accuracy of target discrimination as a function of display type (distractor present vs. distractor absent), the prior probability of interference given the location that was cued (distractor probable vs. distractor improbable), and the locus of attention (attended vs. unattended). A three-way analysis of variance with these factors showed that target discrimination was significantly better at attended locations, $F(1, 19) = 28.91$, $MSE = 0.432$, $p < .01$, $\eta_p^2 = .683$, and this effect was amplified when distractors were present, $F(1, 19) = 13.82$, $MSE = 0.164$, $p < .01$, $\eta_p^2 = .422$ (see Figure 2). The key result, however, is that spatial attention effects were significantly larger—with identical distractor-laden displays—when there was a high probability of distractor interference. Because the bottom-up interference was identical in these two conditions, we attribute these probability effects to changes in control settings for visual selection. In distractor-free displays, however, the prior probability of distractors did not influence the attention effect, leading to a significant interaction of distractor probability, display type, and the locus of attention, $F(1, 19) = 6.36$, $MSE = 0.022$, $p < .03$, $\eta_p^2 = .251$.

The fact that distractor probability effects were contingent on the presence of interference suggests that this manipulation had a selective influence on control settings for distractor exclusion. We do not argue that visual selection is accomplished entirely through distractor exclusion. On the contrary, we observed significant benefits of spatial attention even when there were no distractors in the display, $F(1, 19) = 4.42$, $MSE = 0.042$, $p < .05$, $\eta_p^2 = .189$. In line with previous demonstrations of attention effects in distractor absent displays, we interpret this effect in terms of a contribution from a selection process like signal enhancement (e.g., Hillyard et al., 1998). In addition, these attention effects demonstrate that the absence of probability effects in the distractor-free trials did not result from a lack of sensitivity to signal enhancement effects. Thus, if the increased probability of interference in the distractor probable condition had caused amplified sensory gain at those locations, accuracy should have also been affected, even with the distractor absent displays. We there-

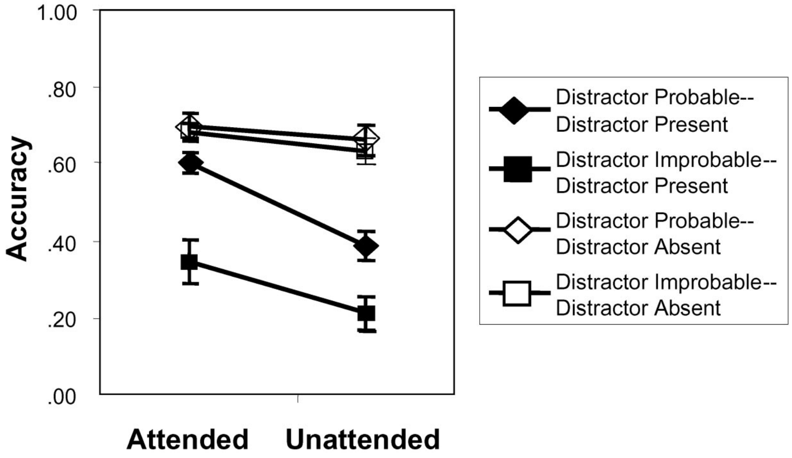

Figure 2. Accuracy in Experiment 1 as a function of the locus of attention, distractor presence, and the probability of distractor interference given the attended location. A higher probability of distractor interference led to significantly larger attention effects in the presence of distractor interference but had no effect on performance in the absence of distractors. Error bars represent the standard error of the mean across subjects.

fore conclude that the probability manipulation altered control settings for distractor exclusion, an effect that would not be apparent in distractor absent displays.

Another alternative to this distractor exclusion hypothesis bears some discussion. Specifically, consider the possibility that observers voluntarily oriented attention—prior to the onset of any cues—toward the distractor probable locations.[1] Could voluntary orienting toward the distractor probable locations explain the full pattern of results? Experiment 1 demonstrated that target identification is influenced by the spatial distribution of attention, even in the distractor absent displays. Thus, we argue that the absence of probability effects with the distractor absent displays provides strong evidence against the claim that distractor probability caused changes in the spatial distribution of attention. Such changes should have influenced performance with the distractor absent displays. However, given that some aspects of voluntary and stimulus-driven attention can be dissociated from one another (e.g., Jonides, 1980), the demonstration of sensitivity to stimulus-driven attention effects may leave doubt about whether this procedure is sensitive to the influence of voluntary orienting (see also Prinzmetal, McCool, & Park, 2005). Two arguments contradict this possibility. First, Awh et al. (2003) demonstrated clear attention effects with almost identical target displays that appeared over 1,500 ms after cue onset—well after stimulus-driven effects would have diminished (Mueller & Rabbitt, 1989). Thus, the present procedure is likely to be sensitive to shifts in the spatial distribution of voluntary attention. Second, we see a consistent pattern in these experiments that performance is somewhat *worse* in the distractor probable locations when distractor absent displays are presented. Though this pattern of evidence was not found in Experiment 1, we did find trends in this direction for Experiments 2, 3, and 4. Moreover, the same pattern was apparent in all five experiments reported by Awh et al. (2003). Thus, although the effect is small, its consistency across experiments suggests a true decrement with the distractor absent displays during the distractor probable condition. This pattern directly contradicts the voluntary attention hypothesis.

Experiment 2

The data thus far are consistent with the claim that increased levels of distractor exclusion were elicited by high probabilities of distractor interference. At the same time, the absence of probability effects with the distractor absent displays argues against changes in where attention was oriented during distractor probable and distractor improbable trials. Nevertheless, we considered the possibility that observers had oriented attention over a broader region of space during the distractor improbable trials (the *attentional breadth hypothesis*). This change in the spatial distribution of attention could lead to increased interference from distractors near the cued locations. In this case, however, the increase in distractor interference could be elicited through increased signal enhancement at the cue-adjacent locations (i.e., increased processing of irrelevant distractor stimuli). One argument to the contrary is that previous research has shown reductions in processing efficiency when attention is spread over a broader area (Eriksen & St. James, 1986), and performance with the distractor absent displays showed no such impairment in the distractor improbable condition. However, even though Experiment 1 showed sensitivity to attention effects with distractor absent displays, these effects may have been easier to detect than the (potentially small) decrements associated with increased attentional breadth. Thus, Experiment 2 was designed to provide a more direct test of the attentional breadth hypothesis. If attention is spread over a broader region of space during distractor absent trials, target discrimination should improve at the cue-adjacent locations.

At first glance, one might conclude that our distractor exclusion hypothesis should make the same prediction as the attentional breadth hypothesis. That is, decrements in processing at the cue-adjacent locations would be a plausible consequence of increased levels of distractor exclusion. However, this prediction assumes that distractor interference is resolved solely through the *direct suppression* of processing at the unattended locations. A qualitatively different mechanism for reducing distractor interference would be the *gating* of the inhibitory inputs from the unattended locations to the attended ones. This computational distinction has been elucidated in models of attentional gating in extrastriate cortex. When a visual object is surrounded by competing objects, the neural representation of that object is suppressed owing to competitive interactions between sensory representations. Moran and Desimone (1985) observed the neuronal correlates of this competition in extrastriate cortex. They found that when attention was directed toward a stimulus, neuronal firing was tuned to reflect the properties of the attended object, thereby minimizing the suppressive influence from unattended objects. Of importance, this effect was restricted to cells whose receptive fields contained both attended and ignored stimuli. In the absence of such competitive interactions, attention had no effect. The finding that attention effects in extrastriate cortex are enabled by competition mirrors our finding that distractor probability effects are enabled by the presence of distractor interference.

Desimone (1992) described two distinct models for these attentional gating effects. According to *cell gating* models, visual responses could be tuned in favor of attended stimuli by the direct inhibition of cells that respond to unattended stimuli. In our experiments, this would be equivalent to the direct suppression of visual processing at the unattended locations. By contrast, *input gating* models suggest that attention can regulate the specific subset of inputs that are allowed to influence a given neuron. For example, the responses of a neuron processing an attended location (Neuron A) could be tuned by gating off the inhibitory inputs from a neuron that represents an unattended location (Neuron B). The key feature of this model, for the present discussion, is that selection is accomplished by inhibiting the connection between A and B, rather than by inhibiting B directly (see also Reynolds, Chelazzi, & Desimone, 1999). In other words, input gating can reduce distractor interference without directly suppressing the perceptual representation of unattended stimuli. If our probability manipulation influences input gating, then the perceptual representation of stimuli in the cue-adjacent positions might not be suppressed in the distractor probable condition. Thus, Experiment 2 addressed two separate issues. First, it provided a direct test of the idea that there was a broader focus of attention in the distractor improbable trials. Second, it provided some initial evidence regarding the mechanism by which distractor exclusion is accomplished in this paradigm.

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[1] We thank an anonymous reviewer for pointing out this alternative explanation.

Method

Observers. Sixteen volunteers from the University of Oregon community were paid for their participation in a 1.5-hr experimental session. All observers had normal or corrected-to-normal vision.

Stimuli, design, and procedure. The sequence of events in a trial was very similar to that in Experiment 1, with the following exceptions. Instead of a single peripheral cue, two peripheral cues were presented during each trial. These cues subtended 0.2° in diameter, and they were centered on the target locations that were cued. In addition, two digit targets were presented instead of one. Finally, observers made two unspeeded responses after each target display, indicating the identity of the target digits.

Each observer participated in a staircase timing procedure and an experimental procedure. In the timing procedure, all trials were validly cued, and both targets were presented along either the distractor probable diagonal or the distractor improbable diagonal. During the timing procedure, cues in the distractor probable locations were always followed by distractor present displays, and cues in the distractor improbable locations were always followed by distractor absent displays, allowing observers to encode the associations between the probability of distractor interference and the cue positions. Each observer participated in 10 blocks of 30 trials of the staircase timing procedure, with the average exposure durations over the last 2 blocks determining the duration of the distractor present and distractor absent displays in the subsequent experimental procedure.

The experimental phase consisted of 10 blocks of 46 trials. For 23 of these trials, both cues were presented on the distractor probable diagonal. For the remaining 23 trials, both cues appeared on the distractor improbable diagonal. The potential configurations of cue and target stimuli are illustrated in Figure 3. Within the 23 trials that constituted each probability condition, 15 of the trials were validly cued (i.e., the targets appeared in the cued locations) and 8 trials were invalidly cued. For one group of 8 subjects, all invalidly cued targets were presented one space closer to the horizontal meridian than the targets (the positions labeled “A” in Figure 3). For another group of 8 subjects, all invalidly cued targets were positioned one space closer to the vertical meridian than the targets (the positions labeled “B” in Figure 3). During valid trials, the probability of distractors was set to .80 in the distractor probable positions and .20 in the distractor improbable positions. By contrast, during the invalid trials, the probability of distractors was always set to .50. Given that the goal of Experiment 2 was to measure how processing at the cue-adjacent locations would be influenced by the probability manipulation at the cued locations, we wanted to maintain a “neutral” probability state during the invalidly cued trials. This design provided an unbiased estimate of processing at the cue-adjacent positions. The alternative procedure would have been to maintain a .80 or .20 probability of distractors after all distractor probable and improbable cues, respectively, regardless of the validity of the cue. However, allowing these contingencies at the cue-adjacent positions could induce changes in target discrimination at these positions that may not be caused by the probability manipulation at the nearby cued locations. One potential concern with the design we chose is that the neutral probability of interference associated with the invalid trials might reduce the strength of the association between a given cue (distractor probable or improbable) and the subsequent appearance of distractors. This reduced association between the cues and the probability of interference could in turn weaken the predicted probability effects at the cued locations, thereby reducing our sensitivity to changes in processing at the cue-adjacent positions. However, the data show that we still observed strong effects of distractor probability at the cued locations, indicating that this procedure provided a sensitive test of whether performance at the cue-adjacent locations was influenced by the prior probability of distractors in the validly cued trials.

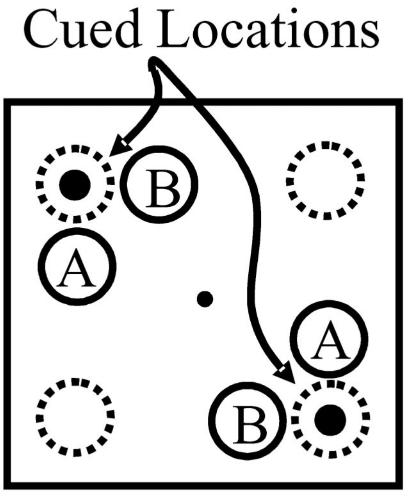

Figure 3. Schematic of the display used in Experiment 2. The dotted circles indicate the pairs of locations that could be cued (upper left and lower right, or upper right and lower left). Example cues are shown in the upper-left/lower-right position pair. During unattended trials, the two targets could fall in either of two possible arrangements relative to the cued locations (examples illustrated here are based on the upper left/lower right cue positions). The “A” positions were one grid position closer to the horizontal meridian, and the “B” positions were one grid position closer to the vertical meridian.

Results and Discussion

Figure 4 illustrates the accuracy of target discrimination for the validly cued trials as a function of display type (distractor present vs. distractor absent), and the prior probability of interference (distractor probable vs. distractor improbable).[2] For the distractor present trials, target discrimination was 30.1% more accurate for targets in the distractor probable positions (67.5%) than for targets in the distractor improbable positions (37.4%). By contrast, in the absence of distractor interference, accuracy showed a small drop in the distractor probable trials (63.8%) relative to the distractor improbable trials (70.9%), leading to a strong interaction between distractor probability and display type, $F(1, 15) = 46.00$, $MSE = 0.557$, $p < .01$, $\eta_p^2 = .754$. This interaction between distractor probability and display type replicates the key result from Experiment 1; target discrimination was improved when observers directed attention toward distractor probable locations, but only when there was substantial interference in the display. Again, these data are consistent with increased levels of distractor exclusion during the distractor probable trials, in the absence of concurrent changes in signal enhancement. In addition, the strong effects of distractor probability on target discrimination at the cued locations suggested that this procedure provided a sensitive test of whether these probability effects elicit changes in the quality of target processing at the cue-adjacent positions.

Figure 5 illustrates the data from the key trials in Experiment 2, in which the targets were presented directly adjacent to the cued

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[2] We carried out separate analyses for the valid and invalid trials, because differences in the perceptual characteristics of these displays preclude a clear comparison of performance in the valid and invalid trials. Specifically, both the retinal eccentricity of the targets (greater in the valid condition) and the orientation of the target stimuli were different in the valid and invalid conditions. Fortunately, the key comparisons in this experiment are between accuracy with target displays that differ only with respect to the prior probability of interference.

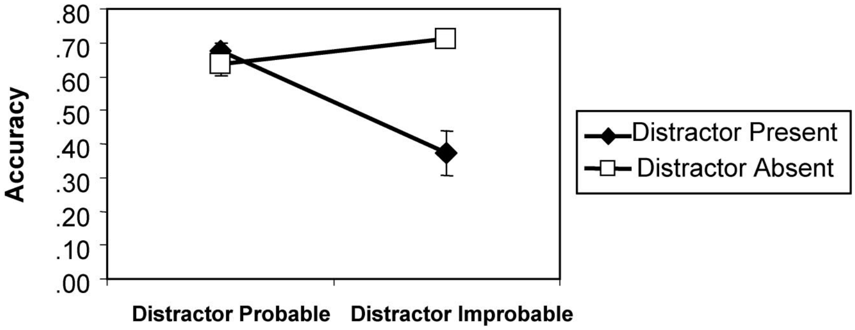

Figure 4. Accuracy for the validly cued (attended) trials in Experiment 2 as a function of distractor presence and the probability of distractor interference. A higher probability of distractor interference led to significantly larger attention effects in the presence of distractor interference but had no effect on performance in the absence of distractors. Error bars represent the standard error of the mean across subjects.

locations. A three-way analysis of variance was carried out with the following factors: display type (distractor present vs. distractor absent), the prior probability of interference given the cued locations (distractor probable vs. distractor improbable), and the specific cue-adjacent positions that were tested (Position A vs. Position B). We observed a main effect of display type, with higher accuracy for distractor absent than for distractor present displays, $F(1, 14) = 130.86$, $MSE = 3.21$, $p < .01$, $\eta_p^2 = .904$. Given that these targets were presented in unattended positions, the latter finding is in line with the conclusions from a number of other studies that show greater deficits at unattended locations when there is significant interference from distractors (e.g., Awh et al., 2003; Dosher & Lu, 2000; Kastner et al., 1998; Shiu & Pashler, 1994). In addition, there was a main effect of target position, with higher accuracy in the cue-adjacent positions that were closer to the horizontal meridian (Position A, 61%) than in the cue-adjacent positions that were closer to the vertical meridian (Position B, 49%), $F(1, 14) = 5.12$, $MSE = 0.248$, $p < .05$, $\eta_p^2 = .269$. Awh and Pashler (2000) also observed a strong advantage for horizontally arrayed targets over vertically arrayed targets using a procedure with very similar stimulus displays. Although the present studies are not informative with regard to why Position A was easier than Position B, this effect did provide an opportunity to observe performance over a range of difficulty at the cue-adjacent positions.

Finally, the most important result from Experiment 2 was that target processing at the cue-adjacent positions was unaffected by whether the cued locations were distractor probable or distractor improbable. This null result was observed for both distractor absent and distractor present trials, regardless of whether the targets were presented in Position A or B. For the cue-adjacent trials, there was no main effect of distractor probability, $F(1, 14) = .002$, $MSE = 0.004$, $p = .97$, and no interaction between this factor and any other factor (all Fs < 1). These data are inconsistent with the view that distractor exclusion is accomplished through the direct suppression of information in the cue-adjacent positions,

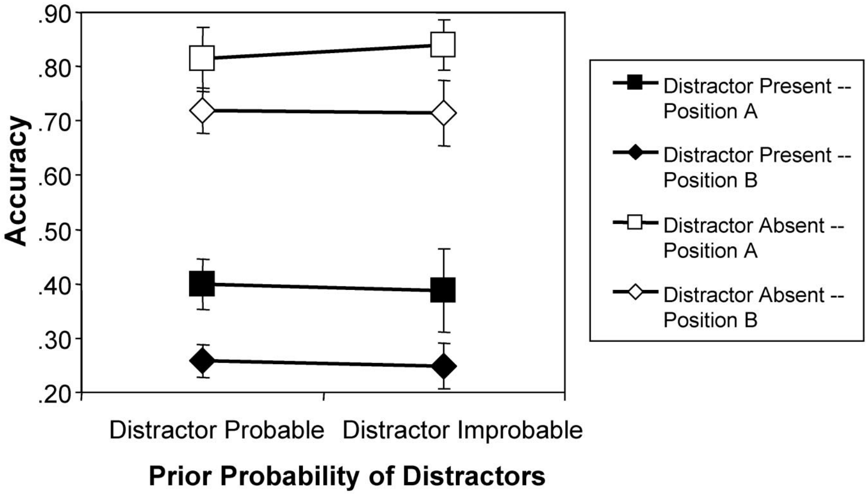

Figure 5. Target discrimination in cue-adjacent positions. The figure shows accuracy in Experiment 2 for the invalidly cued (unattended) trials, when targets were presented directly adjacent to the cued locations. Accuracy is shown as a function of distractor presence and the probability of distractor interference associated with the cues for that trial. No effects of distractor probability were observed at these cue-adjacent positions. See Figure 3 for an illustration of Positions A and B. Error bars represent the standard error of the mean across subjects.

because this hypothesis would have predicted worse target identification at the cue-adjacent positions during the distractor probable trials. Finally, these data disconfirm the hypothesis that a broader focus of attention was established during the distractor improbable trials; this hypothesis predicted better performance at the cue-adjacent positions during the distractor improbable trials, and no trace of this effect was observed.

In addition to replicating the observations of Awh et al. (2003), Experiments 1 and 2 demonstrate that these probability effects can be observed with a cue–target SOA of only 59 ms. These data cast some doubt on the hypothesis that control settings for distractor suppression were being reconfigured between the onset of the cue and the target. In the remaining experiments, we test and elaborate the hypothesis that attentional control over distractor exclusion does not require online shifts in a global setting for distractor exclusion. Instead, we argue that the prior probability of distractor interference is maintained within a static map of the prior probability of interference at different locations. Such probability maps could maintain a parallel record of settings for distractor exclusion at each location in the visual field, precluding the need for online switches in top-down settings with each shift of attention. By this view, the different settings for distractor exclusion were already in place by the time the attention was directed toward distractor probable and distractor improbable locations. When attention was captured at one of these locations by the peripheral cue, the corresponding setting for distractor exclusion was implemented.

In both Experiments 1 and 2, we observed a strong interaction between the locus of attention and distractor probability; distractor probability had a significantly stronger effect at attended locations than at unattended ones (replicating the interaction observed by Awh et al., 2003). Thus, to further examine the processes that control these changes in distractor exclusion, in the remaining experiments we focused on target discrimination at the attended locations. In each case, the marker for selective changes in distractor exclusion was a significant improvement in target identification during the distractor probable trials that was observed only with the distractor present displays. This approach allowed an increased number of observations at the attended locations, which in turn provided greater sensitivity to the key interaction between display type and distractor probability.

Experiment 3

The brief cue–target SOAs in Experiments 1 and 2 may cast doubt on the hypothesis that control settings for distractor exclusion are reconfigured between the onset of the cue and the target. However, this result does not provide conclusive evidence that parallel settings for distractor exclusion are maintained at different target locations, because the time required for the proposed shifts in distractor exclusion has not been determined empirically. Experiment 3 provided a stronger test of our hypothesis that different settings were maintained in parallel at each potential target location. During each trial of Experiment 3, two target locations were cued and observers reported the identity of the digits that appeared in each location (see Figure 6A). Just as in Experiment 1, there were two distractor probable locations and two distractor improbable locations for each observer. In the *matched-probability* trials, two cues appeared in locations that had equal probabilities of distractor interference (i.e., two distractor probable locations or two distractor improbable locations). However, in a minority of trials (*split-probability* trials), one cue appeared in a distractor probable location whereas the other cue appeared in a distractor improbable location. If separate settings for distractor exclusion are maintained in parallel at each target location, then accuracy should vary independently as a function of the prior probability of interference at each location. Specifically, when the targets are

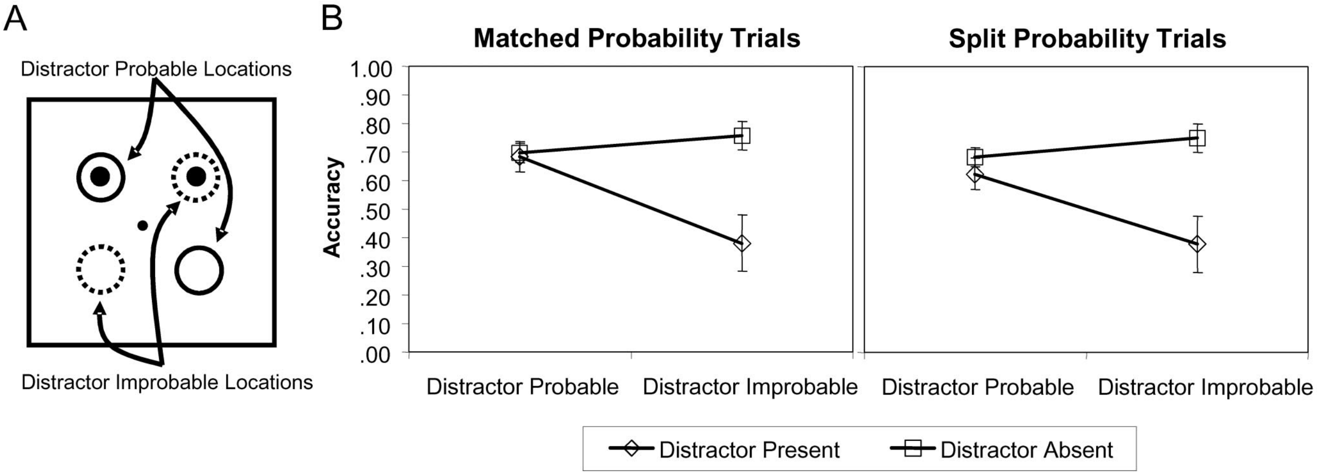

Figure 6. A: Schematic of the distractor probable and distractor improbable locations in Experiment 3. A split-probability trial is illustrated, in which one target fell in a distractor probable location and the other fell in a distractor improbable location. B: Left: Accuracy as a function of distractor presence and distractor probability in the matched-probability trials. Right: Accuracy as a function of distractor presence and distractor probability (based on the location of the individual targets) in the split-probability trials. The effect of distractor probability was equivalent in the matched- and split-probability trials, suggesting simultaneous maintenance of distractor suppression settings at each cued location. Error bars represent the standard error of the mean across subjects.

embedded within distractors, accuracy should be high at the distractor probable location and low at the distractor improbable location during the split-probability trials.

Method

Observers. Eight volunteers from the University of Oregon community were paid for their participation in a 1.5-hr experimental session. All observers had normal or corrected-to-normal vision.

Stimuli, design, and procedure. All trial events were identical to those in Experiment 2, with the following exceptions: Targets were always presented in the cued locations. Each block was composed of 48 trials. Twenty trials were in the distractor probable condition; in these trials one cue was presented in each of the distractor probable locations, and observers reported the identity of both of the subsequent targets. Twenty trials were in the distractor improbable locations; one cue was presented in each of the distractor improbable locations, and observers reported the identity of both targets that appeared in those locations. Finally, eight trials were in the split-probability condition. In these trials, one cue appeared in a distractor probable location and one cue appeared in a distractor improbable location (see Figure 6A for an illustration of a split-probability cue arrangement). The split-probability cues were either horizontally or vertically arranged, with equal probability. By analyzing the accuracy of digit report independently at each cued location, we were able to test whether the degree of distractor exclusion at each location would be independently determined by the prior probability of interference at each location.

Results and Discussion

Figure 6B shows the accuracy of target discrimination as a function of display type and the prior probability of interference in the matched-probability trials and the split-probability trials. Target discrimination in the presence of distractors was 27% more accurate in the distractor probable locations (65%) than in the distractor improbable locations (38%). In the absence of distractors, however, target discrimination was statistically equivalent in distractor probable (69%) and distractor improbable (75%) locations, $t(7) = 1.50$, $p = .18$, leading to a significant interaction of distractor probability and distractor presence, $F(1, 7) = 17.13$, $MSE = 0.264$, $p < .01$, $\eta_p^2 = .800$. The selective influence of the probability manipulation on performance with distractor present displays once again implicates a change in the degree to which distractor interference was resolved at the attended locations. The key result was that virtually identical effects of distractor probability were observed during the split- and matched-probability trials. During the split-probability trials, target discrimination accuracy in the distractor present displays was simultaneously high at the distractor probable location and low at the distractor improbable location. This result is inconsistent with a global setting for distractor exclusion that shifts as attention moves from one location to the next. This hypothesis predicted equivalent performance at the distractor probable and distractor improbable positions during the split-probability trials. By contrast, the results are readily explained by our hypothesis that independent settings for distractor exclusion were maintained in parallel at the distractor probable and distractor improbable locations. We propose that this information is stored within a static map of the visual field that records the prior probability of interference at each potential target location. Attentional control over distractor exclusion could then be implemented by using the probability map as a template for guiding the resolution of interference as attention moves across the visual field.

Experiment 4

We have suggested that attentional control over distractor exclusion may be mediated by internal maps of distractor probability. In Experiment 4 we attempted to determine the nature of the coordinate system used for these maps. Thus far, the distractor probable and distractor improbable locations were distinguished by both fixation-centered (retinotopic) and environment-centered (spatiotopic) coordinates. To distinguish these possibilities, we contrasted conditions in which distractor probability varied as a function of only spatiotopic coordinates or both spatiotopic and retinotopic coordinates (see Figure 7A). The fixation point appeared on either the right or the left side of the screen (3° eccentricity). One side of the screen was distractor probable, and the other side of the screen was distractor improbable. A small marker in the center of the screen served to highlight the difference between the two potential positions for the fixation point. For half of the observers, the retinotopic position of the cues that summoned attention were identical regardless of whether the fixation point appeared on the left or right side of the screen (the overlap condition; Figure 7A, left). For the other observers, the retinotopic position of the cues varied with the position of the fixation point (the nonoverlap condition; Figure 7A, right). If the maps of distractor probability are retinotopically organized, then the probability effect should be eliminated in the overlap condition because each retinotopic position would be associated with the same prior probability (.50) of interference. If the maps had a spatiotopic organization, however, then the obvious separation between the screen coordinates of the distractor probable and distractor improbable positions should lead to the same probability effects that were observed in Experiments 1 and 2. In the nonoverlap condition, by contrast, the distractor probable and distractor improbable conditions were distinguished by both retinotopic and spatiotopic coordinates. Thus, regardless of whether the probability maps are organized in retinotopic or spatiotopic coordinates, the probability effect from the previous experiments should be replicated.[3]

Method

Observers. Twenty-four volunteers from the University of Oregon community were paid for their participation in a 1.5-hr experimental session. All observers had normal or corrected-to-normal vision.

Stimuli, design, and procedure. All trial events were identical to those in Experiment 3, with the following exceptions. A single landmark dot (0.2° in diameter) marked the center point of the screen. At the beginning of each trial, a single fixation point appeared on either the right or the left side of the central landmark at a distance of 3.0°. At 1,528 ms after the onset of the fixation point, two peripheral cues were presented for 59 ms. In the overlap condition, the peripheral cues were always in the same positions relative to fixation, regardless of which side of the screen contained the fixation point. Half of the subjects in this condition saw peripheral cues in the upper right and lower left target positions, and the other half

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[3] Although the previous experiments have made clear that the probability effects can be observed when both spatiotopic and retinotopic coordinates are distinct between the distractor probable and distractor improbable conditions, the nonoverlap condition provides an important baseline for comparison with the overlap condition. For example, the nonoverlap condition allowed a test of whether eye movements alone could obscure the predicted differences in performance at the distractor probable and distractor improbable locations.

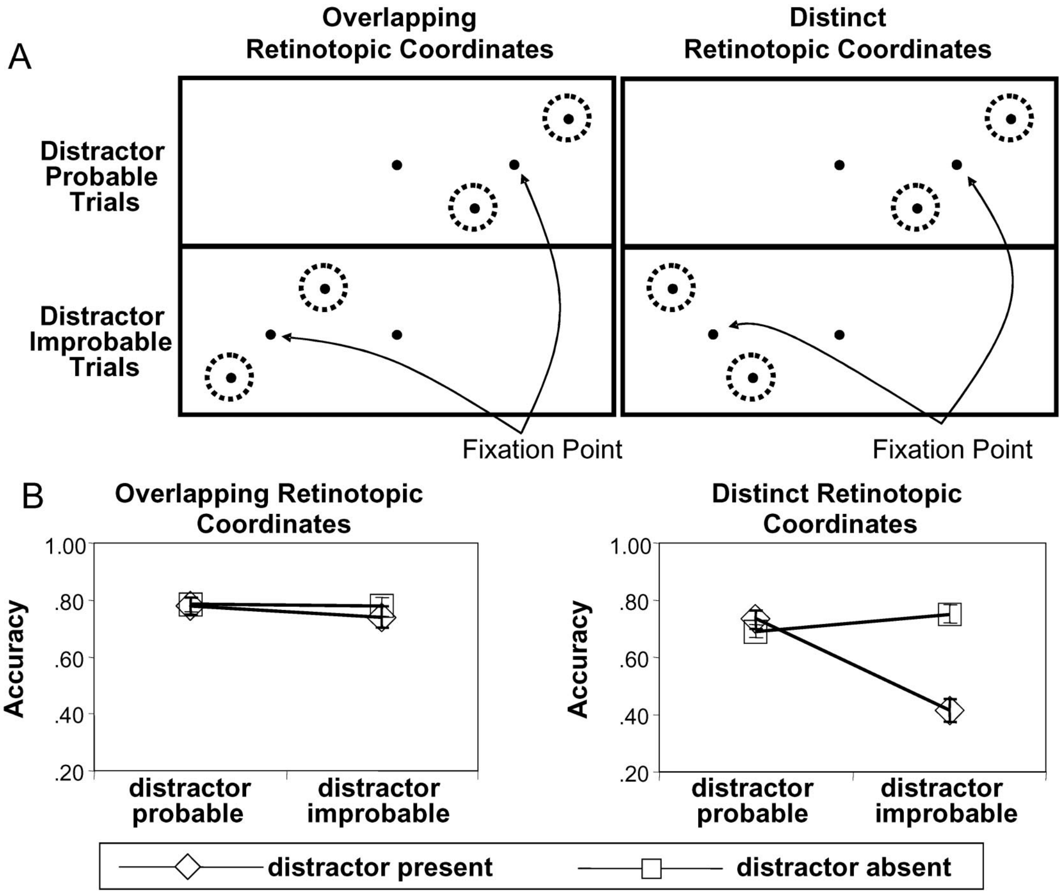

Figure 7. A: Schematic of the cued locations (Experiment 4) when distractor probable and distractor improbable locations occupied overlapping (left side) or distinct (right side) retinotopic coordinates. The side of the screen associated with the distractor probable condition was counterbalanced across observers. B: Accuracy as a function of distractor presence and distractor probability when distractor probable and distractor improbable positions were in overlapping (left side) or distinct (right side) retinotopic coordinates. Distractor probability affected performance only when different retinotopic coordinates were associated with a different probability of interference. Error bars represent the standard error of the mean across subjects.

saw peripheral cues in the upper left and lower right target positions. In the nonoverlap condition, half of the observers saw peripheral cues on the upper right and lower left target positions when the fixation point was on the right side of the screen and saw cues on the upper left and lower right target positions when the fixation point was on the left side of the screen; this mapping was reversed for the remaining half of the observers. In both the overlap and nonoverlap conditions, the assignment of distractor probable and distractor improbable conditions to the right and left sides of the screen was counterbalanced across observers. Each observer completed 12 blocks of 30 trials in the experimental condition. The same within-subject timing procedure was used to estimate appropriate exposure durations for the distractor present and distractor absent displays (10 blocks of 30 trials).

Results and Discussion

As Figure 7B illustrates, the overlap and nonoverlap conditions produced very different patterns of results. The prior probability of distractor interference had an effect only in the nonoverlap condition, when distinct retinotopic coordinates were associated with distractor probable and distractor improbable locations. Under these conditions, target discrimination in distractor-laden displays was far more accurate in the distractor probable locations (73%) than in the distractor improbable locations (31%); once again, the probability manipulation had no significant effect in the distractor-free displays, leading to a significant interaction between distractor probability and distractor presence, $F(1, 11) = 30.21$, $p < .01$, $\eta_p^2 = .733$. In the overlap condition, however, distractor probability had no significant effect on performance (no significant main effects or interactions were observed). These results suggest that the proposed maps of distractor probability are retinotopically organized. With a retinotopic coordinate system, every target position in the overlap condition was associated with a .50 probability of distractor interference, and performance was identical at the distractor probable and distractor improbable locations. In the nonoverlap condition, by contrast, the distractor probable and distractor improbable locations had distinct retinotopic coordinates, and robust effects of distractor probability were observed.

Experiment 5

The conclusion that the proposed maps of distractor probability are retinotopically organized raises an immediate question. Given that the eyes move during a typical scene inspection, how could a retinotopic map provide a reliable guide for distractor exclusion? One solution would be to retrieve different retinotopic maps for different fixation points. If an observer has a stereotyped pattern of fixations for a given object, then the retinotopic coordinates of interference would be predictable for a given fixation point. Following this logic, we hypothesized that object-based cues could guide the retrieval of the appropriate probability map after the eyes move. We tested this idea in Experiment 5 by placing a reference object in the background of the visual display and defining distractor probable and distractor improbable locations by their position on the object. As Figure 8A illustrates, when the observer fixated the right side of the object, the position up and to the right of fixation was distractor probable whereas the position down and to the left was distractor improbable. However, when the observer fixated the left side of the object, the retinotopic positions of the distractor probable and distractor improbable locations were reversed. Thus, across fixation points, the distractor probable and distractor improbable positions had overlapping retinotopic coordinates. Nevertheless, if background objects can provide reliable cues for retrieving the appropriate probability map, then the degree of distractor exclusion should still vary across the distractor probable and distractor improbable positions.

Method

Observers. Fourteen volunteers from the University of Oregon community were paid to participate in a single 1.5-hr session. All observers had normal or corrected-to-normal vision.

Stimuli, design, and procedure. The size and spacing of the characters in the target arrays were identical to those in the previous experiments. The overall grid, however, was 9 cells wide and 6 cells tall. The fixation point during each trial varied randomly between the left and right positions (located 3 cells in from the left and right sides of the grid, respectively, and centered with respect to vertical position). During each trial, the current fixation point was indicated by the color white, whereas the irrelevant fixation point was colored black. The background object was the same size as the rectangular region that defined the potential stimulus positions. To emphasize the distinction between different parts of the background object, the center region of the object (3 cells wide and 6 cells tall) was colored red

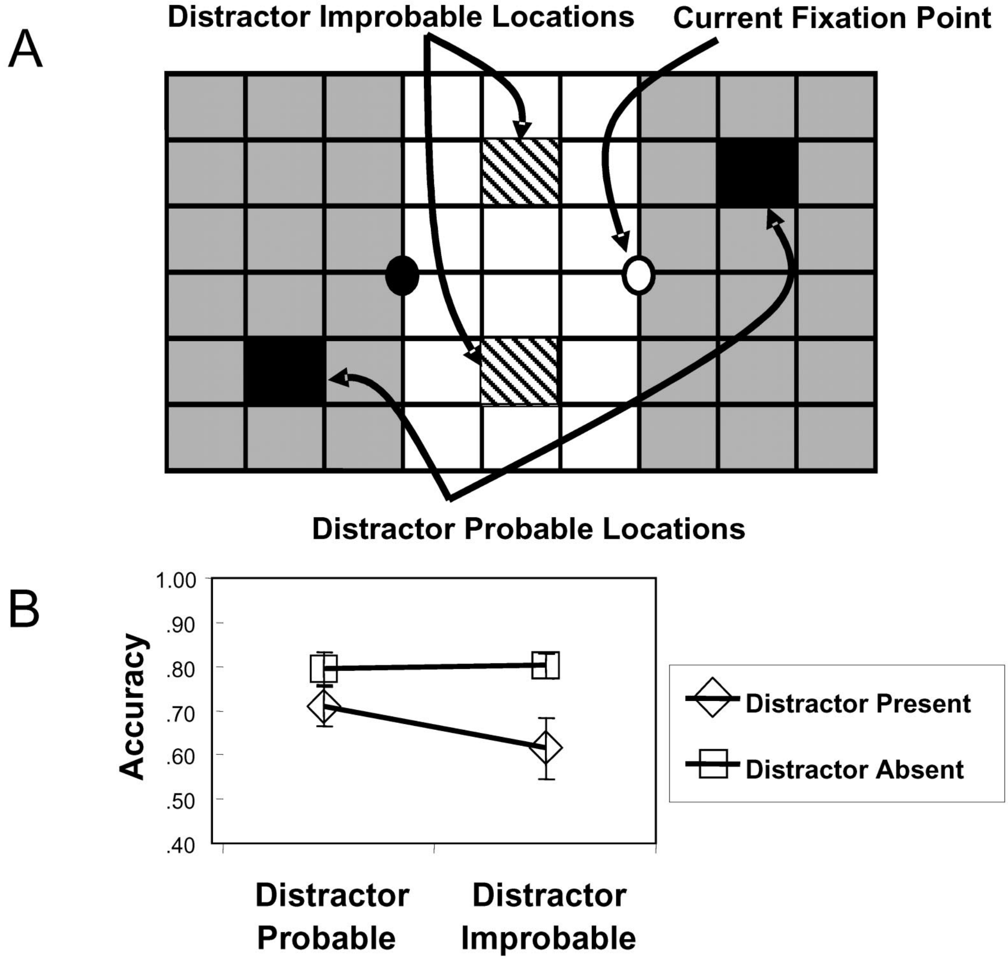

Figure 8. A: Schematic of the background object, potential target positions, and potential fixations points in Experiment 5. B: Accuracy as a function of distractor presence and distractor probability. In the presence of a salient background object, a significant influence of distractor probability was observed (despite overlapping retinotopic coordinates for distractor probable and distractor improbable positions), suggesting object-based retrieval of different probability maps when different parts of the object were fixated. Error bars represent the standard error of the mean across subjects.

(depicted in white in Figure 8A), and the outer regions of the object were colored blue (depicted in gray in Figure 8A). As Figure 8A illustrates, the potential target positions were up and to the right of fixation and down and to the left of fixation. For half of the observers, the distractor probable locations were both located in the center region of the object, and the distractor improbable locations were located in the upper right and lower left of the grid. For the remaining subjects, the distractor probable and distractor improbable positions were reversed. Similar to Experiment 1, one location was cued, and one target digit was presented during each trial. Each observer completed nine blocks of 40 trials in the experimental procedure. To estimate exposure durations for the distractor present and distractor absent displays, each observer began each session with eight blocks of 40 trials in the timing procedure.

Results and Discussion

Figure 8B illustrates target discrimination accuracy as a function of display type and the prior probability of noise at the target location. Consistent with our hypothesis that different probability maps would be retrieved for different fixation points, performance in this experiment showed reliable effects of the prior probability of interference at each target location. Target discrimination was significantly better at distractor probable locations than at distractor improbable locations when distractors were present in the display. Once again, a selective effect on the degree of distractor exclusion was suggested by the absence of probability effects in the distractor-free displays: Display × Probability interaction, $F(1, 13) = 5.15$, $MSE = 0.035$, $p < .05$, $\eta_p^2 = .284$. Recall that in Experiment 4, overlapping retinotopic coordinates for the distractor probable and distractor improbable locations led to equivalent target discrimination in these conditions. In Experiment 5, when both fixation points are considered, the retinotopic positions of the distractor probable and distractor improbable locations also overlapped. The key difference was that in Experiment 5, the distractor probable and distractor improbable locations were consistently cued by their position on a background object.

At present, two different hypotheses are consistent with the results of Experiment 5. It may be that the background object provided cues for the formation and retrieval of independent maps for each fixation point. Alternatively, it is possible that a single map represents the prior probability of distractors in object-based coordinates. Such object-based coordinates could be integrated with the current eye position to represent the appropriate setting for distractor exclusion across multiple fixation points. At first glance, the results of Experiment 4 may seem to contradict this possibility. Recall that the overlap condition of this experiment did not yield any effect of distractor probability even though the monitor itself could be viewed as a background object. However, it is likely that the object-based cues provided by the background object in Experiment 5 were more salient than the cues provided by the screen in Experiment 4. Further study is necessary to determine the boundary conditions for this object-based effect. It is clear, nonetheless, that the background object enabled an object-based record of the positions that were associated with high and low probabilities of interference. When eye position changed from one trial to the next, the degree of distractor exclusion was determined by the object-based coordinates of the cued location.[4]

General Discussion

There are many instances in which attentional control requires active changes in control settings as task demands change. For example, the task-switch paradigm (Jersild, 1927; Pinard, 1932; Rogers & Monsell, 1995) requires participants to switch the relevant rules for performing a task from one trial to the next. This switch in task sets imposes a large reaction time cost that is associated with the retrieval of the appropriate stimulus–response rules when a new task cue is presented (e.g., Mayr & Kliegl, 2000). Because the target stimuli in this paradigm may be ambiguous regarding the correct task rules, successful performance seems to demand online changes of the internal settings that specify the task set (but see Logan & Bundesen, 2003). Likewise, in our own procedure the observers received cues on each trial regarding the locations where attention should be directed. The resulting benefits for the processing of attended relative to unattended targets demonstrate online changes in a control setting for where attention is allocated. Nevertheless, the present results suggest a different conclusion for attentional control over distractor exclusion. Whereas control over the locus of attention requires online changes in top-down settings, we propose that static maps of distractor probability can allow the parallel maintenance of distinct control settings for distractor exclusion at each potential target location. Thus, as attention moves across the visual field, varying levels of distractor exclusion can be elicited without online shifts in the control settings for the resolution of interference.

The proposed probability maps have a strong influence on the degree to which distractor interference is resolved at the attended locations, despite the fact that distractor probability was not disambiguated until 59 ms prior to target onset (i.e., when the cues that captured attention were first presented). We have argued that distinct settings for distractor exclusion may already be in place for each potential target location, even before the cues appear. In this sense, the probability maps may influence visual selection in a way that is analogous to the way that top-down settings can influence attentional capture. For example, Folk, Remington, and Johnston (1992) found that color singletons but not abrupt onsets will capture attention when observers are anticipating a target that is defined by color. However, when observers are anticipating a target that is defined by its status as an abrupt onset, abrupt onsets will capture attention whereas color singletons will not. In this contingent orienting paradigm, the observer's top-down settings provide a context that determines which visual events will capture attention. In our experiments, maps of distractor probability may provide a context that determines whether attention-capturing cues will elicit increased levels of distractor exclusion. There may be limits to this analogy, however. In the contingent orienting paradigm, the relevant top-down settings are thought to be maintained

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[4] Experiment 5 did not rule out the possibility that different probability maps could have been activated in a post hoc fashion, once the position of the cue and target became apparent within the 6 × 9 target array. By this view, the background object may not have played any role in differentiating the right and left fixation points. Instead, the consistent shape of the target and distractor array may have provided the cue that differentiated the distractor probable and distractor improbable positions. Thus, we ran a parallel control experiment that tested whether the background object in Experiment 5 had a functional role. All aspects of this control experiment were identical to those of Experiment 4, except that the background object was not presented at any time. No main effects or interactions were observed for display type or distractor probability. We conclude that the background object was an essential cue for the formation and/or retrieval of distinct maps for each fixation point.

through the observer's response to explicit task instructions (e.g., "Search for red targets"). The present experiments do not address the means by which the relevant probability map is kept active. These maps could be maintained within working memory, but it is also possible that an implicit representation of distractor probability is at work in these experiments. Future experiments can examine whether the probability effects documented in the present research are dependent on the same kinds of resources that maintain online representations in working memory.

We note that there have been previous demonstrations that long-term representations guide visual selection. For example, Chun and colleagues (e.g., Chun, 2000; Chun & Jiang, 1998, 1999) have demonstrated that visual search performance is improved when the target stimuli are presented within a visual context that is consistent with prior experience. In this contextual cuing paradigm, visual search is facilitated for targets that occupy a consistent position within a specific spatial arrangement of distractors, or targets whose shape is consistently paired with a specific set of distractor shapes (see also Maljkovic & Nakayama, 1994, for a demonstration of memory influences during visual search). Our paradigm supports a similar theoretical point, namely that prior visual experiences provide an important guide for ongoing visual processing. However, there may be an important distinction between these paradigms in terms of the kind of information that is cued by context. We refer here to a distinction between the cuing of static representations and the enabling of a specific mode of processing. Kolers and Roediger (1984) argued for a similar distinction when they suggested that studies of learning and memory might benefit from a stronger focus on the procedures that facilitate the acquisition of new information, rather than on the information itself. Their point was that models of learning and memory should acknowledge how stored representations are shaped by the processes that enable the information to be acquired in the first place. Likewise, we suggest that influence of distractor probability on later visual processing is best understood in terms of how a specific process for resolving distractor interference is enabled during distractor probable trials. Thus, the present paradigm and the contextual cuing paradigm may represent distinct facets of the interactions between long-term representations and visual selection. On the one hand, the contextual cuing paradigm provides an elegant demonstration of how visual context can prime representations of specific target attributes such as target location (Chun & Jiang, 1998) or target identity (Chun & Jiang, 1999). On the other hand, the present paradigm provides an example of how contextual cues can prime the deployment of a specific mode of visual selection.

Another finding that highlights an interaction between long-term representations and visual selection was reported by Moores, Laiti, and Chelazzi (2003). Using visual search and free-recall procedures, they showed that targets took longer to find and distractors were more likely to be remembered when the distractors were semantically associated with the relevant target in the display. They suggested that semantically associated distractors were more likely to capture attention, thus hindering the search for the relevant target or increasing the probability that an irrelevant distractor would be encoded. This result dovetails nicely with the previous demonstrations that attentional capture is influenced by top-down control settings (e.g., Folk et al., 1992) by showing that long-term associations can also influence the salience of objects in the visual field. However, one important difference should be highlighted between our findings and those of Folk et al. (1992), Moores et al. (2003), and Chun and Jiang (1998, 1999). The previous results have addressed the factors that influence the spatial distribution of attention. That is, these studies have shown that current top-down settings, or previously acquired associations, will influence where visual attention is likely to be deployed or which stimuli are more likely to capture attention. However, a primary conclusion from our studies is that control over the spatial distribution of attention can be distinguished from control over the degree of distractor exclusion.

Even though a higher probability of distractor interference induced large benefits in the processing of distractor present displays, no similar effects of distractor probability were observed with the distractor absent displays. Given that this procedure is sensitive to changes in the spatial distribution of attention during distractor absent trials (as demonstrated by significant cuing effects in Experiment 1), changes in this parameter of selection should have been apparent regardless of whether distractors were presented. We therefore conclude that the probability effects observed during distractor present trials result from changes in the resolution of distractor interference. Experiment 2 addressed the alternative hypothesis that observers adopted a broader focus of spatial attention during the distractor improbable trials. This hypothesis makes a clear prediction that processing at the locations directly adjacent to the cued locations should be improved during distractor improbable trials, because these locations should benefit from the increased breadth of the attentional window during these trials. No such differences were observed, however, suggesting that the breadth of attentional focus did not expand during distractor improbable trials. Instead, we suggest that all of these data can be explained by selective increases in the degree to which target processing is shielded from distractor interference during the distractor probable trials.

There are unresolved issues regarding the formation of the proposed probability maps. For example, Experiment 5 suggested that distinct probability maps can be formed for separate fixation points when object-based cues are available to distinguish the distractor probable and distractor improbable locations. Given regular changes in eye position, the availability of multiple retinotopic maps would be an essential feature of the proposed mechanism for controlling distractor exclusion. What other cues are sufficient to guide the formation of multiple maps? Pilot experiments in our lab have explored whether symbolic cues (e.g., the word *noise* or *clean*) or varying task sets (i.e., cues indicating different stimulus–response mappings) would influence the degree of distractor exclusion when these cues were strongly predictive of the probability of distractor interference. However, neither type of cue led to differential levels of distractor exclusion during distractor probable and distractor improbable trials.

It is possible that *location* is a key dimension for distinguishing one context from another—a process that would be critical if separate maps were to be associated with each context. In line with this hypothesis, when the distractor probable and distractor improbable positions could be distinguished by virtue of their location on a background object, reliable probability effects were observed. At first glance, this interpretation may seem inconsistent with the results of the overlap condition in Experiment 3; this condition had revealed an absence of probability effects when the distractor probable and distractor improbable locations were in separate parts of the screen but had overlapping retinotopic coordinates. Why was location a sufficient cue for distinguishing the distractor probable and distractor improbable conditions in Experiment 4 but not in the overlap condition of Experiment 3? This apparent contradiction may be reconciled by distinguishing between the coordinate system by which a single map is organized and the kinds of cues that allow the formation of multiple probability maps. By this view, the overlap condition of Experiment 3 failed to produce differential performance at the distractor probable and distractor improbable locations because a single probability map recorded the probability of interference when the observers fixated the right and left sides of the screen, leading to an equal probability of interference at each position on that map. In Experiment 4, by contrast, the cues provided by the object in the background allowed separate retinotopic maps to be formed for the left and right fixation points, leading to the differential levels of distractor exclusion in the distractor probable and distractor improbable conditions. One productive question for future research concerns the necessary and sufficient features of the cues that can guide the formation of multiple maps. Understanding these principles may provide insight into the basic features that distinguish one perceptual context from another.

Multiple studies have suggested that distractor exclusion is a core component of the benefits provided by visual selective attention (e.g., Desimone & Duncan, 1995; Kastner et al., 1998; Luck, Chelazzi, Hillyard, & Desimone, 1997; Shiu & Pashler, 1994). Moreover, visual selective attention represents only one of a host of contexts in which goal-driven processing requires the resolution of interference between relevant and irrelevant representations. For example, interference resolution has been proposed as a crucial element in the retrieval of long-term memories (e.g., Anderson & Spellman, 1995), the maintenance of information in working memory (e.g., Kane, Bleckley, Conway, & Engle, 2001; Gray, Chabris, & Braver, 2003), and executive task switching (Mayr & Keele, 2000). Thus, understanding the control processes for resolving interference is an important goal for a broad array of cognitive domains. The present research contributes to this goal by providing a clear example of how attentional control can be accomplished through interactions with static visual representations. This mechanism for controlling distractor exclusion has the virtue of cognitive economy. Settings for distractor exclusion can be optimized for current processing needs, while the parallel maintenance of settings for each location minimizes the executive demands that are associated with online shifts in control settings. Thus, although the spatial distribution of attention may shift from moment to moment, control over distractor exclusion can be tuned on the basis of statistical regularities that emerge during prior visual experiences. It is clear that attentional control often entails online switches in control settings, but the current results demonstrate one instance in which static representations can provide a flexible and powerful guide for online processing. Future research can address whether other instances of attentional control can be understood in terms of similar interactions between dynamic and static control representations.

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The Publications & Communications (P&C) Board is pleased to announce the appointment of Michael E. J. Masson, PhD, as the Acting Editor for the *Journal of Experimental Psychology: Learning, Memory, and Cognition* through 2005. The P&C Board appreciates Dr. Masson's willlingness to accept this editorial responsibility on short notice after the unexpected death of Thomas O. Nelson, PhD. Dr. Masson's editorial term will run through the end of 2005.

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