

Negligible Effect of Spatial Precuing on Identification of Single Digits

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The present study examined the effects of spatial precuing on identification of a single object appearing in an otherwise empty visual field. A digit target was preceded by a valid, neutral, or invalid location cue, presented either peripherally or centrally. The target was followed by either a single mask or multiple masks covering the target and nontarget (empty) locations. Precuing significantly affected identification accuracy when multiple masks were used but had little effect when the target was followed by a single mask. The results strongly favor a model in which spatial precuing allows the contents of noncued locations to be excluded from decision (and possibly perception). Exclusion may or may not facilitate performance, depending on what is there to be excluded.

The role of spatial visual attention in modulating perception has intrigued psychologists for a long time. Helmholtz (1866/1924) noted that in a completely dark room, a person can concentrate his attention on any part of the room, so that when a spark of light illuminates the whole room, he will get an impression about the objects in that particular region only. Because the spark is too brief for an eye movement, Helmholtz reasoned that covert orienting of attention must be independent of the position and accommodation of the eyes.

Modern experimental psychologists have adopted similar paradigms, albeit with better experimental controls, to study voluntary and involuntary deployment of spatial attention. In a typical experiment of this kind, a target appears in one of several locations. The manipulation of spatial attention is supposed to be accomplished by presenting a location cue shortly before the target display. This precue is valid when it indicates the location of the target. It is invalid when it cues a location where the target does not appear. It is neutral if it carries no information whatsoever about the location of the target. Researchers have examined effects of both peripheral cues (appearing near the location of the target) and

central cues that vary in symbolic content (e.g., an arrow at the center of the display pointing to a particular location). When the target display contains some distractors in addition to the target (i.e., a multiple-element display, or MED), it has usually been found that task performance is better when the precue is valid than when it is invalid, with the neutral condition lying somewhere in between (e.g., Grindley & Townsend, 1968; Posner, 1980). Several recent studies (e.g., Henderson, 1991; Henderson & Macquistan, 1993; Posner, 1980; Van der Heijden, Schreuder, & Wolters, 1985; Van der Heijden, Wolters, Groep, & Hagenaar, 1987) report a similar advantage for cued elements that appear alone against a blank field (i.e., a single-element display, or SED). It is commonly believed that the spatial precue directs attention to the probable location and produces some localized enhancement in perceptual efficiency, regardless of whether the cued target appears alone or with some distractors. The goal in this study is to explore whether this is really the case.

Precuing in Single-Element Displays

Many SED studies have measured simple reaction times (RTs) to the onset of a stimulus (e.g., a suprathreshold luminance increment in Posner, 1980, and Posner, Snyder, & Davidson, 1980) and found faster RTs when the target location was validly cued. As Shaw (1984) and Sperling and Doshier (1986) noted, however, that RTs are faster to cued stimuli may not necessarily imply improvement in perceptual sensitivity. Subjects may adopt a more liberal decision criterion for evidence accumulated in channels corresponding to the cued location. In fact, precuing effects are substantially smaller in choice RT tasks (e.g., Posner, 1980; Posner et al., 1980). This is consistent with Shaw's analysis, because choice RTs cannot be substantially sped up by adjustments of decision criterion, without trading off response accuracy.

This study is concerned only with the effects of spatial precuing on accuracy of perception. It has often been claimed that a valid location precue improves the quality of perceptual processing at the cued region. If so, one might

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expect this to be most clearly manifested in measurements of discrimination accuracy with brief displays. Response time is dependent on several postperceptual factors (such as response confidence, ease of response selection, and motor factors) and is, therefore, a more difficult measure to interpret. Santee and Egeth (1982) reported dissociations of accuracy and response time measures. They found that in a letter recognition task with brief exposure, response accuracy was more sensitive to perceptual interference between targets and distractors, whereas RT was more sensitive to response-related interference. It would seem, therefore, that accuracy measures should provide the most appropriate indicators of perceptual sensitivity. In certain tasks, accuracy measurements may also permit the separation of sensitivity- and criterion-related measures, for example, d' and β in the framework of signal detection theory.

Effects of spatial precues in SEDs appear much less impressive in studies that have used discrimination accuracy as the dependent measure. More than 20 years ago, Grindley and Townsend (1968, Experiment 1) compared the effect of verbal instruction about target location in SEDs with that in MEDs. The task was to identify the orientation of a letter *T*, which appeared in one of four locations. The verbal cue was 100% valid. In the SED condition, the letter appeared alone. In the MED condition, it was accompanied by three simultaneous plus symbols. No mask followed the target display. They found that a cue almost doubled the accuracy in the MED condition. However, the cues produced no benefit in the SED condition. The no-cue condition was, in fact, slightly better than the cue condition.

Whereas Grindley and Townsend used letter stimuli, Nazir (1992) used a gap-resolution task in a recent study and did not find any effects of spatial precuing, either. She presented a single Landolt ringlike figure and asked the subjects to identify the location of the gap (right, top, left, or bottom side). The figure was surrounded by lateral masks and was not followed by any posttarget mask. Nazir found that whether the location of the target was precued by a peripheral dot made little difference in discrimination performance.

Other recent investigations using letter discrimination tasks, however, seem to find precuing effects in SEDs without any difficulty (e.g., Henderson, 1991; Henderson & Macquistan, 1993; Van der Heijden et al., 1985, 1987). Henderson (1991), for example, presented a letter (*X* or *O*) in one of eight locations for 67 ms, and followed it by a mask, which was a superimposed *X* and *O*, at each of the eight locations. Preceding the target display was a location precue (a line near one of the eight locations) that appeared for 100 ms. He found that a valid spatial precue improved discrimination accuracy by .14 and response speed by 150 ms, relative to an invalid precue.

The starting point for this study was our suspicion that the discrepancy between Grindley and Townsend (1968) and Nazir (1992) on the one hand and Henderson (1991) on the other might be due to the masks used by Henderson. Neither Grindley and Townsend nor Nazir used any mask at all, whereas Henderson put up a mask at each of the eight

possible target locations. Putting up multiple masks is a standard procedure with MEDs, because one wishes to curtail processing time for all locations, target or distractor. There is no obvious reason to do this with SEDs, however; there is nothing to mask at the empty, irrelevant locations.

Possible Causes of Precuing Effects

Because precuing effects are clearly more robust in MEDs, one wonders how a cue might facilitate discrimination in this situation. Precuing effects are usually discussed in connection with capacity models of attention (e.g., the zoom-lens model of Eriksen & St. James, 1986, and Eriksen & Yeh, 1985; and the gradient model of LaBerge & Brown, 1989). These models assume that there is a limited pool of processing resources, capacity, or attention, which can be distributed across a spatial region that varies in size. Perceptual processing is done in parallel within the region, with the quality of processing dependent on the amount of capacity devoted. The rate of processing is assumed to be faster with more capacity (e.g., Reinitz, 1990). When a target location is unknown, resources are evenly distributed across all the spatial regions. On the other hand, when the target is indicated by a valid location precue, more of the limited resources can be allocated to this region in advance, thus speeding up the processing. If accuracy of perception is monotonically related to the quality of perceptual processing within a fixed period of time (e.g., before the visual persistence decays), the valid cue condition will show improved target identification.

A special kind of limited capacity model—serial processing—assumes that the capacity is allocated in an all-or-none manner. Treisman and Gelade (1980), for example, proposed such an account for detection of feature conjunctions. This serial mechanism scans all of the objects in an MED one by one, until the target is found. When the target location is unknown, this mechanism has to start randomly with one of the several locations. When the target location is validly cued, it can always start at the correct location. When it is misinformed about the location, it always starts with the wrong location. Given that the time for scanning is limited (e.g., by masking), performance will be best with valid precues, followed by neutral and invalid precues.

In most capacity models, the assumption is that target identification in a display containing one or a few simple characters is limited by some type of processing resources. The validity of this assumption was called into question some time ago by Shiffrin and Gardner (1972). In their experiments, the subjects were asked to identify a target letter (*T* or *F*) in a brief display with three distractors. The crucial manipulation involved presenting four items either simultaneously or successively (in two pairs), with the exposure duration the same in the two presentation methods. Any limited capacity model would predict that simultaneously presented objects compete for capacity (either a limited pool of resources, or a single mechanism), and the competition would be reduced if fewer objects must be dealt with at any given instant. Therefore, performance in the

successive condition should be better than that in the simultaneous condition. What Shiffrin and Gardner found, however, was that performance in the simultaneous condition was as good as, if not better than, the successive condition (see Duncan, 1980; Pashler & Badgio, 1985, 1987, for confirmations of this result). In other words, a person can process four characters at a time as efficiently as two at a time. There is no indication that "dividing attention" over four spatial regions has any cost.¹

Given that perception of a target letter apparently does not suffer from "less attention" when three other letters must be perceived at the same time, it is hard to see how an item can benefit from "more attention" when its location was cued in advance (as in the spatial precuing studies described above). Therefore, the capacity interpretation of spatial precuing is hard to reconcile with Shiffrin and Gardner's (1972) results. This does not mean that there is no way to reconcile Shiffrin and Gardner's results with the existence of any form of spatial cuing effects, however. Consider the following analysis of a task like Shiffrin and Gardner's (Shiffrin & Geisler, 1973): The four objects are identified in parallel with no capacity limitations at all. People make mistakes in the task for various reasons, however. One reason is that—having insufficient time to process any of the stimuli—they sometimes confuse a distractor with a target. These confusions occur with the same frequency regardless of whether the items are presented simultaneously or successively (which follows from the absence of capacity limits). However, for purely statistical reasons, the greater the number of items in the display (henceforth, display size), the greater the likelihood of an erroneous decision: The chance that one or more items will be confused with a target grows with the number of items that could be so confused.

This analysis of the task suggests another way of understanding how spatial precuing effects could arise, at least in MEDs. Distractors that are confusable with the target create noise for the decision process (in the statistical sense), as noted above. Cuing the most likely location of a target allows this noise to be excluded, attenuated, or weighted less in the decision. The decision is thus less affected by noise than it would be if all possible locations had to be considered; hence the beneficial effect of a valid spatial cue. Similarly, when a nontarget location is cued (invalid cue), cost occurs because target information (in a noncued location) is attenuated (cf. Eriksen & Spencer, 1969; Lappin & Uttal, 1976; Palmer, Ames, & Lindsey, 1993; Sperling & Doshier, 1986). According to this view, spatial precuing does nothing more than reduce noise (reducing the effective display size). Even an "ideal detector" with no capacity limitations could show a cuing benefit attributable to noise reduction, just as it would respond more accurately with smaller display sizes (cf. Cohn & Lasley, 1974). This noise reduction model does not imply any particular locus of selection. Selection may occur early (e.g., before stimulus identification) or late (e.g., after identification). In either case, the amount of noise at the decision stage is reduced by the selection.

Noise Reduction in MED and SED

Multiple-element displays do not enable one to differentiate the capacity and the noise-reduction models. This is because in these situations perceptual performance can be improved either by signal enhancement at the cued region, noise attenuation at the noncued regions, or both. The situation where single targets appear in an otherwise blank field is very different. Without distractors, the empty irrelevant locations should hardly be confusable with a target, so long as the stimulus intensity is well above that of the blank background. Because there is not much noise to be reduced, the noise-reduction models predict that spatial precuing would not affect discrimination performance.

This analysis is consistent with the fact that location precues have little effect on the latency or accuracy of visual search for a distinctive feature surrounded by distractors (e.g., Briand & Klein, 1987; Nakayama & Mackeben, 1989; Treisman, 1985), given the assumption that the target (e.g., a vertical line or a red object) and the distractors (e.g., horizontal lines or blue objects) are separately processed by nonoverlapping mechanisms (i.e., perfectly discriminable; cf. Watson & Robson, 1981). On the other hand, when the task is to detect near-threshold stimuli against an empty background (e.g., Hawkins et al., 1990), even the blank locations may contribute substantial noise. Performance in near-threshold detection has been found to improve with valid spatial precuing to the degree that the noise is screened out at a decision stage (e.g., Davis, Kramer, & Graham, 1983). In short, the noise-reduction model predicts that spatial precuing would improve the perception of a signal embedded in a background of elements from which it cannot be perfectly discriminated (given the viewing conditions).²

¹ The capacity models can be made consistent with Shiffrin and Gardner (1972) by adding assumptions about the function of capacity and simple item identification. One can assume that identification of simple characters reaches asymptote with a minimal amount of resources (e.g., $\frac{1}{4}$ of the whole pool), such that more resources in the successive condition (e.g., $\frac{1}{2}$) would not improve performance. This predicts that the disadvantage of simultaneous presentation will emerge as the number of possible locations increases to a level where the resources allocated to each location are not sufficient for efficient processing. Furthermore, it predicts that as a processing task becomes sufficiently resource demanding, the number of processings that can be done in parallel without decrement in efficiency would be reduced. Hence, there will be an advantage of successive presentation.

² Although Grindley and Townsend (1968) said that they used stimuli at "acuity threshold" (p. 11), it should be noted that the stimuli were clearly more intense than the blank background. In the SED condition, the worse accuracy was 36 correct responses out of 80. This was the condition with verbal location cue. The response was a joint localization and identification judgment. The chance level is 5 out of 80. It is clear that subjects did well beyond chance level. If detection threshold had been measured, these stimuli should have been well above it. Therefore, the noise-reduction model has no problem accounting for their results. The stimuli used in their experiment were not "weak" in the definition of the noise-reduction model.

The noise-reduction model suggests another interpretation of Henderson's (1991; Henderson & Macquistan, 1993) experiments: The cuing effects might have depended on the presence of masks at the irrelevant locations. The masks immediately followed the SED, so the subjects' task might have required discriminating the target plus mask from mask alone for each position in the display. The masks were the two target letters (*X* and *O*) superimposed, which would seem to maximize the difficulty of this discrimination. To the degree that spatial precues allowed the unlikely positions to be excluded as possible loci of targets, Henderson's results could reflect noise reduction rather than any localized changes in perceptual sensitivity. If the noise-reduction explanation is correct, these effects should disappear when there are no masks at positions other than that of the single target

In summary, noise-reduction models suggest that the effects of a spatial precue depend on the presence of stimuli that are confusable with targets—stimuli that can be excluded on the basis of the cue. Cues should not produce benefits when nontarget locations contain nothing that could be confused with a target (as in SEDs). Capacity models, on the other hand, suggest that cued signals are perceived more efficiently because the cue allows more capacity to be allocated to the cued location in advance. The distribution of capacity is determined by the location cue; signal enhancement should occur regardless of whether the nontarget locations are empty or filled.

We conducted the following experiments to analyze the effect of a spatial location precue on the identification of a single high-contrast target against a blank field (followed by a variable number of masks). Our overall goal was to determine whether signal enhancement or noise exclusion is the cause of the benefits of valid precuing in these conditions.

Experiment 1

In this experiment, we investigated the hypothesis that precuing effects in SEDs are dependent on the presence of masks at the irrelevant locations. A single digit identification task was used. The target display was preceded by a peripheral location precue (valid or invalid) or no cue at all. The number of masks following the display was varied. One should expect to find the usual facilitation and inhibition effects of precuing in the multiple-masks condition, given the results of Henderson (1991; Henderson & Macquistan, 1993). However, if these effects are due to noise reduction, they should be largely absent in the single-mask condition.

Method

Subjects The 12 subjects were students at the University of California, San Diego. They participated for course credits.

Materials and apparatus. All the stimuli were presented on a cathode-ray tube (CRT) NEC MultiSync 2A controlled by an IBM/PC. The target digits (4, 5, 6, or 7) had a size of approximately .5 X 1 cm, or 0.48° X 0.95° visual angle from a viewing distance of 60 cm. A digit appeared in one of the four quadrants of

the screen. The midpoint of a digit and the center of the CRT formed a rectangle of approximately 3.5 X 4 cm. The luminance of the digits was approximately 50 cd/m², against a background luminance of 1 cd/m². The location cue was a 5 X 5 mm square placed above or below a target location. It had the same luminance as the target digits.

Design. This was a 2 (single mask vs. multiple mask) x 3 (valid, invalid, and no cue) design. Both factors were manipulated within subjects. In the experimental session, there were 12 blocks of 60 trials. In 10 of the blocks, the target display was preceded by a location cue, either valid (75% of the time) or invalid. In the remaining 2 blocks, no cue was given, but the same amount of time lapsed before the target appeared. The presentation order of the blocks was counterbalanced across subjects. Multiple masks were used for half of the blocks, and single mask for the other half. The order of mask conditions was also counterbalanced across subjects.

Procedure. The sequence of displays for a trial is illustrated in Figure 1. Subjects were seated in front of a computer screen at a typical distance of 60 cm. Their heads were not restrained. Every trial began with a plus sign appearing at the center of the screen. Subjects were instructed to fixate at the sign and not to move their eyes during a trial. The fixation sign appeared for 500 ms and was then followed by a location precue. The cue appeared in one of the four possible locations for 50 ms (subject to the variability introduced by the 60 Hz refresh rate of the monitor). In a randomly selected 75% of the trials (i.e., 45 trials in each block of 60 trials), the location of the cue coincided with the location of the target. These were the valid trials. In the invalid trials, the target appeared randomly at one of the other three noncued locations. A target digit (4, 5, 6, or 7) appeared for 50 ms after the cue had disappeared. The stimulus onset asynchrony (SOA) between cue and target was

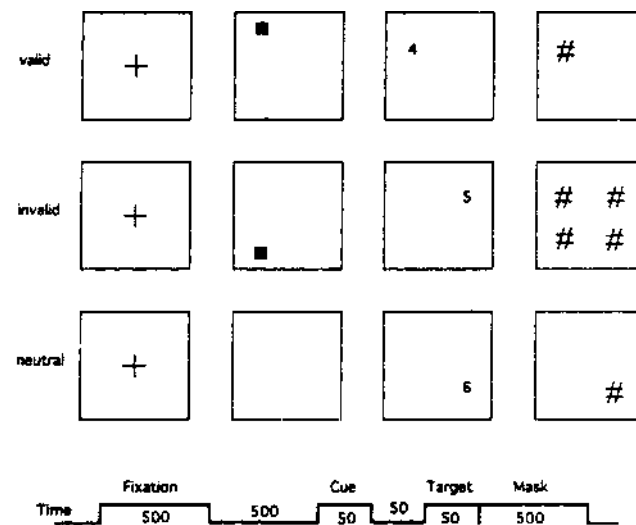


Figure 1. The sequence of stimulus displays used in Experiment 1. A fixation sign (+) appeared at the beginning of a trial, followed by a cue (filled square), a target digit (4, 5, 6, or 7), and then one or four masks (#). The timing of these events is indicated in the time line at the bottom of the figure. This diagram illustrates single mask in the valid and neutral condition, and multiple masks in the invalid condition. The two factors were factorially combined in the experiments. There was no cue in the neutral condition in Experiment 1, but there was a cue appearing at the fixation location in all the other experiments. (Note: This figure is not drawn to scale.)

approximately 100 ms. In the no-cue blocks, there was no display of cue, but the same amount of time elapsed between the offset of the fixation cross and the onset of the target.

The target display was immediately covered by a mask display, which lasted for 500 ms. In the single-mask condition, the mask display consisted of a number symbol (#) at the target location. In the multiple-mask condition, there were three additional number symbols, each at one of the other three locations. This latter condition was used in most of the previous experiments using the spatial precuing paradigm (e.g., Henderson, 1991). Subjects were to respond to the digit by pressing one of four labeled keys on a keyboard. They were asked to maximize response accuracy and were allowed as much time as they wanted for a response. A warning tone was given after every incorrect response. The next trial started 750 ms later. At the end of each block of trials, subjects received feedback on performance in the form of percentage correct. They rested until they felt comfortable to continue. Before the experimental session began, subjects practiced with four blocks of 20 trials each.

Results and Discussion

The percentage of identification errors in each combination of cue conditions and mask conditions is plotted in Figure 2. Altogether, there were 360 valid-cue trials, 120 invalid-cue trials, and 240 no-cue trials per subject. Multiple- and single-mask condition each appeared in half of the trials.

The mean error rates in the valid, invalid, and no-cue conditions were 23.61%, 28.68%, and 19.55%, respectively. This main effect of cue condition was significant, $F(2, 22) = 5.61, p < .05$. The valid condition was significantly more accurate than the invalid condition. Strictly speaking, it may not be appropriate to discuss these results in terms of cost and benefit relative to the no-cue condition, because the no-cue trials were blocked, and the valid and invalid trials were intermixed (Jonides & Mack, 1984). We noted that the no-cue condition was slightly better than the valid-cue condition, though the difference was not significant. Pure no-cue trials have been reported to produce better performance

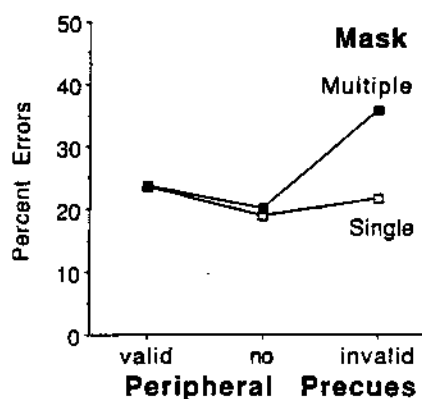


Figure 2. The percentages of identification error shown as a function of (peripheral) precuing validity in the single- and multiple-mask conditions (represented by the open and filled square, respectively) in Experiment 1.

than valid trials (mixed with invalid trials) in SEDs (e.g., Grindley & Townsend, 1968; Remington, Johnston, & Yantis, 1992, Experiment 4).

The mean error rate in the multiple-mask condition was 26.51%, significantly higher than the 21.38% in the single-mask condition, $F(1, 11) = 13.05, p < .01$. This result supports the hypothesis that the masks at the irrelevant locations interfere with identification of the target digits.

The predicted interaction effect can be seen clearly in Figure 2; it was highly significant, $F(2, 22) = 11.78, p < .001$. Cues affected performance when multiple masks were used (the mean difference between valid and invalid cue was 11.99%), but barely at all in the single-mask condition (the mean difference between valid and invalid cues was 1.85%). We did F tests comparing cue type for each mask condition. The results indicate that the precuing effect was significant only in the multiple-mask condition, $F(2, 22) = 10.97, p < .001$, but not in the single-mask condition, $F(2, 22) = 1.34, p > .2$.

As expected, the effect of the masks was completely absent when the target location was validly cued. The masks had their biggest effect when the cue was invalid (a difference of 12.02%). We also expected a similar effect of multiple masks in the no-cue condition, in which exclusion of the irrelevant locations was not possible because the target location was not certain. This trend was not found in the results, however. The difference between the two mask conditions with no cue was 1.18%, which was far from significant. Explanation of this surprising result will be sought in Experiment 4.

Eye movement toward the cued location is a possible spurious cause of spatial precuing effects, although the timing of the displays was chosen to make that unlikely. In any case, the Cuing Effects X Mask Type interaction cannot be explained by eye movements alone.

In summary, this experiment shows that extra masks at the irrelevant locations can be critical in producing precuing effects with SEDs. Without these masks, identification of the target digit was not affected by the validity of the cue to any detectable extent. That these masks produced no interference when the target location was validly cued demonstrates the efficacy of selective attention; the mechanism will be discussed below.

Experiment 2

We thought it worthwhile to replicate Experiment 1 using a symbolic location cue that appeared at the fixation location. A number of studies have suggested that central pre-cues may require a longer cue-target SOA to reach maximal effects (e.g., Posner, 1980). Others have suggested that different mechanisms or operations may be involved in peripheral and central precuing (e.g., Klein, Kingstone, & Pontefract, 1992; Umiltá, Riggio, Dascola, & Rizzolatti, 1991).

Method

Subjects. Twelve new subjects from the same subject pool as those in Experiment 1 participated.

Procedure. The procedure was the same as in the last experiment, except that the location cue was an arrow at the fixation location. This arrow pointed to one of the four locations. As in Experiment 1, the cue was valid on 75% of the trials. The neutral-cue condition, a square presented at the same location as the arrow, was also blocked. The SOA between the cue and the target, the exposure duration of the cue, the target and the masks, and the number of trials per condition were the same as Experiment 1. Both multiple- and single-mask conditions were included.

Results and Discussion

Figure 3 shows the percentage of identification errors in each combination of cue and mask conditions. The results were similar to Experiment 1. The mean error rates in the valid-, invalid-, and neutral-cue conditions were 26.90%, 29.86%, and 21.63%, respectively. The differences between cue conditions were highly significant, $F(2, 22) = 16.03$, $p < .001$. Again, the neutral-cue condition was slightly better than the valid-cue condition, though the difference was not significant.

The main effect of mask condition was also significant, $F(1, 11) = 17.44$, $p < .01$. The mean error rate in the multiple-mask condition (29.95%) was higher than that in the single-mask condition (22.31%). This reinforces the similar finding in Experiment 1.

The predicted interaction effect between cue condition and mask condition was significant, $F(2, 22) = 3.67$, $p < .05$. The mean difference between valid and invalid cue was 5.88% with multiple masks, but only .19% with single mask. An F test of cue types at each mask condition confirmed that cuing effect was significant only in the multiple-mask condition, $F(2, 22) = 13.01$, $p < .001$.

Unlike Experiment 1, the effect of mask was evident across all of the cue conditions, although it was still biggest

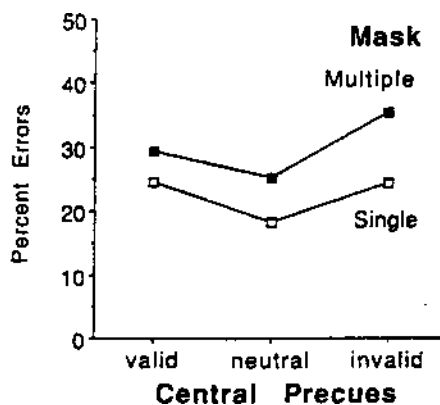


Figure 3. The percentages of identification error shown as a function of (central) precuing validity in the single- and multiple-mask conditions (represented by the open and filled square, respectively) in Experiment 2.

with the invalid cue (a difference of 11.12%). The mask effect in the invalid and the neutral conditions confirms our expectation (see the Results and Discussion section in the last experiment). We also expected that the mask effect would be eliminated when the target location was validly cued, just as was found in the last experiment. The results did not fully support this expectation, however. The discrepancy may be due to the differences of peripheral and central cuing. A central cue may not be as effective as a peripheral cue in indicating the target location. Because of its symbolic nature, a central cue requires some processing to know what location is being implicated. This may require a longer SOA between cues and targets for the information to be fully used. This explanation can also account for the fact that the cuing effect in the multiple-mask condition was smaller in this experiment (the difference between valid and invalid was 6%) than in the last experiment (12%). Despite this difference, the conclusions drawn for Experiment 1 also hold for this experiment.

Experiment 3

The results of the previous two experiments are quite favorable to the noise-reduction model: There was no precuing effect unless there were stimuli potentially confusable with the target (i.e., masks) that could be excluded with the cue. This hypothesis was elaborated and further examined in this experiment.

The hypothesis suggests that precuing effects may be restricted to cases where the precue allows information from the noncued locations to be attenuated. Attenuation would not influence performance, however, unless the contents of the nontarget locations are sometimes confused with the target. If the noise is perfectly discriminable from a target, then no matter how much or how little it is attenuated, identification response would hardly be affected.

One way to examine the suggestion that sometimes the content of the nontarget locations is mistaken for a target, when multiple masks are used, is to ask the subjects to report the location at which they believe the target has appeared.³ Given the close binding of identity and location information (Johnston & Pashler, 1990), subjects should report the location that contains the information that determined their identification response. If a precue is likely to induce the acceptance that a target is actually presented in the cued location, this should improve localization when the cue is valid, and impair it when it is invalid, producing "precuing effects" in localization. In addition, just like precuing effects in identification, location uncertainty should be a function of target-noise confusability (Shiffrin & Gardner, 1972). Putting these together, a strong relationship between location judgments and identification is predicted.

On the other hand, the capacity models do not make any definitive predictions with regard to the relationship between localization and precuing effects in identification. If

³ We thank Jeff Miller for this idea.

the relationship turns out to be strong, it is consistent with a restrictive spotlight model that assumes that attention has to move to a correct location before a discrimination response to the target can be made (e.g., Posner, 1980). Some capacity models, on the other hand, (implicitly) assume that the system always "knows" where the capacity should be allocated, and only the speed of allocation is affected by precuing (e.g., Cheal, Lyon, & Gottlob, 1992). For example, a valid precue may lead to faster allocation and hence more accurate identification than an invalid precue, though they may not differ in locating the target. This assumption seems to predict accurate localization in all precuing conditions, despite the variations of identification accuracy across conditions. In summary, although a close relationship of identification and location across precuing conditions cannot reject all capacity models, it is inconsistent with at least some of them.

Before proceeding, one should bear in mind that location judgments may be affected by some other variables besides confusability of target and noise. First, even if the subjects have no idea where the targets are, they can just report the location of the cues. Owing to the overall validity of the cues, this strategy would produce more correct than wrong responses. For subjects who adhere faithfully to this strategy, they should have perfect accuracy in the valid condition, perfect error in the invalid condition, and chance accuracy in the neutral condition. Even if the subjects do not rely solely on the cues, the cues may nevertheless induce a response bias favoring reporting the locations of the cues, especially when they are uncertain about where the target is. This bias would improve accuracy in the valid condition and impair accuracy in the invalid condition, producing a "precuing effect." Second, because the subjects were asked to report the identities of the targets before they reported the locations, some memory loss may occur. This memory factor is likely to reinforce the bias favoring the cued locations.

In summary, although the association between location and identification judgments can be caused by more than one factor, it is critical for the noise-reduction models. This class of models should be rejected if it turns out that the targets can be located very accurately despite cuing conditions, but nevertheless identification accuracy shows costs and benefits of advanced cuing. On the other hand, a close relationship is inconsistent with at least some capacity models.

Furthermore, the noise-reduction and the capacity models may have another contrasting prediction. The noise-reduction account suggests that the precues, valid or invalid, would cause people to conclude that a target was actually presented at the cued location. This implies that in the invalid condition, the subjects would frequently report the miscued location. On the contrary, if enhancement occurs at the cued location, as the capacity account asserts, then the perceptual system should be more likely to recognize that the miscued location does not contain a target. Hence, the subjects should probably not report the cued location when they fail to locate a target correctly.

In Experiment 3, conditions were as in the multiple-mask condition of Experiment 1, but subjects were asked to locate the targets after they had identified them. The single-mask condition was not included. Because the single mask indicated the location of the target, it did not make much sense to ask subjects to locate the target.

Method

Twelve new subjects from the same subject pool participated. The design, stimuli, apparatus, display conditions, and procedure of this experiment were the same as those in Experiment 1, with five exceptions. First, only the four-mask condition was included. Second, the subjects were asked to indicate the location of the target after identifying it. They received separate feedback for each response. Third, the experiment consisted of eight blocks of 60 trials. Fourth, a new trial started 1 s after a location response was made. Finally, the neutral-cue condition (i.e., a small square appearing at fixation, instead of no cue) was intermixed with the valid and invalid conditions within blocks. In the previous two experiments, it was presented in separate blocks.

Results and Discussion

The percentages of identification errors in the valid, neutral, and invalid conditions were 17.26%, 17.45%, and 37.60%, respectively. The effect of precuing was significant, $F(2, 22) = 20.72$, $p < .001$. Thus, most of the effect of precuing was cost (20.15%), whereas the benefit was less than 0.5%. The error rates for location judgments were 1.46%, 7.14%, and 42.19% for the three conditions, respectively, showing a significant effect of precuing, $F(2, 22) = 17.96$, $p < .001$. The cost and benefit of precuing were 35.05% and 5.68%, respectively. Overall, localization was more accurate than identification, but the effect of precuing in the former closely matched that in the latter (see Figure 4).

The results show a strong correspondence between location and identification judgments, and the cuing effects in each. This is inconsistent with the assumption (implicitly)

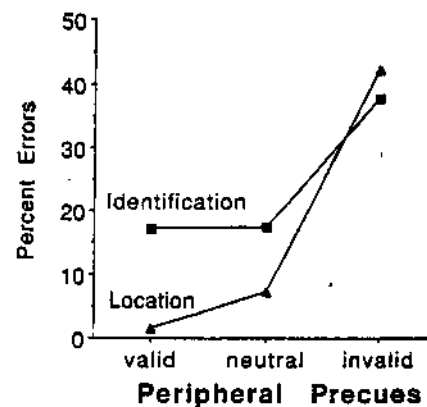


Figure 4. The percentages of identification (filled square) and location (filled triangle) error shown as a function of (peripheral) precuing validity in Experiment 3. Multiple masks were used.

held by some capacity models (e.g., Cheal et al., 1992) that only the latency of capacity allocation, but not the localization of a target, is affected by spatial precuing. We also computed the probabilities of identification conditional on correct localization [$P(I | L)$]. They were 83.12%, 85.73%, and 79.84% for the valid, neutral, and invalid conditions, respectively. There was still a significant, though much reduced, effect of precuing, $F(2, 22) = 4.05$, $p < .05$, but only the neutral condition was significantly more accurate than the invalid condition (Newman-Keuls test, $p < .05$). If perceptual efficiency of a noncued target is reduced relative to a cued target, as the capacity models assume, the deficit of the invalid and neutral conditions relative to the valid condition should be manifested in both overall probabilities of identification and conditional probabilities. The observed difference between the valid and invalid conditions was, however, fairly small (3.28%) and not statistically significant when conditional probability was considered.⁴

It seems reasonable to assume that localization is limited by the extent that a target could be differentiated from the noise, and that identification is further limited by the extent that a target could be differentiated from the other targets. The result that precuing primarily affected overall identification, but had little or no effect on conditional identification, seems to suggest that most of the effect is related to the first limiting factor, namely, the difficulty of finding the target (with multiple masks present). This difficulty may be alleviated or accentuated by the location cues. However, whenever the target is correctly located despite cuing (i.e., whenever the first limiting factor is overcome), valid precuing has little or no effect on (conditional) identification.⁵ On this account, there is little effect of precuing with a single mask because the first limiting factor is absent.

Before putting too much confidence on this interpretation, one should consider a possible problem. Because the subjects might just report the cued location in case they did not see the target at all, the correct localization responses in the valid condition might contain those trials in which the subjects had no idea what the target was. This would "unfairly" reduce the $P(I | L)$ in the valid condition. There are two reasons to believe that this guessing strategy would not have been very important, however. First, the big difference between overall identification (62.4%) and conditional identification (79.84%) in the invalid condition implies that much of the cost of invalid precuing has to do with locating the target. This conclusion does not depend on the $P(I | L)$ in the valid condition. Second, the overall probability of identification, $P(I)$, in the valid condition is the same for the single- and multiple-mask conditions (Experiment 1). If location guessing, $P(\text{guessed } L)$, had indeed occurred, it would have been more frequent in the multiple-mask condition, assuming that finding the target had been more difficult. Given that guessing would have reduced $P(I | L)$, its impact would also have been apparent in $P(I)$. Because there was no difference in $P(I)$ between the single- and multiple-mask conditions, it has to be the case that $P(\text{guessed } L)$ was the same across conditions, unless there were some compensations (e.g., a larger $P(I | \text{real } L)$ or a larger $P(\text{real } L)$ in the multiple-mask condition. Such com-

pensations seem unlikely, so it seems reasonable to assume that $P(\text{guessed } L)$ had been equally high or low in either mask condition. As $P(\text{guessed } L)$ in the single-mask condition should have been quite low, it follows that $P(\text{guessed } L)$ in the multiple-mask condition should also have been low. In other words, most of the localization responses should have been genuine. In addition, the results of the next experiment showed that $P(I | L)$ for the valid condition was the same whether there were one, four, or eight masks. One would expect that location guessing, if it indeed occurred, would have been more prominent as there were more masks. This would have impaired $P(I | L)$ in the multiple-mask conditions more than in the single-mask condition. The result that $P(I | L)$ was roughly independent of the number of masks suggests that this was not the case.

The dependence of identification on localization is again observed when the wrong localization responses are considered. The probability of identification given wrong location, $P(I | \text{not } L)$, was 33.2% in the invalid condition. Identification differed slightly (though significantly) from chance (25%) when location information was lost (one-sample $t(11) = 2$, one-tailed $p < .05$). This is consistent with previous findings about the coupling of detection and localization (Johnston & Pashler, 1990; Shiffrin & Gardner, 1972). The $P(I | \text{not } L)$ was not computed for the other two cuing conditions, because the number of wrong location responses was too small to allow meaningful estimates.

⁴ To make up an explanation consistent with capacity allocation, one can argue that in those invalid trials where localization was correct, for some reason capacity had not been allocated to the miscued location. Instead, it had been allocated to the target location. As a result, the identification accuracy in this portion of invalid trials was as good as that in the valid condition. However, this explanation must hold that the precues failed to direct capacity allocation in the majority of the trials, including those in the valid condition, because the subjects had no way to distinguish valid and invalid trials before a target had appeared.

⁵ According to the noise reduction model, whenever an invalidly cued (or noncued) target is correctly located, it must be because its strength (assuming this to be measured on a one-dimensional scale, as in signal detection theory) is strong enough to overcome the attenuation induced by the precue. Therefore, what is sampled should have been mostly the top part of the signal strength distribution. This may or may not produce a larger $P(I | L)$ in the invalid (and neutral) condition, relative to the valid condition, depending on the shape of the noise and signal distributions, as well as the relative position of the localization and identification criteria. In general, if the minimum signal strength sufficient for deciding that a location contains a target is not sufficient for identifying it, then sampling the distribution of signal strength above that sufficient for localization would not affect $P(I | L)$. However, a larger $P(I | L)$ in the invalid condition is expected if the signal strength required for localization is more than sufficient for identification. In the follow-up experiment to this one, as well as the next experiment, there are some indications that $P(I | L)$ in the invalid condition is larger than the neutral condition, and the neutral is larger than the valid. In any case, that the valid condition did not have higher $P(I | L)$ is evidence against the capacity models.

In the invalid condition, when the subjects did not report the location of the target, they reported the location of the precue 89% of the time. This may be another piece of evidence against the signal enhancement models. If enhancement had occurred, the perceptual system ought to have been more likely to detect the fact that the miscued location did not contain any object at all; hence, it should have been less likely to mislocate the target at the miscued location. Instead, the mislocation errors probably indicate a strong bias in favor of reporting the cued location, or a tendency for the noise from the miscued location (due to the mask) to be mistaken for a target, as predicted by the noise-reduction account.

The benefit of precuing in identification was again small (as in Experiment 1). We were concerned that the peripheral precues could possibly have produced forward masking. To test this, the experiment was repeated with 10 new subjects. The only change was that a precue was placed farther away from the target (0.5 cm between the nearest contours). This alteration did not change the pattern of the results, however. The error rates in the valid, neutral, and invalid conditions were 36.42%, 34.12%, and 53.00%, respectively. There was a significant effect of precue validity, $F(2,18) = 43.20$, $p < .001$, but no significant difference between the valid and the neutral conditions. The conditional probabilities, $P(I | L)$, for the valid, neutral, and invalid conditions were 64.97%, 71.62%, and 72.17%, respectively, $F(2, 18) = 3.09$, $p > .05$. Because moving the peripheral cues farther away from the target did not improve the accuracy for the valid condition relative to the neutral condition, forward masking could not explain why the benefit of precuing was small.

There seems to be another possible explanation of the small precuing benefit. We have suggested that the size of the precuing effect depends on the noise. The small benefit may indicate that in the neutral condition, without the misleading cue of the invalid condition, the subjects were generally able to differentiate the targets and the noise.⁶ If this were true, the subjects should also have been quite accurate in telling the locations of the targets, as was indeed the case. We therefore expect larger benefits in case the noise in the neutral condition is more substantial.

The results of this experiment suggest that the precuing effects in identification may have to do with the difficulty of finding the target when there are confusable items in the display. It seems that an invalid cue impairs identification primarily because it leads to acceptance of noise as evidence for target. On those occasions when the targets are correctly located, identification is approximately as good as when the locations are precued. If one believes that more attention is allocated when the location is known in advance, one is led to the view that such attention does not facilitate identification.

Experiment 4

In the previous experiment, the masks in the neutral condition impaired location judgments only slightly, prob-

ably indicating that the noise was not very confusable with the target. This may explain why the valid cues did not improve identification accuracies, either. One may expect that when the amount of noise is increased, localization in the neutral condition would increase in difficulty. A concomitant effect would be a larger benefit of valid precuing in identification.

In this experiment, we tried to increase the amount of noise by doubling the number of irrelevant masks. There might be one, four, or eight masks following each target. Although the number of possible target locations was fixed at eight, the noise-reduction model assumes that location uncertainty is determined by the number of confusable items, not the number of locations to be monitored. Therefore, it has two major predictions. First, location accuracy in the neutral and invalid conditions would be a function of the number of masks. This would produce a larger benefit of valid precuing as the performance in the neutral condition got worse. Second, the size of precuing effects in identification should be related to location accuracies in the same way as found in the last experiment.

These predictions contrast with those from the capacity models. Because capacity distribution is assumed to be determined by the number of locations to be monitored and is set as soon as a precue appears, it is difficult to see how the number of posttarget masks can affect performance.

Method

This experiment was very similar to the last one, with a few changes. First, a target appeared in one of eight locations, which formed an imaginary circle centered around fixation. There were three levels of mask display: one, four, or eight masks. In the one-mask condition, the mask covered the target digit. In the four-mask condition, the masks covered the target and three other locations, which together formed either a square (in the top-left, top-right, bottom-left, and bottom-right corners) or a diamond (in the "north," "east," "south," and "west"). In the eight-mask condition, every location was masked. Notice that the invalid cue was never in a masked location in the one-mask condition, always in a masked location in the eight-mask condition, and sometimes in a masked location in the four-mask condition.

In the first two experiments, the single- and multiple-mask conditions were separated by blocks. This might have permitted different strategies to be used with different mask conditions. To reduce this possibility, the mask conditions in this experiment were mixed within blocks. As in the last experiment, the valid, neutral,

⁶ Although this suggestion appears to contradict the original hypothesis that precuing effects are due to confusable noise, it in fact does not. The hypothesis suggests that errors due to noise would occur whenever the noise (N), weighted by a factor (W), is stronger than the target (T) signal (i.e., $W*N - T > 0$). The value of W is dependent on the cue validity. W is assumed to be 1 in the neutral condition, and to be several times bigger than 1 in the invalid condition (suppose it is 3, for example). It is plausible that the probability of ($1*N - T > 0$) is small, whereas the probability of ($3*N - T > 0$) is quite substantial. The former probability may be responsible for the small benefit of precuing, whereas the latter may be responsible for the substantial cost.

and invalid conditions were also mixed within blocks. The cue validity was again 75%.

The subjects were asked to identify a target digit and indicate its location in every trial, including the single-mask condition. Separate feedback was given after each response. The subjects were instructed about the validity of the cue and the different mask displays. There were 12 blocks of 54 trials.

This was a 3 (one, four, and eight masks) X 3 (valid, neutral, and invalid cues) within-subjects design. Twenty-two subjects participated for course credits.

Results and Discussion

The percentages of identification error in the valid, neutral, and invalid conditions, pooled over mask conditions, were 31.52%, 31.67%, and 41.62%, respectively. The effect of precuing was significant, $F(2, 42) = 30.21, p < .001$. Although the number of locations to be monitored was fixed at eight, identification was significantly affected by the number of masks, $F(2, 42) = 25.23, p < .001$. Error rates were 31.33%, 33.90%, and 39.58% for one, four, and eight masks, pooled over cuing conditions.

The most striking finding was the significant interaction effect of mask and cue conditions, $F(4, 84) = 7.87, p < .001$. The effects of cue types were significant⁷ only in the four- and eight-mask conditions, $F(2, 42) = 12.93$ and $F(2, 42) = 26.78$, respectively, but not in the single-mask condition, $F(2, 42) = 3.48$. As shown in Figure 5, there was not much difference across cue conditions when a single mask was used, although the neutral condition appears more accurate than the other two conditions (mirroring the results of Experiment 1). When four masks were presented after the display of the target, there was a substantial cost (8.85%), but little benefit (0.44%) of precuing, replicating the results of Experiment 3. Finally, when eight masks were presented, there was more evidence of benefit (3.09%), besides a large cost (17.93%), of precuing. The magnitude of the precuing effects increased as there were more confusable items in the display, even though the locations to be monitored were

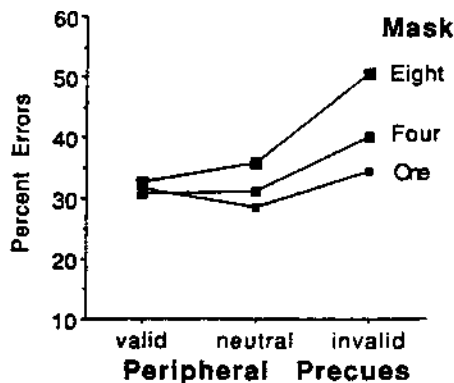


Figure 5. The percentages of identification error as a function of (peripheral) precuing validity in Experiment 4. The results are shown separately for the one-, four-, and eight-mask conditions.

kept constant, and the subjects had no way to know beforehand how many masks would appear. This should not have happened if identification accuracy is determined by the amount of capacity distributed before the onset of the target. On the other hand, this pattern of results matches closely with the predictions of the noise-reduction hypothesis.

As expected, when the cue was valid, identification accuracy remained relatively stable despite the number of masks (replicating Experiment 1). But the effect of masks got larger in the neutral condition, $F(2, 42) = 5.69$, and became very substantial in the invalid condition, $F(2, 42) = 25.08$. The benefit of valid precuing emerged only when the performance in the neutral condition got worse. This provides evidence that precuing effects may be better described as impairment in the noncued locations and supports the suggestion of the noise-reduction model that information in the noncued location is attenuated.

The effects of the two factors on location judgment mirrored those on identification. The error rates, pooled over mask conditions, were 3.55%, 11.97%, and 49.07% for the valid, neutral, and invalid conditions, respectively, showing a significant effect of precuing, $F(2, 42) = 95.89, p < .001$. The masks also had significant effects on location judgment, $F(2, 42) = 88.84, p < .001$. Error rates were 9.60%, 23.47%, and 31.52% for one, four, and eight masks, pooled over cuing conditions. The Mask X Cue Conditions interaction was also significant, $F(4, 84) = 45.13, p < .001$. This is shown in Figure 6.

When the precues were valid, the number of masks hardly affected localization accuracy at all. However, the effects of the masks were substantial in the neutral condition and very large in the invalid condition, illustrating that in these two conditions, finding the target became increasingly difficult as there were more stimuli that might be mistaken for the target. Notice that the number of possible target locations was constant across mask conditions. Hence, the chance probability of error was the same for different mask conditions.

Because the single mask always covered the target, it seems reasonable to expect that location judgment in this condition would be close to perfect. This is the reason that this condition was not included in the previous experiment. The expectation was confirmed to some extent: the error rates in the neutral and valid conditions were minimal ($< 4\%$) and did not differ between conditions, whereas they differed by more than 10% in the four- and eight-mask conditions. The location errors in the invalid condition were, however, surprisingly large (23.48%). The problem might be that in this condition, the subjects had to remember the target location, as distinguished from the miscued location. Confusion might have occurred, producing the wrong responses. In this condition, the probability of correct identification given wrong location is 53%, more than double

⁷ One-way analyses of variance were used for testing these effects. To avoid the inflation of false alarms due to multiple comparisons, the significance level of all of the follow-up F tests was set at .01.

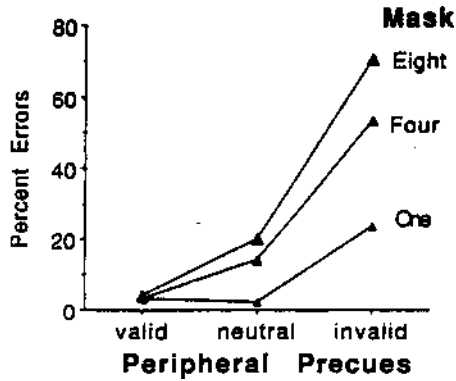


Figure 6. The percentages of location error as a function of (peripheral) precuing validity in Experiment 4. The results are shown separately for the one-, four-, and eight-mask conditions.

the chance level. Perhaps the subjects sometimes forgot the locations of the targets that they were able to perceive.⁸

The probabilities of identification conditional on correct localization were also computed and are shown in Table I.⁹ There was no significant effect of precuing, $F(2, 40) = 1.92, p > .1$. The $P(I | L)$ s in the neutral and invalid conditions were actually slightly larger than that in the valid condition. This contradicts the belief that valid precuing produces perceptual facilitation. On the other hand, the effect of mask was significant, $F(2, 40) = 4.54, p < .05$. The four-mask condition had slightly higher $P(I | L)$ than the other two conditions, but the latter two did not differ from each other. The Cue X Mask Conditions interaction had no significant effect on $P(I | L)$, $F(4, 80) = 1.49, p > .2$. In other words, most of the effects of precuing and mask vanished when conditional probabilities were considered.

The overall pattern of results is largely in line with the noise reduction hypothesis. It seems that mask numerosity and precue validity affect the overall identification accuracies primarily because they affect how likely a target would be correctly located. The deficit in identification accuracy was found when the probability of failure to locate the target was high. In those trials where the target could be located, there was no difference regardless of the validity of the precue. As far as the precue is concerned, it seems that it is only an indicator of location. When the location of the target is clear, as is the case when a single bright target appearing

against an empty background is followed by a single mask, this function is redundant, and it should cease to have an effect on identification.

General Discussion

Four experiments were conducted to investigate the nature of spatial precuing effects in single element displays. The results can be summarized in five main points:

1. There was no significant precuing effect (on identification accuracy) when a single target was followed by a single mask.
2. Precuing effects were found when there were multiple masks in the display. The effects got larger with more masks.
3. The masks had almost no effect when the target location was validly cued.
4. When the target location was not cued in advance, identification was impaired by the masks. The impairment got larger with more masks.
5. Validity of the precues and the number of masks had little effect on identification, given that the targets were correctly located.

In the following sections, we compare the present results with previous studies of spatial precuing in SEDs and then discuss the implications of our results for the understanding of spatial precuing effects.

Previous Reports of Precuing Effects

Our experiments reinforce the earlier findings by Grindley and Townsend (1968) and Nazir (1992) that spatial precuing does not affect discrimination accuracy with brief SEDs. They also show that the results of Henderson (1991; Henderson & Macquistan, 1993) are not inconsistent with the noise reduction models. There are others who also reported precuing effects in SEDs, however. We consider explanations for their results in terms of the noise reduction model.

Van der Heijden. Van der Heijden, Brouwer, and Serlie (1992) reported results consistent with the noise-reduction hypothesis. In their first experiment in which there was significant precuing effect (relative to a neutral condition), the target stimuli were yellow letters presented against a white background. Although posttarget masks were not used, performance was kept below ceiling by having the

Table 1
Percentages of Correct Identification Conditional on Correct Location for the Valid-, Neutral-, and Invalid-Cue Conditions in Each Mask Condition (Experiment 4)

Mask	Cue			M
	Valid	Neutral	Invalid	
One	70.15	73.18	70.86	71.40
Four	71.81	74.15	77.66	74.54
Eight	70.38	71.94	72.24	71.52
M	70.78	73.09	73.59	72.49

⁸ With invalid precues, the probability of correct identification given wrong location was 43.6% and 42% in the four-mask and eight-mask conditions, respectively, 10% lower than that in the single-mask condition. The higher accuracy in the single-mask condition might be attributed to those trials where the targets were correctly identified and located, but their locations were forgotten when the responses were made.

⁹ Two subjects' data were excluded from the analysis of conditional probabilities because one did not make any and the other made only one correct location judgment in the invalid four- and eight-mask conditions. Discarding these two subjects would not change the results of the analyses of probabilities of identification and probabilities of location.

color of the letter so pale that it was difficult to discriminate a letter from the background. When the same letter was circled by a gray ring in Experiment 2, there was no observable cuing effect. According to the noise-reduction model, when the yellow letter is hardly separable from the background, the white background produces confusable noise. When the letter is clearly marked by a gray ring, the target location is so distinct that the cues would not have any effect.

Van der Heijden et al. (1992) also asked their subjects to report the location of each target. As one would expect from the noise reduction account, location errors were more frequent in the neutral condition than in the valid condition in the first experiment without a gray ring. With a gray ring, however, location errors were almost absent in either precuing condition. In their study there is once again the coupling of noisy background, location uncertainty, and precuing effects.

Earlier, Van der Heijden et al. (1985) reported significant precuing effects with SEDs, although the magnitude of their effects were very small. Their subjects were asked to identify a letter that could appear in one of five locations. A valid cue improved identification accuracy by 3.2%, compared to a neutral-cue condition. They did not have masks in any position following the exposure of the target but relied on a brief, low-intensity display. So the source of noise could not be the mask. The problem might lie, instead, in the neutral precues. In this condition, a dot was put up at each of the five locations. With a dim target exposed for 4 to 16 ms and a cue-target SOA of 50 or 100 ms the bright dots might have introduced noise. This noise seems unlikely to be large in magnitude, but it may well be sufficient to explain the small benefit observed with the valid cues, relative to the neutral cue condition.

Van der Heijden et al. (1987) used the same neutral cuing technique. The benefit of a valid cue was again small (3.5% in Experiment 2; no benefit in Experiment 1 unless the target was 3° of visual angle from fixation, in which case benefit was 18.7%, atypically large compared to Experiment 2). It will be interesting if the same experiments are repeated with another type of neutral cue, for example, a single dot at the center of the display. Perhaps investigators ought to be cautious about putting up extraneous objects (e.g., outlines of boxes) on displays used to investigate spatial precuing effects in SEDs.

Van der Heijden (1992) commented on the difficulty of obtaining spatial precuing benefit in recognition accuracy of a single item. He remarked that "the targets need to be presented in a degraded way: a low luminance or target-background contrast, a short exposure duration, a position at some distance from the fixation point" (p. 85). If Van der Heijden is right, the key to obtaining precuing effects in single-element displays without masks is to make the targets barely distinct from the blank background. Van der Heijden also mentioned that they had tried degrading the target with backward masking and did not observe precuing effects (e.g., Van Werkhoven, Wolters, & Van der Heijden, 1986, and Fleur, Lapre, Van der Heijden, & Wolters, 1986; both

cited in Van der Heijden, 1992). These claims are entirely consistent with the noise-reduction hypothesis.

Egly and Homa (1991). Egly and Homa's experiments required discrimination of a single letter (*R/L* or *X/O*) appearing in a blank field. Most of the targets appeared at 4° eccentricity for 50 ms, without backward masks. Egly and Homa found a significant difference between valid and invalid spatial precuing in both RT and accuracy. The differences were proportional to the spatial distance between the expected and unexpected locations. This distance effect was the same whether or not a meridian was crossed. The cuing effects were larger for *R/L* discrimination than for *X/O* discrimination.

It is not clear why they obtained very different results from ours. One difference between the two sets of experiments was that Egly and Homa (1991) did not use masks. Their discrimination task seems easy, and without backward masking it is puzzling why their subjects made any error at all, unless performance was limited by other factors. Recall that Van der Heijden (1992) remarked that in SEDs without masks, the stimuli need to be degraded in order to obtain significant cuing effects. Egly and Homa did not report the contrast level of their stimuli. If they had used dim stimuli, then their results would fall into the same category as those of Van der Heijden and coworkers.

One problem of omitting backward masks is the possibility of eye movement. Egly and Homa (1991) did not describe what was done to insure that eye movements could not have affected their results. Notice that the duration from the onset of the cue to the offset of the target was 167 ms. Eye movement toward the target might possibly help performance, if the phosphor did not decay fast enough.¹⁰ Egly and Homa used P31 phosphor, which is generally regarded as fast decaying, although recently there was a debate about its persistence (see Groner, Groner, Müller, Bischof, DiLollo, 1993; and Westheimer, 1993).

It should also be mentioned that Nazir (1992), who reported no effect of precuing on a gap-resolution task, did not describe how eye movements were controlled, either. However, this is not a serious problem for Nazir's results, because eye movements are a possible spurious cause of spatial precuing effects, but cannot be a cause for the absence of these effects. If Egly and Homa's (1991) results were obtained with high-contrast stimuli and not contaminated by eye movements, then they may provide evidence that spatial precuing might have effects beyond noise reduction.

Prinzmetal, Presti, and Posner (1986). Although they did not exactly deal with SEDs, the experiments by Prinzmetal et al. are also relevant here. Their subjects were asked

¹⁰ This suspicion is encouraged by the fact that the "attentional" system they described is rather like an eye-movement system: (a) its speed of reallocation is a function of spatial distance, (b) its effects increase as the discriminations increase in difficulty, and (c) it shows no meridian effects. Of course, we have no way of knowing whether eye movements in fact occurred. Without ruling out this possibility, however, these findings do not unequivocally suggest covert resources reallocation, either.

to detect a pink *X* among several blue *X*s, pink *O*s, or blue, *O*s. The whole array consisted of four letters and appeared in one corner of the screen. The location of the array was cued validly or invalidly by a preceding spatial cue. In other words, a valid cue reduced the location uncertainty of the target from 16 to 4. Because the empty corners were also masked, it might be expected that the invalid condition should be less accurate. In the first experiment, they did not find such effects in the hit rates. There were more false alarms in the invalid condition, however.

There were two types of false alarms. A feature false alarm was counted when one of the features reported had not been presented in the display. A conjunction false alarm was counted when one of the features reported belonged to the nontargets.¹¹ The interesting finding was that in the second and third experiment, the numbers of feature errors in the valid and invalid conditions were the same, but still there were more conjunction errors in the invalid condition. This suggests that in addition to excluding the irrelevant locations, valid precuing may prevent illusory feature conjunction at the selected location.

Whereas their findings are important to the understanding of spatial precuing effects, they might not generalize to true SEDs. Conjunction false alarms, which imply that a feature of a distractor is incorrectly conjoined with a feature of the target, would not occur in SEDs, where a target is accompanied by no distractor. To avoid such errors, the distractors need to be excluded. Perhaps knowing in advance the location of a forthcoming array of letters makes it easier to perform finer exclusion within the array. This sort of exclusion, however, might not be required when only a single object is presented.

Benefits of Valid Precuing

In the present experiments, the benefits of valid precuing (with multiple masks) were often small and insignificant. This is true regardless of whether the neutral trials were blocked (Experiment 1) or mixed with the valid and invalid trials (Experiment 3). The benefits seemed to get larger when the number of masks increased from four to eight (Experiment 4), which, according to noise-reduction models, might have increased the probability that some noise would be mistaken for a target. Henderson (1991; Henderson & Macquistan, 1993) reported a larger benefit of valid precuing than we did. Notice that they used masks that were the two target letters superimposed. Their masks seemed to be more confusable with their targets than ours were with our targets. This difference may explain why they found larger benefits than we did.

In addition, in both Henderson (1991; Henderson & Macquistan, 1993) and Van der Heijden et al. (1985, 1987), in which benefits of valid precuing were reported, the neutral conditions involved a peripheral cue at each of the possible target locations. These cues might have made a target less discriminable from the other supposedly empty locations. This might have impaired the accuracy in the neutral condition, making the valid condition relatively bet-

ter. This problem, however, did not exist in the present experiments, because the neutral cues appeared at the fixation location.

Taking into consideration these two features in experimental setup seems to provide a fairly consistent picture across studies. Van der Heijden et al. (1985, 1987) used a neutral precuing technique that might have impaired the neutral condition, without masking. They obtained a small though significant benefit of valid cuing. Henderson (1991; Henderson & Macquistan, 1993) used confusable masks in addition to this neutral cuing technique. They obtained more sizable benefits. When we did not use either, we found small benefit of valid precuing.

Signal Enhancement or Noise Reduction?

Spatial precuing effects are commonly taken to reflect localized changes of perceptual sensitivity due (solely) to differential allocation of attentional resources. This interpretation involves two claims. First, valid precues summon attentional resources to the target location whereas invalid precues withdraw attentional resources from the target location. Second, the distribution of attentional resources is determined by the number of locations to be monitored and is initiated as soon as the precue appears. If the first claim is true, precuing should produce effects even if the target appears without distractors. If the second claim is true, precuing effects should be independent of the masks that appear after the target. The present results show that neither of these claims can be sustained.

Instead, the present results favor a simpler model that assumes that a precue allows nontarget information to be excluded from the decision. With a blank field and a single target followed by a single mask, exclusion cannot help performance, so the validity of the precues does not matter. Thus far we have not been very explicit about the locus of exclusion. This is quite deliberate, because noise reduction could potentially occur before or after stimuli are identified. The major point of departure from the signal enhancement hypothesis is that this account does not assume any changes in perceptual efficiency of the cued objects. Of course, noise reduction and signal enhancement are not mutually exclusive. It is conceivable that precuing might serve both functions. The results we obtained, however, provide no evidence that there is any effect other than noise reduction.

This conclusion about spatial precuing effects may have considerable generality. In the context of MEDs, a recent analysis by Palmer et al. (1993) showed that display set size effects in visual search of simple features can be fully explained by an increase in decision noise. The authors found no indication that perceptual efficiency suffers from dividing attention as the distractors increase in number, reinforcing the conclusion of Shiffrin and Gardner (1972). They also found that precuing the location of the target in such contexts improved detection accuracy to just the extent

¹¹ This is the definition they used for Experiment 3. The definition differed slightly for Experiments 1 and 2.

as one would expect if decision noise was being reduced. Thus, it seems that spatial precuing may operate by noise reduction, instead of signal enhancement, in both SEDs and MEDs, at least when the stimuli are simple features or characters.

Modifications of Enhancement Models

The present results alone probably would not be sufficient to rule out all possible models that assume that spatial precuing enhances the signal by pooling attentional resources. One may be able to come up with exotic variants that need to be considered. Nevertheless, the finding that there is little spatial precuing effect with single target and single mask imposes severe constraints on what kind of capacity models would be viable.

To uphold the view that spatial precuing produces differential distribution of processing capacity and to explain why this distribution produces no observable effect on stimulus identification (with single mask), one may argue that either (a) the task is not demanding enough to reveal capacity effects, or (b) reallocation of capacity takes place so fast that an invalidly cued stimulus enjoys as much resources as a validly cued stimulus does.

Adopting the first explanation, however, would make a capacity model unable to account for any precuing benefits (e.g., as found with multiple masks). The second explanation deserves more serious consideration. It is possible that when a target stimulus appears alone in an empty field and is followed by a single mask, resources can be allocated to the correct location quickly enough to be there when they are first needed. Perhaps the sudden onset of the target captures resources especially quickly (Yantis & Jonides, 1984, 1990). In case capacity is misdirected to a wrong location by an invalid cue, it may be reallocated very fast, almost instantaneously (Cheal & Lyon, 1989; Lyon, 1990) to a correct location. This view may be called the instantaneous allocation hypothesis (although obviously no mental processing can be truly instantaneous).

To explain the precuing effects found with multiple masks, this hypothesis would have to assume that somehow the irrelevant masks, which appear shortly after the target, have engaged capacity or hindered its reallocation. As a result, a validly precued object would have been given a larger share of capacity than a noncued object. When these masks are removed, capacity can be allocated freely to the single target; consequently, the target always enjoys full capacity, whether or not its location has been precued.

This instantaneous allocation hypothesis seems to be the only alternative capacity model that can account for the present results. Notice that the notion of rapid reallocation contradicts the usual explanations of spatial precuing effects that assume either analog movement of an attention spotlight across space (e.g., Tsai, 1983), or gradual pooling of resources (e.g., Cheal et al., 1992). It also contradicts the assumption that an empty space consumes attentional resources.

This modified hypothesis, however, still faces a severe problem. Shiffrin and Gardner (1972), it should be recalled,

found comparable performance with successive presentations of two pairs of letters and simultaneous presentation of four letters. Because the two successive presentations were separated by an interval of 500 ms, there should have been plenty of time for reallocation of any putative capacity. If rapid capacity reallocation takes place, as the instantaneous allocation hypothesis asserts, then each character in the successive presentations should have shared half the capacity, and thus received enhanced processing compared to the simultaneous presentation, where each character would have only one fourth of the capacity. The absence of successive advantage indicates that rapid reallocation probably does not occur. If one tries to back out of this by saying that the simple characters are processed equally efficiently with one-half capacity and one-quarter capacity, then one has redefined capacity so completely that it cannot offer any explanation of precuing effects.

Thus, we are at a loss to formulate a reasonable version of the signal enhancement hypothesis that can explain the absence of precuing effects in SEDs together with other key results in the literature. If this is correct, the rather natural explanation in terms of noise reduction should be preferred.

Cuing and Spatial Uncertainty in Threshold Tasks

It has been known for quite a long time that detection of a near-threshold stimulus is worse when the location of the stimulus is random than when it is fixed (Cohn & Lasley, 1974; Davis et al., 1983). Uncertainty about other parameters of the stimulus, such as spatial frequency, orientation, direction of motion, and so on, also elevates the detection threshold (Ball & Sekuler, 1981; Davis et al., 1983; Graham, Kramer, & Haber, 1985). In auditory detection, frequency uncertainty effects have been intensively investigated since the 1950s (e.g., Green, 1961; Veniar, 1958a, 1958b; and see review by Swets, 1963). Uncertainty effects can be removed by a precue (e.g., before the first interval of a two-interval two-alternative task) that specifies a parameter (location, orientation, or spatial frequency) of the to-be-detected stimulus (e.g., Davis et al., 1983).

When the parameter is not specified, multiple mechanisms that are responsive to the stimuli to variable degrees must be monitored. This will inflate the probability that just by chance the noise in one of the mechanisms will exceed its threshold and produces a false alarm. Because the magnitude of uncertainty effects is generally no greater than what is predicted from this account, there is no need to postulate decrements due to capacity limitations in monitoring multiple mechanisms.

This account of spatial uncertainty effects assumes that when monitoring for a near-threshold signal, even an empty location introduces substantial noise. When the level of noise is minimal in comparison with the strength of the signal, as when a suprathreshold signal is presented against a blank background, the model predicts that there will not be much effect of spatial uncertainty, because the activity in the mechanism most sensitive to the signal would exceed those in the noise mechanisms so much that the probability

of the noise mechanisms evoking a false alarm would be very small.

Our results with the single-target single-mask condition confirm that spatial uncertainty does not affect discrimination of suprathreshold stimuli (see also Nazir, 1992). The targets we used were clearly above detection threshold, so that the empty background was unlikely to produce a false alarm that a target had been presented. However, effects of spatial uncertainty can be produced by elevating the noise level, for example, by filling the empty locations with posttarget masks, which are not perfectly discriminable from the target. Noise is also introduced when a target is accompanied by distractors. The benefit of valid precuing in such situations may be, therefore, nothing more than reducing the probability that one of the distractors is being mistaken for a target (cf. Palmer et al., 1993).

Noise Reduction and Response Bias

The distinction between noise reduction and signal enhancement is sometimes confused with the distinction between sensitivity change (as indicated by d' , for example) and criterion shift (i.e., response bias, as indicated by β , for example). There are suggestions in the literature that any attentional effects at the decision level must primarily be reflected in changes in response bias but not in sensitivity (e.g., Bashinski & Bacharach, 1980). This is a misconception. Reduction of decision noise may produce improvement in an overall sensitivity measure such as d' in some paradigms (e.g., Cohn & Lasley, 1974), but not in others (e.g., the single-target single-mask condition in the present study). Let us consider several cuing paradigms and ask how a cue might affect performance in each of them.

Consider first a speeded detection paradigm. Here, valid precuing produces a faster response than neutral or invalid precuing to the onset of a single suprathreshold target (e.g., Posner et al., 1980). We have pointed out that eliminating decision noise in such displays should not have much effect on the perception of the target. Instead, the improvement in RTs with valid precues may be achieved by requiring less evidence at the cued location to trigger a response (e.g., Shaw, 1984; Sperling & Doshier, 1986). Because evidence accumulates gradually over time, shorter RTs result. If this explanation is correct, then precuing in this paradigm produces criterion shift but no improvement in accuracy of detection.¹²

In threshold detection in which response accuracy is measured without speed stress (e.g., Bashinski & Bacharach, 1980), changing the decision criterion in accordance with the precues would not help performance, because target presence and absence are equally likely regardless of precues. In this paradigm, however, the blank field is confusable with a target, and spatial precuing allows exclusion of noise. A precue indicates the location most likely to contain task-relevant information. To make the best use of this cue, an ideal observer should consider the cued location as if it contains the information needed for the decision, and exclude the other locations. In other words, one should let

the decision depend mostly on the information derived from that particular location. The optimal "weighting" factor is a function of cue validity. In an extreme case of 100% valid precues, for example, one should report *yes* if one finds a signal at the cued location, and *no* if not.

Given that the noise from the irrelevant locations could be excluded or discarded from the decision, false alarm is less likely than when all possible locations have to be considered (i.e., the neutral condition). This would produce gain in overall detection performance, for example, as measured in $P(A)$ or d' (e.g., Bashinski & Bacharach, 1980; Cohn & Lasley, 1974). Performance gain with noise reduction could be achieved without changes in decision criterion although a more liberal decision criterion for the cued location has sometimes been observed (e.g., Hawkins et al., 1990). Notice that the method used in these studies to measure β may be controversial (see Footnote 12). Assuming the measurement is correct, the results may suggest that having a location expectancy confirmed has some extraneous effects on false detection.

In suprathreshold discrimination with a target surrounded by noise (e.g., distractors or masks), valid precuing may help discrimination by allowing exclusion of the noise as a possible source of task-relevant information, very much like it does in threshold detection. In this paradigm, the precues are still neutral as to what the correct response is. But they predict where a target will be. Hence, an observer is induced to accept whatever information can be derived from that location as evidence for a target (see the Results and Discussion section of Experiment 3). This is a bias (which changes the localization criterion discussed in Footnote 5), but it is "rational" given that a cue is predictive of the location of a target. This bias does not favor any particular identification response. It is certainly not the kind of bias indicated by β in presence-absence judgments. This bias should not exist in threshold detection because the cued location is equally likely to contain or not to contain a signal. In a discrimination paradigm in which a target appears on every trial, however, the cued location contains a target more often than not.

Exclusion of decision noise with valid precuing can improve discrimination performance (without affecting the identification decision criterion), if there is noise to be excluded. When a suprathreshold target is the only object on

¹² The speedup in response with valid precues is expected to be associated with an elevated false-alarm rate at the cued location, *had it been measured*. In signal detection paradigms, however, the validity of the precues loses meaning on the target-absent trials and there is no good way to assign the false alarms to a cued or an uncued location (see Muller & Findlay, 1987, and Hawkins et al., 1990, for a discussion of this problem). Simply measuring the overall false-alarm rate may not reveal evidence of criterion shift, because the inflated false alarms at the cued location are compensated for by the reduced false alarms at the other locations. The compensation may even exceed the inflation, depending on a number of task parameters, including the number of locations to be monitored.

¹³ This view is similar to that of Shaw (1984) and Sperling and Doshier (1986).

a blank screen (i.e., no extraneous objects including masks), the blank locations, which are so different from a target, would not be able to affect the identification response to any significant extent, no matter how much or how little weight they are given in the decision. Spatial precuing in this context can, as our experiments showed, cease to have any effect, either.

In summary, spatial precuing effects attributable to noise reduction could produce improvement in overall task performance in some paradigms, depending on what is there to be excluded. The improvement could be independent of criterion shift. This is not to say, of course, that precuing would never produce criterion shift in any paradigm. Decision criteria could well be lowered for the cued location when speed of response is stressed. This criterion shift need have nothing to do with noise reduction.

Implications for Masking

The suggestion that a mask may produce noise at a decision level does not contradict the usual assumption that masking curtails perceptual processing (Turvey, 1973). In the present experiments, masking both the target and non-target locations seems to have made the empty background more confusable with the target than it would be otherwise. This may be caused by the mask being integrated with the stimulus (either a target or a blank field), or by the mask interrupting and "overwriting" the perceptual encoding of the stimulus. Either way, the masks seem to be a source of additive noise (Sperling, 1990), which lowers the signal-to-noise ratio and renders the discrimination between target and blank field more difficult.

Questions for Further Study

As noted above, the observations of Shiffrin and Gardner (1972) and others suggest that identification of several simple, highly familiar characters is not subject to capacity limitations. More complex visual search tasks (e.g., detecting words or certain feature conjunctions) sometimes show sizable successive-display advantages (Duncan, 1985; Kleiss & Lane, 1986), suggesting that these tasks are capacity limited. This does not necessarily imply that they would benefit from spatial precuing when the stimulus to be discriminated is displayed against a blank field. We have begun investigating this issue.

A number of investigators have reported spatial precuing effects in speed of discrimination responses using SEDs. Their results, however, do not necessarily contradict our findings with discrimination accuracy. First, it is open to question whether improvement in RTs must reflect genuine improvement in perceptual sensitivity. If the explanation suggested by Shaw (1984) and Sperling and Doshier (1986) with regard to spatial precuing in simple RTs can be generalized to other speeded tasks, then faster discrimination RTs may be a consequence of criterion shift (i.e., in that case, trading speed with accuracy).

Second, even if the improvement in discrimination RTs is genuine, it may still be reconciled with the finding of no improvement in discrimination accuracy. Perhaps a spatial precue determines the order of entry of the information into a decision mechanism (e.g., Müller & Humphreys, 1991). When there is just a single stimulus, the delay of entry into the decision mechanism due to lack of accurate advance location information (in neutral and invalid precuing) may not be long enough to produce deficit in response accuracy, but sufficient to produce slight decrement in response time.¹⁴ This model predicts that precuing effects in SEDs would only be revealed in speeded tasks. Further investigations are needed to settle these issues.

Conclusion

At present, it would seem to be a reasonable working hypothesis that providing a valid precue about the location of a target that appears alone in an otherwise empty field simply allows irrelevant information to be excluded from the decision. This may or may not improve performance, depending on what is there to be excluded. Further studies are needed, however, to see if the results generalize to more difficult perceptual discriminations, and to reconcile them with the findings of studies using response time as the dependent variable.

¹⁴ Here, it is assumed that the input from every one of the possible target locations, empty or filled, needs to be considered by the decision mechanism. Although the input from an empty location would not cause any decision error no matter what weight it is given, the decision mechanism may be very briefly occupied before the target is being considered. This could produce a small effect in RT comparable to those observed in many single-target cuing experiments (e.g., Eriksen & Hoffman, 1974).

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