Journal of Experimental Psychology:
Human Perception and Performance
1996, Vol. 22, No. 3, 780–787

0096-1523/96/$3.00

OBSERVATION

Spatial Precues Affect Target Discrimination in the Absence of Visual Noise

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In 2 earlier sets of experiments, the author reported that shape discrimination in an otherwise empty visual field is facilitated when the target shape is preceded by a valid spatial precue (J. M. Henderson, 1991; J. M. Henderson & A. D. Macquistan, 1993). L. Shiu and H. Pashler (1994) recently suggested that these earlier results were due to the presence of multiple posttarget pattern masks. They concluded that precue effects are observed only when visual noise is present. The author reviews the existing evidence and presents new data supporting the view that spatial precues influence shape discrimination in the absence of visual noise, consistent with a limited capacity conception of visual–spatial attention.

A fundamental question in the study of human visual cognition is how we are able to select a particular stimulus from among the many stimuli that are constantly impinging on our visual receptors. This ability to direct visual–spatial attention toward a location or object often involves overt movements of the body, as when we rotate our eyes and head to orient the receptor-rich fovea toward a visual target (Rayner, 1978; Yarbus, 1967). In addition, we have the ability to orient visual–spatial attention covertly by way of neural systems that select internally without corresponding body movements. The evidence for this covert selectivity derives from behavioral, neuroanatomical, and neuropsychological investigations (Johnston & Dark, 1986; Posner & Petersen, 1990).

A controversial issue in the behavioral study of visual–spatial attention is whether the presentation of a spatial precue can influence visual processing when a target appears in an otherwise empty visual field. This issue is important because it bears on the manner by which attention exerts its influence. According to the *limited-capacity* hypothesis, spatial precues exert their influence on visual processing by directing a limited capacity system to the appropriate location or object in the visual field (e.g., Eriksen & St. James, 1986; LaBerge & Brown, 1989; Posner, Snyder, & Davidson, 1980). By directing the limited-capacity system to the stimulus, visual analysis of that stimulus becomes possible or enhanced. According to the limited-capacity hypothesis, spatial precues should exert an influence on the visual analysis of a briefly presented target even when that target appears in an otherwise empty field. In contrast, according to the *noise reduction* hypothesis, spatial precues produce their effect by allowing for the exclusion of noise in the visual field that would otherwise interfere with stimulus processing (Palmer, Ames, & Lindsay, 1993; Shaw, 1984; Shiu & Pashler, 1994). According to the noise-reduction hypothesis, spatial precues should exert an influence on the processing of a target only when the target appears in the presence of potentially confusable visual noise.

Early investigations suggested that spatial precues produce no or, at best, small effects on target processing when the target appeared in an otherwise empty visual field (e.g., Grindley & Townsend, 1968; Posner, 1980), and hence were consistent with the noise-reduction hypothesis. In contrast, more recent experiments have provided evidence that spatial precues can exert reliable and robust effects on the accuracy of visual shape discrimination when the target appears in an otherwise empty field (Egly & Homa, 1991; Henderson, 1991; Henderson & Macquistan, 1993). In our experiments, the participant's task was to determine which of two simple visual forms (an X or an O) had appeared at one of eight (Henderson, 1991; Henderson & Macquistan, 1993) or one of four (Henderson & Macquistan, 1993) locations falling on an imaginary circle centered at the fixation point. On each trial, a peripheral precue was presented for 100 ms at one or two of the potential target locations (or, in the case of a neutral condition, simultaneously at all of the potential target locations) prior to presentation of the discrimination target. The target was presented immediately following the offset of the precue. The participant's task was to press a button to indicate

I would like to thank Karen McClure for her assistance in data collection for the experiment reported here. I would also like to express my appreciation to Glyn Humpreys, Ling-Po Shiu, and Harold Pashler for their comments on an earlier version of this article. The research reported here was supported by an All University Research Initiation Grant from Michigan State University and by a grant from the Department of the Army, Army Research Office. The contents of this article are those of the author and should not be construed as an official Department of the Army position, policy, or decision.

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which of the two forms had appeared as the target on that trial. The target was displayed for either 67 or 50 ms and was immediately followed by pattern masks (made up of the superimposition of the X and O targets) at each potential target location. A central finding in these experiments was that discrimination accuracy was higher at the cued location compared with other, noncued locations (Henderson, 1991; Henderson & Macquistan, 1993). On the basis of this result and the function relating performance to spatial distance between the precue and the target, we concluded that a gradient model of attention (e.g., Downing & Pinker, 1985; LaBerge & Brown, 1989; Shulman, Wilson, & Sheehy, 1985) best accounted for our data.

Recently, however, Shiu and Pashler (1994) reported new results that challenge the results and interpretation of Henderson's (1991; Henderson & Macquistan, 1993) experiments. The nature of the challenge centers on a methodological issue: In several of these experiments, a brief presentation of the target was immediately followed by presentation of posttarget pattern masks at each potential target location. These masks were composite stimuli created by overlapping the two possible targets (X and O). Shiu and Pashler (1994) suggested that perhaps the masks were confusable with the targets, and therefore selection by way of the precue was useful for reducing the noise caused by these confusable objects. In support of this hypothesis, Shiu and Pashler (1994) conducted several experiments in which they manipulated the presence of confusable masks. They found that when a single mask was presented at the target location following a single target in an otherwise empty field, there was no effect of a precue. When multiple masks were displayed (a mask at each potential target location), however, so that confusion about the identity of the target versus the masks was possible, clear effects of the precue were observed. On the basis of these results, Shiu and Pashler (1994) suggested that the precue effects in our earlier experiments (Henderson, 1991; Henderson & Macquistan, 1993) were caused by the use of multiple posttarget masks.

Shiu and Pashler (1994) argued that their finding is important because it poses a challenge to models of attention that are based on the notion of limited capacity. In their view, capacity models embody three assumptions: (a) A limited pool of processing resources (attention) exists that can be allocated to spatial regions of varying size, (b) perceptual processing is conducted in parallel within the attended region, and (c) processing quality, rate, or both is a function of the amount of resources allocated to a given region.[1] As an alternative to capacity models, Shiu and Pashler (1994) argued that our effects (Henderson, 1991; Henderson & Macquistan, 1993) were due to noise reduction. According to Shiu and Pashler (1994), there are no capacity limits in visual processing. Instead, precue effects are observed because under brief exposure conditions targets can be confused with distractors. In this view, a precue allows the noise to be "excluded, attenuated, or weighted less in the decision." (Shiu & Pashler, 1994, p. 1039). Because capacity models assume that attention is allocated within the visual field on the basis of the precue regardless of whether there are other distractor or noise elements in the display, they predict an effect of a precue on target processing regardless of whether visual noise is present or not. Noise reduction models, in contrast, assume that precues allow the system to ignore potentially distracting noise and, therefore, predict that precue effects should only be observed when potentially confusable visual noise is present.

Shiu and Pashler (1994) discussed two other studies that they took to be consistent with their finding that spatial precues do not produce effects on shape discrimination when a single target is presented in the absence of noise. The first is a study by Grindley and Townsend (1968, Experiment 1). In that experiment, participants were given a 100%-accurate verbal cue concerning in which of four possible locations a "T" was to appear. The participant's task was to report the orientation of the target. In one condition, the target appeared with three "+" distractors, and in another condition, the target appeared in an otherwise empty visual field. In neither case were masks presented following the target. For our purposes, the main finding was that there was a robust precue effect when the target appeared with distractors, but no effect when the target appeared alone. Thus, on the face of it, these data support the Shiu and Pashler (1994) contention that precue effects will not be observed when single targets appear in a noise-free field. However, a number of criticisms have been directed at the Grindley and Townsend (1968) study (e.g., van der Heijden, Schreuder, & Wolters, 1985). Two points are most relevant here. First, Grindley and Townsend (1968) could not compare performance at the cued and uncued locations, because the cues were 100% valid. Instead, the comparison involved cue versus no-cue blocks, which are believed to lead to smaller precue effects (Posner et al., 1980). Second, the conclusion entailed acceptance of the null hypothesis, and the statistical power of the study may have been inadequate to detect precue effects in the single-item display (van der Heijden et al., 1985).

The second study discussed by Shiu and Pashler (1994) was conducted by Nazir (1992). In this experiment, participants were presented with a target square containing a gap in one of the four sides. The target could appear at one of eight positions around the fixation point. At the time of target presentation, the target either was alone in the visual field or was surrounded by four identical lateral masks. The similarity of the mask to the general target shape was manipulated. In the precue condition, a peripheral cue was presented for 100 ms at the target location prior to target onset, whereas in the no-cue condition, no precue was shown. The results indicated no effect of the precue. Shiu

[1] One could hold a capacity model that does not posit variable spatial extent (e.g., a fixed spotlight) does not assume parallel processing within the attended region (e.g., capacity determines the probability of opening a channel in a given location, LaBerge & Brown, 1989, but only a single channel can be opened), and does not affect the rate of processing or quality of the representation in the region (e.g., capacity determines in an all-or-none fashion whether a representation is formed). The Shiu and Pashler (1994) characterization appears to apply most directly to the zoom-lens model of Eriksen and St. James (1986).

and Pashler (1994) interpreted these results as support for the noise-reduction hypothesis because the target appeared without distractors, and no effect of precue was observed. Again, however, there are two problems with this experiment that are very similar to the problems with Grindley and Townsend (1968). First, cue condition was a between-block manipulation and precue effects are reduced when manipulated this way. Second, the conclusion is based on acceptance of the null hypothesis. The latter problem is particularly acute given that the results were based on data from only 3 participants, and 2 of the 3 participants showed facilitated performance in the precue condition. In addition, there is a third potential problem: Despite the large mask effect observed by Nazir (1992), with gap detection accuracy decreasing as the similarity of the mask to the target increased, mask similarity did not interact with the precue condition. The noise-reduction model would seem to predict such an interaction, because as the similarity of the mask to the target increased, the level of noise in the visual field increased. To the extent that precues exert an influence by reducing visual noise, an increasing effect of the precue would be expected as the noise level increased. Of course, this null result might again be the result of the lack of statistical power, but if so, the study offers no support either for or against capacity or noise-reduction models.

In summary, Grindley and Townsend (1968) and Nazir (1992) reported a combined total of two experiments addressing the issue of precue effects on shape processing. Both experiments used inadequate precue manipulations, both suffered from inadequate statistical power, and both based their conclusions on acceptance of the null hypothesis.

In the remainder of this article, I discuss the support for the claim that precue effects can be observed on target discrimination in an otherwise empty field. This discussion comprises three parts. First, I review the evidence demonstrating precue effects on shape discrimination when the target appears alone in the visual field and without multiple posttarget masks. This review focuses on shape discrimination because the experiments at issue used that task. Second, I report the results of a new experiment demonstrating a precue effect on shape discrimination when a single target appears in an otherwise empty field and is followed by a single mask at the target location. Third, I offer some suggestions concerning why Shiu and Pashler (1994) did not find such an effect.

Evidence for Precue Effects on Target Discrimination in the Absence of Visual Noise

Response Time in Forced-Choice Shape Discrimination

One way to circumvent the problem caused by the presentation of multiple masks in a forced-choice discrimination task would be to present the target without masks and for a duration exceeding threshold so that accuracy is at ceiling level, and to measure response time. In fact, we have reported two such experiments (Henderson, 1991; Henderson & Macquistan, 1993). These experiments used paradigms that were identical to the experiments that displayed masks and measured accuracy, with the important difference that no masks were displayed. Thus, in these experiments, there was no visual noise either at the time of target display (the target appeared in an otherwise empty field) or after target display (an empty field was displayed until response). The important point for our purposes is that these previous experiments produced several specific patterns of data that were identical to those observed in the accuracy experiments that used multiple masks. First, discrimination accuracy (in the masked-presentation experiments) and response time (in both the masked- and unmasked-presentation experiments) were affected by the relationship of the target position to the precue position: Error rates and response times were lower when the target appeared at a cued location compared with an uncued location. Second, the facilitation produced by a valid precue was greater at the cued location than at other nearby locations. Again, this effect was true in both the masked- and unmasked-presentation experiments. Third, the effect of the cue was mediated by the size of the cue: A smaller, more spatially specific cue led to greater facilitation at the cued location and less inhibition at the uncued locations compared with a less spatially specific cue.

Shiu and Pashler (1994) argued that response time data are not useful for distinguishing between-capacity models and noise-reduction models because response time may reflect changes to decision criteria rather than to perceptual processing (Shiu & Pashler, 1994, see also Shaw, 1984). However, the high degree of similarity between the pattern of accuracy data from the masked-presentation experiments and the pattern of response time data from the unmasked-presentation experiments in our previous studies (Henderson, 1991; Henderson & Macquistan, 1993) strongly suggests that the effects of the precues in the masked-presentation cases were not due to the masks. Of course, one could always speculate that a precue invokes two different types of processes; one involving effects of noise reduction on target discrimination when masks are present, and the other involving decision bias on response time when masks are not present, and that these processes happen to produce similar patterns of data. However, such an explanation would constitute an unwarranted violation of parsimony, particularly given the complexity of the patterns observed.

Finally, it would be difficult to argue that the pattern of response time data in the unmasked-presentation experiments was due to the need to filter noise from unoccupied space, because the targets were far above discrimination threshold in those experiments (accuracy was generally close to 100% in all conditions, e.g., 98% in Henderson, 1991, Experiment 2, and 98% in Henderson & Macquistan, 1993, Experiment 3). One might speculate that there were small, undetected differences in the accuracy data that produced a speed–accuracy trade-off, thereby making the response time data uninterpretable (Shiu & Pashler, 1993). A reexamination of the accuracy data, however, indicated that the nonsignificant differences across conditions (ranging from 97% to 98%) exactly mirrored the response time data. Thus, there is no reason to discount the response time data.

Accuracy in Forced-Choice Shape Discrimination

Equally damaging to the noise reduction hypothesis is a demonstration of the effects of spatial precues on forced-choice discrimination accuracy in a set of experiments that did not use pattern masks. These experiments, reported by Egly and Homa (1991), were very similar in spirit to those reported by Henderson (1991). For example, in Experiment 1 of Egly and Homa (1991), a peripheral precue was presented at one of four potential target locations for 117 ms, followed by one of two target letters (R or L) in an otherwise empty field for 50 ms. A blank field immediately followed the target. Egly and Homa (1991) were primarily interested in the response time data, but they reported a reliable 10.2% difference in discrimination accuracy when the target appeared at the cued location versus at an uncued location. Similarly reliable effects were found in six of the seven experiments that Egly and Homa (1991) reported (ranging from 13.1% in Experiment 2 to 3.3% in Experiment 6). These data clearly indicate that reliable effects of spatial precues can be observed in a target discrimination task, even when the target appears in an otherwise empty field and no other potentially noise-producing stimuli are presented following the target. In addition, Egly and Homa (1991) found a robust 63-ms effect on response time in the one experiment (Experiment 3) that did not produce a reliable effect on accuracy. As discussed in the previous section, we have similarly observed response time effects in the absence of accuracy effects (Henderson, 1991; Henderson & Macquistan, 1993). Unfortunately, because Shiu and Pashler (1994) did not report response times, there is no way to determine whether similar effects were produced in their experiments.

Shiu and Pashler (1994) suggested that perhaps the Egly and Homa (1991) results were due to eye movements and phosphor persistence. The concern is that participants may have executed a saccade to the precued location, thereby facilitating performance for targets appearing at the cued location by means of increased visual acuity. Shiu and Pashler (1994) pointed out that this explanation naturally accounts for some of the other aspects of the Egly and Homa (1991) data, including the finding that performance decreased as the spatial distance between the precue and the target increased. However, there are two reasons for discounting this possibility. First, the time needed to program and execute a saccadic eye movement of 4° with conditions of spatial uncertainty make it extremely unlikely that the eye would reach the target prior to offset. Mean programming latency for such a saccade is about 200 ms, and the fastest saccades in the latency distribution are usually more than 150 ms (Fisher & Weber, 1993; Rayner, Slowiaczek, Clifton, & Bertera, 1983; Saslow, 1967). Second, the duration of a 4° saccade, excluding pre- and postsaccadic suppression, is on the order of 35 ms (e.g., Abrams, Meyer, & Kornblum, 1989). Thus, assuming that participants were moving their eyes as quickly as possible on each trial and that they were perfectly accurate and therefore had no need for corrective saccades, their eyes would not be expected to reach the target location for about 235 ms on average, or until 68 ms following offset of the target. Even on the trials with the fastest saccades, the eyes would not reach the precued location for about 185 ms, or 18 ms after the target had been extinguished. Given the lighting conditions used by Egly and Homa and the decay properties of the P-31 phosphor (Groner, Groner, Muller, Bischof, & Di Lollo, 1993; Westheimer, 1993), it is extremely unlikely that the results of Egly and Homa can be dismissed on the basis of eye movements and phosphor persistence. Ironically, phosphor persistence may well have been a problem in the Shiu and Pashler (1994) study, as I discuss in detail later.

Second, Henderson (1991; Henderson & Macquistan, 1993) observed effects that were very similar to those of Egly and Homa (1991), including performance gradients, with error rates and response times increasing with the distance between the precued and target locations. Because Henderson presented all displays in reverse video (cues and targets with pixels-off against a pixels-on background), these effects cannot have been due to phosphor persistence. The similarity of Henderson's results to those of Egly and Homa adds further evidence against the proposal that the results of the latter study were due to a combination of saccadic eye movements and phosphor persistence.

The convergence of the response time data from Henderson (1991; Henderson & Macquistan, 1993) with the accuracy and response time data from Egly and Homa (1991) provides a compelling case that precue effects can be observed in a target-discrimination task even when visual noise (from either distractor stimuli or multiple masks) is absent, and hence against the hypothesis that visual–spatial attention operates solely by means of noise reduction.

Signal-Detection Analyses

An additional source of evidence concerning the effect of spatial precues on visual processing derives from studies that used signal detection analysis. The assumption is that attention can have an effect either on a perceptual encoding or a decision stage. Precue effects on d' (or the nonparametric variant, A') are assumed to indicate that the quality of the perceptual representation has been affected by the precue, whereas changes to beta reflect criterion changes.[2]

[2] There may be some tendency to conflate the capacity versus noise-reduction distinction with the early versus late selection dichotomy. This would be a mistake. As Shiu and Pashler (1994) pointed out, visual noise could affect target processing either at an early stage where perceptual representations are formed, or at a later stage where representations are selected. Similarly, capacity models may place the capacity limitations early in the system, such as by boosting the gain on a particular perceptual pathway (e.g., Downing, 1988; Posner, 1980), or later, such as at the level of selecting a representation from among noise (Müller & Humphreys, 1991). Thus, both capacity and noise-reduction models seem capable of accounting for precue effects at either a perceptual or decision stage. An implication of this fact is that, whereas experiments using signal-detection theory are of interest for other

Although there has been controversy over whether precues can influence d' in a target detection task (Bashinski & Bacharach, 1980; Downing, 1988; Hawkins et al., 1990; Müller & Findlay, 1987; Müller & Humphreys, 1991; Shaw, 1984), the data clearly indicate that precues do affect d' in shape discrimination tasks (Downing, 1988; Müller & Findlay, 1987; Shaw, 1984). Unfortunately, these studies have included multiple targets, position markers, or both at all potential target locations. Because it may be that such markers introduce visual noise, these studies cannot be used to decide unambiguously between capacity and noise-reduction models.

Experiment: Precue Effects on Discrimination Accuracy With a Single Mask

The above review demonstrates that precue effects can be observed on shape discrimination when a target appears in an otherwise noise-free visual field. However, Shiu and Pashler (1994) did not find a precue effect when they followed target presentation in an otherwise empty field with a single mask at the target location. Therefore, the question remains whether it is possible to observe a precue effect when a shape discrimination target is followed by a single mask. This experiment was conducted to investigate this question.

Method

Participants. Eighteen undergraduate students at Michigan State University participated for credit toward their introductory psychology class. All participants had normal or corrected-to-normal vision, and all were naive with respect to the hypotheses under investigation.

Apparatus and stimuli. The stimuli were presented in black-on-white on a high-resolution color video monitor placed 35 cm from the participant. A chin and forehead rest was used to maintain viewing position and distance. The target stimuli were the letters X and O created in a 7 × 12 pixel matrix 1° of visual angle high and 44 min wide. The spatial masking stimulus consisted of the same two characters superimposed. The location cue was an underline 15 min high and 1° 20 min wide. The distance from the bottom of the target position to the top of the cue position was 30 min.

The stimuli could be displayed at any of the eight locations around an imaginary circle centered at the point of fixation. The eight locations were arranged so that two locations appeared in each quadrant of the visual field (see Figure 1 of Henderson & Macquistan, 1993). The center of each target location was 9° 41 min from the fixation point. Target locations were equidistant from each other, with about 7° 14 min center to center.

The stimuli and the display monitor used in this experiment were identical to those used by Henderson and Macquistan (1993), with the exception that a single mask was used rather than the simultaneous display of eight masks at all target positions that we have previously used.

Participants responded to the target by pressing one of two microswitches located on a table-mounted response panel. The response panel was interfaced with a dedicated input/output board; pressing a microswitch generated a system interrupt and stopped a millisecond clock on the input/output board. Stimulus presentation and response collection were controlled by an i386-based microcomputer.

Procedure. Participants were asked to make a judgment regarding the identity of a target stimulus viewed peripherally. Each trial began with the presentation of a central fixation cross along with markers indicating the eight possible target locations. When the participant was ready, he or she pressed a switch to start the trial. The central fixation cross was then presented alone for 1,000 ms, followed by the location precue for 100 ms, followed by a target stimulus (X or O) for 67 ms. A single mask at the target location followed presentation of the target and remained on the screen until the participant responded. The mask consisted of a superimposed X and O. Each display immediately followed the preceding display, giving an interdisplay interval of 0 ms. Each display was extinguished with the onset of the next display; the precue was removed when the target appeared, and the target was removed when the mask appeared. The fixation cross remained visible throughout the trial. The participant executed a forced-choice response by pressing one of two switches. The instructions stressed accuracy more than speed of response. After the response, there was an intertrial interval of about 2 s while the computer loaded the images for the next trial.

At the beginning of a session, participants were given a general overview of the procedure. The rapid nature of the visual events was discussed, and participants were encouraged to pay careful attention to the display on each trial. Participants were further informed that the events occurring on the screen were too rapid to allow them time to move their eyes to the target, and therefore their best strategy was to maintain fixation at the center of the screen.

The exogenous precues used in the present experiment were uninformative about the location of the target. Given a precue at a particular location, the target could appear at the cued location with a .25 probability, at the adjacent location within the same visual quadrant as the cue (defined by the horizontal and vertical meridians) with .25 probability, at the adjacent location outside of the same visual quadrant with .25 probability, and at the diagonally opposite location with .25 probability. These conditions were termed valid, within-quadrant invalid, across-quadrant invalid, and diagonal invalid, respectively. The experiment contained 192 trials determined by the factorial combination of 8 (target locations) × 4 (cue conditions: valid, invalid within, invalid across, invalid diagonal) × 2 (target type: X or O) × 3 (replications).

Each session began with the instructions, along with 20 practice trials, and one test block. The entire experiment lasted about 45 min.

Results

The primary dependent measure was accuracy, as indexed by the mean percentage of targets correctly identified in each condition. In addition, analyses were conducted on the mean response times for correct trials in each condition.

Accuracy. Figure 1 (top panel) presents the means and standard errors for percentage correct as a function of cue condition. A one-way analysis of variance (ANOVA) indicated that the effect of the precue was reliable, $F(3, 51) = 4.85$, $p < .01$. As can be seen in Figure 1, performance in the valid condition was reliably more accurate than in the three invalid conditions, whereas performance in the invalid conditions did not reliably differ.

Response time. Response time analyses included only

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reasons, they do not help to distinguish capacity from noise-reduction models of precue effects.

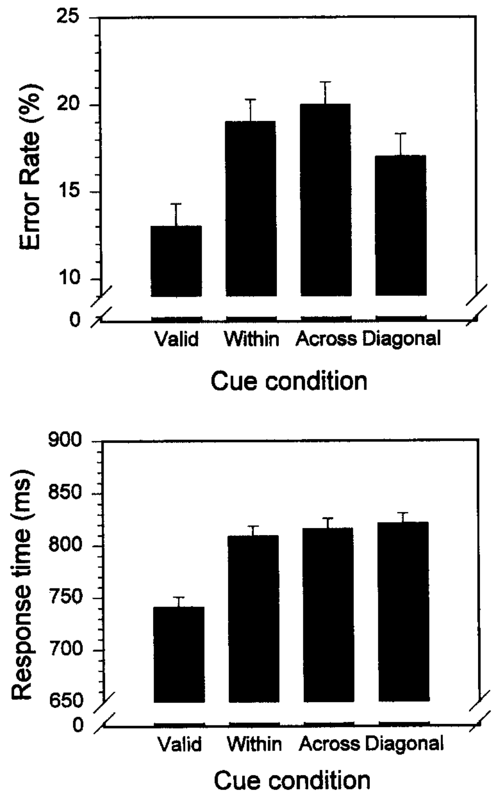

Figure 1. Data from a spatial cuing experiment in which a single posttarget mask is presented following a single target in an otherwise empty field. The top panel shows mean percentage of response errors (and standard errors of the mean) as a function of cue condition (valid, within-quadrant invalid, between-quadrant invalid, diagonal-quadrant invalid). The bottom panel shows mean response time in milliseconds (and standard errors of the mean) as a function of cue condition.

correct trials. In addition, outlier response times less than 100 ms, greater than 3,000 ms, or greater than three standard deviations from the cell mean for that participant were eliminated. In total, 2% of the data were eliminated by these criteria.

Figure 1 (bottom panel) presents mean response times and standard errors as a function of cue condition. A one-way ANOVA indicated that the effect of the precue was reliable, $F(3, 51) = 14.5$, $p < .001$. As can be seen in Figure 1, performance in the valid condition was reliably faster than in the three invalid conditions, whereas performance in the three invalid conditions did not reliably differ.

Discussion

The main question addressed by this experiment was whether a precue can influence shape discrimination accuracy when a single target appears in an otherwise empty visual field followed by a single mask at the target location. The results provide an unambiguous affirmative answer to this question. The finding that a reliable precue effect can be observed when the target appears without simultaneous distracting noise disconfirms the strong version of the noise-reduction hypothesis proposed by Shiu and Pashler (1994). At the same time, the overall precue effect was reduced in the present experiment in comparison to that reported by Henderson and Macquistan (1993), suggesting that a precue may both direct a limited capacity attentional system and reduce confusion caused by visual noise.

Why Did Shiu and Pashler (1994) Fail to Observe a Precue Effect?

To this point, I have reviewed prior evidence and have presented new data indicating that a spatial precue can affect shape processing in a nonnoisy visual field. The question that remains is why Shiu and Pashler (1994) did not find such an effect.

Acceptance of the Null Hypothesis

At the simplest level, one might argue that the Shiu and Pashler's (1994) apparently anomolous failure to find a precue effect does not require explanation, because it is based on an acceptance of the null hypothesis and may simply be a Type II error. Although this explanation has some merit, it is not completely satisfying. Precue effects were observed by Shiu and Pashler (1994) when multiple masks were used, lowering the credibility of the argument that their experiments lacked statistical power in the single-mask conditions. On the other hand, the finding of an effect under one set of conditions (the multiple-mask blocks of trials) does not guarantee that the same effect will be found, even if it truly exists under another set of conditions (the single-mask blocks of trials).

Inappropriate Masking Stimulus

A second explanation for Shiu and Pashler's (1994) results involves the particular type of mask that they used. Shiu and Pashler (1994) presented digits (e.g., 4, 5, 6, or 7) as their target stimuli and followed these targets with a hash mark (#) mask. The use of the hash mark is problematic because it may not completely obliterate the features of the digits. In fact, a careful examination of the digits and mask used by Shiu and Pashler (1994) indicates that some of the features of the digits would be visible through the hash mark.[3] The integrated pattern formed by the combination of digit and mask for each digit is shown in Figure 2. These integrated patterns contained easily discriminable features, such as the number and position of the holes in the centers of the patterns. If participants became aware of the relationship between a given target digit and its integrated digit-plus-mask pattern, and if this pattern persisted either on the display screen or in the visual system, then performance could have been based on a relatively long-lasting discrim-

[3] I thank Ling-Po Shiu and Harold Pashler for making their stimuli available to me.

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Figure 2. Illustrations of the integrated letter-and-mask pattern formed by each of the four-letter targets used by Shiu and Pashler (1994). In this illustration, each pixel is represented by a hash mark (#).

inable pattern rather than a briefly presented and masked pattern (the digit). Such an awareness may have arisen from initial valid trials where attention was oriented to the target letter early enough for encoding of both the digit and the digit-plus-mask pattern. Once the relationship between a digit and its digit-plus-mask pattern had been learned, the digit-plus-mask pattern alone would have been sufficient to allow a correct response. Further, the mask in the single-mask condition may actually have improved performance when the precue was invalid by serving as an abrupt-onset postcue. The postcue would allow attention to be directed to the position of the integrated pattern either on the screen or in the visual system. Thus, whatever advantage might have been expected from the presentation of a valid precue would be diluted by the effect of the single-mask postcue. Note that this latter problem would not arise in the case of multiple posttarget masks, because the masks would not provide any information about the location of the target. Therefore, a single posttarget mask would reduce or eliminate the precue advantage, whereas multiple posttarget masks would not.

Other Possible Factors

The Shiu and Pashler (1994) studies differed on a number of other dimensions from the studies reported by Henderson (1991; Henderson & Macquistan, 1993) and the study reported above, any of which might also have contributed to Shiu and Pashler's (1994) failure to find precue effects in the single-mask condition. Other recent demonstrations of a precue effect on target discrimination using only a single posttarget mask at the target location have attempted to specify these factors (Bacon, Johnston, & Remington, 1994; Luck, Hillyard, Mouloua, & Hawkins, 1996). For example, Luck et al. (1996) suggested that Shiu and Pashler (1994) did not find a precue effect in the single-mask condition because of forward masking of the target by the precue. They suggest that forward masking was a consequence of the short stimulus onset asynchronies used by Shiu and Pashler (1994). Alternatively, Bacon et al. (1994) have suggested that the precues used by Shiu and Pashler (1994) may have been insufficient to draw attention to the cued location, and have also criticized the masks used by Shiu and Pashler (1994) as inadequate.

Conclusion

In two previous sets of experiments we reported reliable effects of a location precue on shape discrimination given a target in an otherwise empty visual field (Henderson, 1991; Henderson & Macquistan, 1993) and accounted for those results with a model based on a limited-capacity view of attention. Shiu and Pashler (1994) challenged that interpretation by suggesting that those precue effects were observed only because the shape-discrimination target was followed by potentially confusable posttarget masks at multiple positions. Shiu and Pashler (1994) concluded that precue effects are not due to a limited-capacity attentional system and instead can best be explained by a noise-reduction model. The present article had three purposes. First, I reviewed the evidence concerning the effect of a location precue on shape processing. The conclusion from this review was that precues can influence shape discrimination in the absence of visual noise. Second, I presented a new experiment with a single posttarget mask as recommended by Shiu and Pashler (1994). The results of this experiment clearly showed a precue effect. Third, I discussed some reasons why Shiu and Pashler (1994) did not find this type of effect in their study.

At this point, the reasonable conclusion to draw seems to be that spatial precues can exert an influence on visual target discrimination by means of two mechanisms, one involving the reduction of noise from irrelevant visual stimuli (Palmer et al., 1993; Shiffrin & Gardner, 1972; Shiu & Pashler, 1994), and the other involving allocation of limited processing resources to a specific location or object (Henderson, 1991; LaBerge & Brown, 1989; Eriksen & St. James, 1986). What does not seem tenable, however, is the proposal that all precue effects are due to noise reduction alone (Shiu & Pashler, 1994).

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Received June 16, 1994
Revision received March 27, 1995
Accepted April 6, 1995 ■