EXOGENOUS SPATIAL ATTENTION INFLUENCES FIGURE-GROUND ASSIGNMENT
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Abstract—In a hierarchical stage account of vision, figure-ground assignment is thought to be completed before the operation of focal spatial attention. Previous results support this account by showing that unpredictive, exogenous spatial precues do not influence figure-ground assignment, although voluntary attention can influence figure-ground assignment. However, in these studies, attention was not summoned directly to a region in a figure-ground display. In three experiments, we address the relationship between figure-ground assignment and visuospatial attention. In Experiment 1, we replicated the finding that exogenous precues do not influence figure-ground assignment when they direct attention outside of a figure-ground stimulus. In Experiment 2, we demonstrated that exogenous attention can influence figure-ground assignment if it is directed to one of the regions in a figure-ground stimulus. In Experiment 3, we demonstrated that exogenous attention can influence figure-ground assignment if it is directed to a gestalt figure-ground cue, suggesting that figure-ground processes are not entirely completed prior to the operation of focal spatial attention. Exogenous spatial attention acts as a cue for figure-ground assignment and can affect the outcome of figure-ground processes.

In visual scenes that contain multiple objects, the ability to visually segregate objects from one another becomes critically important: Without isolating different objects, high-level visual processes such as object recognition would not know where one shape ended and another began. Figure-ground assignment processes allow shapes (figures) to be segregated from backgrounds. This visual process is important because figures form the basis of much visual processing—humans are more likely to recognize and act upon figures than backgrounds.

The visual cues that influence figure-ground assignment were studied extensively by the Gestalt psychologists (Bahnsen, 1928; Koffka, 1935; Metzger, 1953; Rubin, 1915/1958), who identified the stimulus characteristics that would allow one region to appear as the figure and another to appear as the ground. For example, Rubin (1915/1958) reported that in most cases a smaller region is generally reported as figure and a larger region reported as the ground. Bahnsen (1928) reported that symmetric regions were more likely to be perceived as figure than asymmetric regions. Convex regions are more likely to be perceived as figures than concave regions (Hoffman & Singh, 1997; Kaniza & Gerbino, 1976). Regions that fall below a horizon line are more likely to be perceived as figure than regions that fall above a horizon line (Metzger, 1953; Vecera et al., 2002).

Figure-ground assignment is considered a preattentive process that operates in parallel across the visual field before focal attention processes (e.g., Julesz, 1984). What is the relationship between preattentive segregation processes and focal spatial attention? A straightforward account, endorsed by several theories, is a hierarchical stage account in which figure-ground assignment is completed before other high-level visual processes, such as focal attention or object identification (e.g., Biederman, 1987; Julesz, 1984; Kosslyn, 1987; Marr, 1982; Neisser, 1967). Under this account, spatial attention would not influence figure-ground assignment automatically because attention would not operate until figure-ground processes were completed. Voluntary, or strategic, attention might influence figure-ground assignment, but only when a figure-ground stimulus was ambiguous and either region could be perceived as figure equally. In this latter case, figure-ground processes would fail and allow voluntary spatial attention to resolve the perceptual ambiguity (see Peterson, 1999, for relevant discussion). Recent findings support these predictions and support the hierarchical stage view of segregation and attention.

Baylis and Driver (1995; Driver & Baylis, 1996) demonstrated that exogenous (automatic) spatial precues do not influence figure-ground assignment, although endogenous
(voluntary) precues do influence figure-ground processes.\(^1\) Exogenous and endogenous attention were distinguished by manipulating the predictability of a spatial precue. Previous research has demonstrated that uninformative precues tap exogenous attention whereas predictive precues tap endogenous attention (e.g., Jonides, 1981; Klein et al., 1992). Observers viewed ambiguous figure-ground displays in which either of two regions could be perceived as the figure (similar to the figure-ground stimuli shown in Figure 1). Prior to presenting the figure-ground display, a spatial precue was flashed briefly on one side of where the figure-ground display would appear. The figure-ground display then appeared for a short duration, followed by a blank screen. A test display followed the blank screen; the test display contained two shapes, and observers were asked to decide which of the two contours matched one of those from the figure-ground display. The direction of the test contours was manipulated so that the two contours would match either the cued region (Figure 1A) or the uncued region (Figure 1B). If the attentional precue influenced figure-ground assignment, then the precued region should be perceived as figure, and this region should be discriminated rapidly in the test display.

Observers in Baylis and Driver’s study were faster to discriminate the test shape when the spatial precue predicted the region to be tested (endogenous precue), indicating that endogenous spatial attention influenced figure-ground assignment. When the precue did not predict the to-be-tested region (endogenous precue), spatial attention did not influence figure-ground assignment. Thus, voluntary attention influenced segregation, but this attentional influence did not occur automatically, consistent with a hierarchical stage view of segregation and attention.

We ask if exogenous attention might influence figure-ground assignment if attention was allocated directly to the space occupied by one of the shapes in the figure-ground display. The study discussed above may have obscured the effects of exogenous attention in two ways. First, the spatial precues appeared outside the figure-ground stimulus, thereby preventing attention from operating directly on a potential figure. Second, the figure-ground stimulus appeared after the precue; the abrupt onset of the figure-ground stimulus could have captured attention away from the precued location (Yantis, 1998; Yantis & Jonides, 1984). In Experiments 1 and 2, we demonstrated that unpredictable, exogenous spatial precues influence figure-ground assignment when attention is allocated within the boundaries of a potential figure.

**EXPERIMENTS 1 & 2**

Observers reported which of two probe shapes had the same shape as a corresponding region in an ambiguous figure-ground display in which either region could be perceived as ‘figure’ (Figure 1). Our procedure differed from previous studies in two respects: First, the spatial precue was presented inside the figure-ground stimulus. Second, the precue was presented after the onset of the figure-ground stimulus. If exogenous spatial attention influences figure-ground assignment, then reaction times (RTs) should be faster to the cued regions than to the uncued regions in the test displays. The spatial precues were unpredictable and thus tapped exogenous spatial attention; half of the time the precue summoned attention to the to-be-tested region and half of the time the precue summoned attention to the other region.

We manipulated the location of the precue: In Experiment 1, we followed previous research and placed the precue outside the figure-ground stimulus (the Cue Outside condition; Figures 1A & 1B). In Experiment 2, we placed the precue within the figure-ground stimulus, which focused attention directly on one of the two regions (the Cue Inside condition; Figure 1C). Importantly, because the precue was located further in the visual periphery in the Cue Outside condition, we increased the size of this precue in accordance with the cortical magnification factor (Rovamo & Virsu, 1979) to ensure that the precues were represented equivalently in the visual system when located inside and outside the figure-ground display.

**Method**

**Participants.** The participants were 36 University of Iowa undergraduates (18 per experiment) who received course credit; all reported having normal or corrected vision.

**Stimuli.** The figure-ground displays were similar to those used in previous research. Each ambiguous figure-ground display was comprised of a square separated into two distinct

\(^1\) Although these results support a hierarchical stage account, Baylis and Driver (1995; Driver & Baylis, 1996) do not attempt to argue for a strict serial stage relationship between figure-ground assignment and spatial attention. They do state that exogenous attention mechanisms do not influence segregation.
colored regions by a jagged contour (Figure 1). The two regions in each display were equal in area and convexity. Each region was either red or green, and each color was equally likely to appear on the left side or the right side in the figure-ground display. Six different contours were used within the figure-ground displays, all of which produced ambiguous figure-ground displays (i.e., neither region had a bias to be perceived as figure). The stimuli were viewed from a distance of approximately 80 cm. From this viewing distance, each display measured 7.24° by 7.24° of visual angle. All stimuli were drawn on a black background.

In the Cue Outside condition (Experiment 1), the precue was a white rectangle that measured 10.27° by 3.13° and appeared just outside the figure-ground stimulus, falling 1.57° to the left and right edges of the figure-ground display. In the Cue Inside condition (Experiment 2), the precue was a white rectangle that measured 3.48° by 0.99°, located inside one of the two regions of the figure-ground stimulus. These precues appeared 2.28° to the left or right of fixation. All precues appeared equally to the left and right of fixation and appeared equally inside or adjacent to red and green regions.

At the end of each trial, two gray probe shapes appeared, and observers were instructed to determine which probe shape appeared in the previously viewed figure-ground display. The probes appeared 2.28° of visual angle to the left and right of fixation and measured 7.24° by 4.54°. The correct probe—the region that appeared in the figure-ground display—appeared equally to the left and right of fixation in the probe display. There were two types of probe displays: Cued probe displays required observers to remember the region that was either directly precued (Cue Inside condition) or adjacent to a precue (Cue Outside condition); uncued probe trials required observers to remember the region that was not directly cued or not adjacent to the precue. The spatial precue was uninformative regarding the region that would be probed; cued and uncued probe trials appeared equally.

Procedure. The sequence and timing of events are depicted in Figure 1. Each trial began with a fixation point, visible for 500 ms before the probes appeared. The probes remained visible until the observer made a response.

Observers reported which of the two probe shapes had the same shape as one of the regions in the figure-ground display. Observers were instructed to respond as quickly and accurately as possible by pressing one key on a button box to indicate that the left probe shape matched or another key to indicate that the right probe shape matched.

Each observer received a block of 96 practice trials which were not analyzed, followed by 5 blocks of 96 trials. Observers were instructed that the red and green regions in the figure-ground displayed would be tested equally often. To minimize the role of voluntary (endogenous) orienting to the spatial precue, observers were told only that the precue would appear and that it had no relationship to the region that would need to be matched at the end of the trial.

Results & Discussion

Only correct RTs were analyzed. Participants’ median RTs were analyzed with a two-factor, mixed-model ANOVA with cue location (Cue Outside and Cue Inside) and probe type (cued region probed and uncued region probed) as factors. The RT and error data are shown in Figure 2; the RTs show a small effect of the precue when it was located outside the figure-ground stimulus, but a large effect of the precue when it was located inside the stimulus. There were no statistically significant effects in the error data.

Although RTs were shorter in the Cue Outside condition (884.2 ms) than in the Cue Inside condition (964.1 ms), this main effect was not significant, F(1, 34) = 1.78, n.s. There was a main effect for the region probed, with faster RTs when the cued region was probed (908.3 ms) than when the uncued region was probed (940 ms), F(1, 34) = 10.64, p < .005. This main effect was subsumed by a two-way interaction, F(1, 34) = 5.45, p < .03, indicating that RTs to the region probed depended on the whether the cue was inside or outside the figure-ground stimulus. In short, the exogenous precue influenced figure-ground assignment when it appeared inside the figure-ground display, but not when it appeared outside the display.

This conclusion was corroborated with planned comparisons between the cued region probed and uncued region probed conditions. In the Cue Outside condition, there was no difference between RTs to the cued region (879.7 ms) and the
uncued region (887.8 ms), t(17) < 1. In the Cue Inside condition, RTs to the cued region (936.9 ms) were significantly faster than RTs to the uncued region (991.3 ms), t(17) = 3.63, p < .005. These results demonstrate that exogenous spatial attention can influence figure-ground assignment, provided that attention is focused within the boundaries of a potential figural region. Importantly, in the Cue Outside condition, we replicated previous failures to find an attention effect when precues were outside a figure-ground stimulus.

Although our results suggest that directly precuing a region in a figure-ground display allows attention to influence figure-ground assignment, these findings could be explained with a hierarchical stage account of figure-ground processes and attention. Because our figure-ground displays were ambiguous (i.e., either region could be perceived as figure), figure-ground processes may fail to assign figural status to either region (see Peterson, 1999; Vecera & O'Reilly, 2000, for discussion). Instead, both regions are fed forward to attentional processes, which can select the cued region if either the precue is highly predictive (Baylis & Driver, 1995; Driver & Baylis, 1996) or if the precue is unpredictive but a region is cued directly (the present Experiment 2). More convincing evidence against a hierarchical stage account would involve demonstrating that exogenous spatial attention could partially override an unambiguous bottom-up, or gestalt, cue for figure-ground assignment. For example, if one region in a figure-ground display has a bias to be perceived as figure based on the gestalt cue of convexity, could exogenously precuing the concave region reduce or override the bias to perceive the convex region as figure? We addressed this question in Experiment 3.

In Experiment 3, observers viewed figure-ground displays that contained a convexity cue that influenced figure-ground assignment (Hoffman & Singh, 1997; Kaniza & Gerbino, 1976). As in Experiment 2, a nonpredictive spatial precue summoned attention to either the convex region or the concave region. When the convex region was precued, both attention and convexity operate to assign figural status to this region. However, when the concave region is precued, attention and convexity compete with one another for figural status. If figure-ground processes are completed prior to the operation of exogenous attention as assumed under a hierarchical stage account, then the convex region should continue to be perceived as figure as readily as it was when the convex region was precued. Specifically, the region that is cued (convex versus concave) and the region tested (convex versus concave) should produce additive effects on the RTs. In contrast, if both figure-ground processes and attention mutually constrain one another, then convexity should have a smaller effect on figure-ground assignment when the concave region is precued. This latter account predicts an under-additive interaction between the region cued and the region tested; convex regions will not be perceived as figure as readily when attention has been summoned to the concave region.

**EXPERIMENT 3**

**Method**

**Participants.** The participants were 36 University of Iowa undergraduates who received course credit; all reported having normal or corrected vision.

**Stimuli.** The figure-ground displays contained a convexity cue and were similar to those developed by Hoffman and Singh (1997). A sample display appears in Figure 3A. In this display, the left region is more convex than the right region based on Hoffman and Singh’s (1997) part-salience analysis. Based on the local geometry around the shared contour, the left region produces more salient convex parts that influence figure-ground assignment. As in Experiments 1 and 2, the two regions were equal in area. Each region was either red or green, and each color was equally likely to appear on the left side or the right side in the figure-ground display. All stimuli were drawn on a black background and viewed from a distance of approximately 80 cm. From this viewing distance, each display measured (8.1 cm) 5.8° by 5.8° of visual angle.

The spatial precue was a white rectangle that measured 0.60° wide by 3.5° tall and was located inside one of the two regions of the figure-ground stimulus. These precues appeared 1.3° to the left or right of fixation. All precues appeared equally to the left and right of fixation and appeared equally inside or adjacent to red and green regions.

At the end of each trial, two gray probe shapes appeared, and observers were instructed to determine which probe shape appeared in the previously viewed figure-ground display. The center of each probe appeared 2.6° of visual angle to the left and right of fixation and measured 5.8° tall by 2.9° wide. The correct probe—the region that appeared in the figure-ground display—appeared equally to the left and right of fixation in the probe display. The region that was probed was either convex or
concave, and this region could have been cued or uncued. As in the previous experiments, the spatial precue was uninformative regarding the region that would be probed; cued and uncued probe trials appeared equally.

**Procedure.** Observers performed the matching task used in Experiments 1 and 2. One group of 18 participants viewed the figure-ground displays without precues; this control condition ensured that the convex regions were perceived as figure in our stimuli. The remaining 18 participants viewed the figure-ground displays with precues that appeared within either the convex or concave region (similar to the Cue Inside condition in the previous experiments). In the control condition, a 500 ms fixation cross appeared, followed by the figure-ground display for 180 ms. A blank screen then appeared for 500 ms blank screen before the probes appeared; the probe shapes remained visible until a response was made. In the precue condition, the sequence and timing of events were identical to those in Experiment 2. In the precue condition, two variables were factorially manipulated: the convexity of the region cued (convex or concave) and the region probed (convex or concave).

**Results & Discussion**

Only correct RTs were analyzed. In the control condition (Figure 3B), participants’ median RTs were significantly faster when convex regions were probed (615.2 ms) than when concave regions were probed (663.7 ms), $t(17) = 3.6, p < .005$. This result indicates that our convex regions influenced figure-ground assignment. There were no systematic effects in the error data.

In the precue condition, participants’ median RTs were analyzed with a two-factor within-subject ANOVA with precued region (convex or concave) and probe type (convex region probed and concave region probed) as factors. The RT and error data are shown in Figure 3B; there were no statistically significant effects in the error data. As is evident in Figure 3B, convex regions were matched faster than concave regions. Most important, however, was the finding that convexity had a 40% smaller effect on figure-ground assignment when the concave region was precued.

These observations were supported by the ANOVA. There was no main effect of the region that was precued; RTs were similar when the convex region was precued (677.6 ms) and when the concave region was precued (680 ms), $F(1, 17) < 1$. There was an effect of the probed region: Overall, convex regions were matched faster than concave regions (657.7 ms versus 699.9 ms, respectively), $F(1, 17) = 18.2, p < .0005$. Most important, these two factors interacted, $F(1, 17) = 4.5, p < .05$. The difference between matching convex and concave regions was significantly smaller when the concave region was precued than when the convex region was precued.

The interaction between spatial precuing and convexity indicates that exogenous spatial attention can compete with image-based gestalt cues in figure-ground assignment. Further, these results are specific to figure-ground processes: In an additional 18 participants, we found that if the two regions are separated and do not share a central contour, the spatial precue is the predominant influence on responses; cued regions are matched faster (678.8 ms) than uncued regions (708.6 ms). This attentional effect is much larger than that observed in Experiment 3, in which cued regions are matched only slightly faster (673.2 ms) than uncued regions (684.3 ms), because figural status also affects responses. Thus, the results of Experiment 3 are not merely an attentional cuing result, but they depend on the figural status of one of the regions. In general, the results of Experiment 3 are at odds with a hierarchical stage account of figure-ground assignment, which would predict that figure-ground assignment would be based on image-based cues only.

**GENERAL DISCUSSION**

Our results demonstrate that when spatial attention is directed to one of the regions of a figure-ground stimulus, the precued region is perceived as figure and the shared contour is assigned to the precued (i.e., figural) region. However, exogenous spatial attention does not influence figure-ground assignment when spatial attention is directed outside a figure-ground stimulus. Further, exogenous spatial attention can influence the operation of image-based (bottom-up) gestalt cues for figure-ground assignment. This latter result indicates that exogenous spatial attention can influence figure-ground processes per se, as opposed to operating after figure-ground processes. Although it is well-known that voluntary (endogenous) attention can influence figure-ground assignment (see Rubin, 1915/1958), ours are the first results to demonstrate that this influence can occur with unpredictable, exogenous precues, which do not require observers to voluntarily direct spatial attention. Our results indicate that exogenous spatial attention can be viewed as a cue for figure-ground assignment (also see Palmer et al., 2001): Exogenous spatial attention can disambiguate otherwise ambiguous displays (Experiment 2) and can reduce a bottom-up bias provided by a gestalt figure-ground cue (Experiment 3).
It is difficult to reconcile our results with a hierarchical stage account of visual processing. Such an account would have predicted that exogenous spatial attention would, at best, only operate to influence an otherwise ambiguous figure-ground assignment, as we found in Experiment 2. More problematic for the hierarchical stage account are the results from Experiment 3 because this account would have predicted that figure-ground assignment would have been performed using the convexity cue present in these displays. The finding that exogenous spatial attention could reduce the effect of convexity on figure-ground assignment suggests that figure-ground assignment need not be completed prior the influence of spatial attention. Instead, figure-ground assignment and exogenous attentional processes mutually constrain one another, possibly through recurrent, interactive processes.

This interactive view of attention and figure-ground assignment is consistent with other results which show that high-level visual processes can affect figure-ground processes. For example, object familiarity can reduce or override image-based figure-ground cues. When observers view a figure-ground display in which one region depicts a familiar object, this region is perceived as figure, provided that the familiar object is in its canonical orientation (see Peterson, 1999; Peterson & Gibson, 1991, 1994). We have explained these results with an interactive parallel distributed processing model in which orientation-dependent object representations, which occur architecturally late in the model, provide a top-down constraint on figure-ground processes (Vecera & O’Reilly, 1998; 2000).

Because exogenous spatial attention acts as a cue for figure-ground assignment, then the distinction between figure-ground processes and attention is blurred. A region or shape may appear more shape like or may be more memorable either because it has been attended or because it has been perceived as figure. One theoretical advantage to blurred distinction between figure-ground and attention is that figure-ground processes might be interpretable within theoretical views developed in the attention literature. For example, the biased competition account of visual search (Desimone & Duncan, 1995) and related models (e.g., guided search, see Wolfe, 1994) capture the operation of our interactive model of figure-ground assignment (Vecera & O’Reilly, 1998; 2000). Figure-ground assignment and spatial attention may interact with one another in a biased competition view of figure-ground assignment (Vecera, 2000), with exogenous precues providing a top-down ‘biasing’ signal that helps resolve the competition between two regions that are competing for figural status. Figure-ground assignment is also biased by bottom-up factors, such as the gestalt cues. In general, a biased competition account of figure-ground assignment can explain the multiple constraints on figure-ground processes.

Interactions between attention and figure-ground assignment could allow these visual processes to exhibit similar effects. For example, spatial attention appears to operate as a ‘gain control’ on sensory information in which attended items are enhanced relative to unattended items manner (Hillyard et al., 1998). Through its interactions with spatial attention via exogenous precues, figure-ground assignment may exhibit a similar ‘gain control’ effect, with figural regions being perceptually enhanced relative to grounds. Although interacting processes are difficult to separate (Vecera & O’Reilly, 2000), a close relationship between figure-ground processes and focal attention could provide insights into other phenomena, such as object-based attention, which might arise from both exogenous spatial attention and gestalt segregation cues such as symmetry or area.

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REFERENCES


FIGURE CAPTIONS

Figure 1. The visual-working memory match-to-sample paradigm to study figure-ground assignment. The timing parameters reflect those used in the present experiments; the stimuli are not drawn to scale. (A) A trial in which the attentional precue appears outside the figure-ground stimulus; the probe trial requires determining which of the two shapes was in the figure-ground stimulus; this panel depicts a cued trial in which the tested region was on the same side as the spatial precue. (B) Same as Panel A, but the test trial in which the tested region was opposite the spatial precue (an uncued trial). Panels A and B depict the procedure used in Experiment 1. (C) Procedure used in Experiment 2 to determine if directing attention within a region can influence figure-ground
assignment. In all of the test trials depicted, the correct response is the shape on the right.

Figure 2. Results from Experiments 1 (Cue Outside) and Experiment 2 (Cue Inside). When spatial attention is directed to a region within a figure-ground stimulus, the exogenous attentional precuing influences figure-ground assignment. When spatial attention is directed outside the figure-ground stimulus, exogenous attentional precuing no longer influences figure-ground assignment. These results suggest that exogenous attention may contribute to figure-ground assignment. Error bars are within-subject 95% confidence intervals.

Figure 3. (A) Sample display from Experiment 3 in which one region (depicted in black) is convex. (B) Results from Experiment 3. When no precue is present (shaded region), observers use convexity to perform figure-ground assignment. When one of the regions is precued, both the attentional precue and convexity affect figure-ground assignment. Most important, when the concave region is precued, there is a statistically significant reduction in the effect of convexity on figure-ground assignment.
Figure 1

(A) 500 ms +

(B) 500 ms +

(C) 500 ms +

Until response

500 ms

500 ms

500 ms

500 ms

500 ms
Figure 2

- Reaction Time (ms)
- % Error

- Cued Region Tested
- Uncued Region Tested

- Cue Outside (Experiment 1)
- Cue Inside (Experiment 2)