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Lower Region: A New Cue for Figure–Ground Assignment

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Figure–ground assignment is an important visual process; humans recognize, attend to, and act on figures, not backgrounds. There are many visual cues for figure–ground assignment. A new cue to figure–ground assignment, called lower region, is presented: Regions in the lower portion of a stimulus array appear more figurelike than regions in the upper portion of the display. This phenomenon was explored, and it was demonstrated that the lower-region preference is not influenced by contrast, eye movements, or voluntary spatial attention. It was found that the lower region is defined relative to the stimulus display, linking the lower-region preference to pictorial depth perception cues. The results are discussed in terms of the environmental regularities that this new figure–ground cue may reflect.

Figure–ground assignment is a well-known psychological phenomenon; illustrations of figure–ground assignment appear in most introductory psychology textbooks, and most psychology students recognize these examples. Figure–ground assignment is the process by which the visual system organizes a visual scene into figures (occluding, foreground regions) and grounds (occluded regions) following the initial formation of those regions (Palmer & Rock, 1994). Determining which regions are figures and which are grounds is an important visual process because everyday visual scenes contain multiple objects that often overlap and partially occlude one another. Figure–ground processes have been studied most extensively by perceptual and cognitive scientists (see Palmer, 1999; Pomerantz & Kubovy, 1986; Rock, 1983, 1995; and Rock & Palmer, 1990), but developmental studies have also investigated the perception of occluded objects (e.g., Spelke, 1990). Also, social psychologists have demonstrated that figure–ground processes are influenced by motivational factors; reward and punishment appear to influence figure–ground separation (Schafer & Murphy, 1943). Figure–ground assignment is a fundamental visual process because figural regions form the basis of a wide range of behavior; humans are more likely to recognize, attend to, and act upon foreground figures rather than backgrounds. Thus, the study of figure-ground assignment has a central role in explaining higher-level visual and visuomotor behavior.

There are several consequences, or effects, of figure–ground assignment. Rubin (1915/1958), who was the first Gestalt psychologist to study figure–ground assignment rigorously, noted that figures seem more salient than grounds and that figures have a definite shape but grounds are shapeless (see also Koffka, 1935). Perhaps because of this salience, figures are more likely to be remembered than grounds, both in the long term (on the order of minutes and possibly much longer; see Dutton & Traill, 1933; and Rubin, 1915/1958) and in the short term (on the order of a few hundred milliseconds; see Driver & Baylis, 1996). An additional effect of figure–ground assignment is that figures are perceived as being closer to the viewer than grounds.

Well-known cues for figure–ground assignment include area (or size), symmetry, and convexity (Palmer, 1999; see also Pomerantz & Kubovy, 1986; Rock, 1975, 1995; and Rubin, 1915/1958). Smaller regions are more likely to be perceived as figure than larger regions, horizontally symmetric regions with the same left and right sides are more likely to be perceived as figure than asymmetric regions, and convex regions are more likely to be perceived as figure than concave regions. Figure 1 illustrates these gestalt cues for figure-ground assignment. These bottom-up image cues are important because of the flexibility that they afford viewers in interpreting scenes: Viewers can isolate figures in unfamiliar or unexpected scenes, thereby demonstrating the sufficiency of bottom-up, stimulus-driven image cues for figure–ground assignment (e.g., Vecera, 2000; Vecera & O'Reilly, 1998, 2000).

However, the set of gestalt cues, although useful for studying much visual behavior, may not capture some aspects of figure–ground assignment. Despite the flexibility of the gestalt cues, bottom-up figure–ground assignment is limited by the number of image cues registered by the visual system. For example, a coffee cup can be viewed as a figure against a background of a cluttered desk even though the coffee cup may be neither symmetric nor convex. What other cues might the visual system use to segregate the cup from the desk? This example indicates that other, undiscovered image cues may exist for figure–ground assignment, although top-down information also may influence assignment in this example (Peterson, 1994, 1999; Vecera, 2000; Vecera & O'Reilly, 1998, 2000). Palmer and colleagues recently identified several new gestalt principles for perceptual organization (Palmer, 1992; Palmer & Levitin, 1998; Palmer & Rock, 1994), and Weisstein and colleagues demonstrated new principles for figure–ground assignment in the 1980s (e.g., Klymenko & Weisstein, 1986). Also, Lee and Blake (1999) demonstrated that temporal

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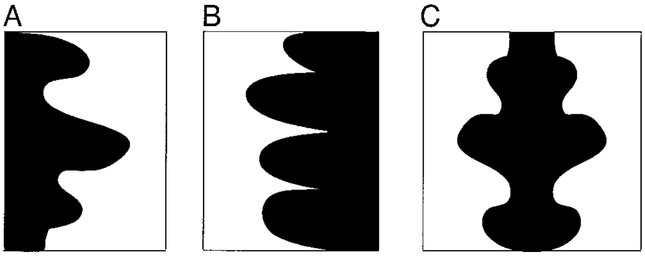

Figure 1. Examples of gestalt cues for figure–ground assignment. A: Area (or size), in which the smaller black region is seen as the foreground figure. B: Convexity, in which the convex black region is seen as the foreground figure. C: Symmetry, in which the horizontally symmetric black region is seen as figure.

structure can influence figure–ground assignment and subsequent shape perception.

As in the studies discussed above, in this article we present a previously unexplored figure–ground assignment cue in which regions falling in the lower portion of a stimulus array are more likely to be perceived as figure than regions falling in the upper portion of the array. This lower-region principle is depicted in Figure 2A. Most viewers report the black, lower region as the figure: it is perceived as closer to the viewer and more shape-like than the upper region. The lower-region effect is not the result of other bottom-up cues to figure–ground assignment, which can be verified by examining Figure 2B, a 90° rotation of Figure 2A. In Figure 2B, most viewers report that neither region has a distinct advantage as the figure, demonstrating that there are no gestalt cues to influence figure–ground assignment in these displays.

Gestalt psychologists may have been aware of this perceptual cue for distinguishing figure and ground. Metzger (1953, p. 37) reproduced a display from Ehrenstein (1930) in which the lower region appears as the foreground figure (Figure 2C). Metzger (1953) briefly mentioned that this stimulus may represent another cue, or law, for figure–ground assignment in which the "standing" region becomes figure more easily than the "hanging" region. Koffka (1935, p. 186) produced a display (Figure 2D) in which the lower region appears more figure-like than the upper region. However, Koffka (1935) did not discuss his display as representing a gestalt cue for figure–ground assignment.

Unfortunately, Metzger's (1953) and Koffka's (1935) observations do not unambiguously demonstrate lower region as a new gestalt cue. There were no systematic studies of this effect, and there are alternative accounts of these observations. The Metzger-Ehrenstein display (Figure 2C) may contain a familiarity cue that can influence figure–ground assignment (Peterson, 1994, 1999; Rock, 1975). The lower region may appear more figure-like because of its similarity to ocean waves, not because of its position in the display. In Koffka's display, there are two components to the black region, a larger component in the topmost part of the display and a smaller strip at the bottom of the display. Thus, the white region may appear more figure-like because it forms a single region that is more easily attended to than two regions (similar to displays used by Baylis & Driver, 1993). Also, a part-salience analysis (Hoffman & Singh, 1997) of the black and white regions in Figure 2D demonstrates that the white region is more convex than the uppermost, black region. Thus, convexity, not lower region, could explain viewers' perceptions of Koffka's display.

Why might lower regions appear to be more figure-like than upper regions? There are at least two possible reasons why a lower region might appear more figure-like. The first possibility relates to differences between the upper and the lower visual fields. If a viewer fixates on the contour separating the upper and lower regions, then the lower region falls in the lower visual field and the upper region falls in the upper visual field. Because the lower visual field typically represents higher-spatial-frequency information and information closer to a viewer (see Previc, 1990, for a

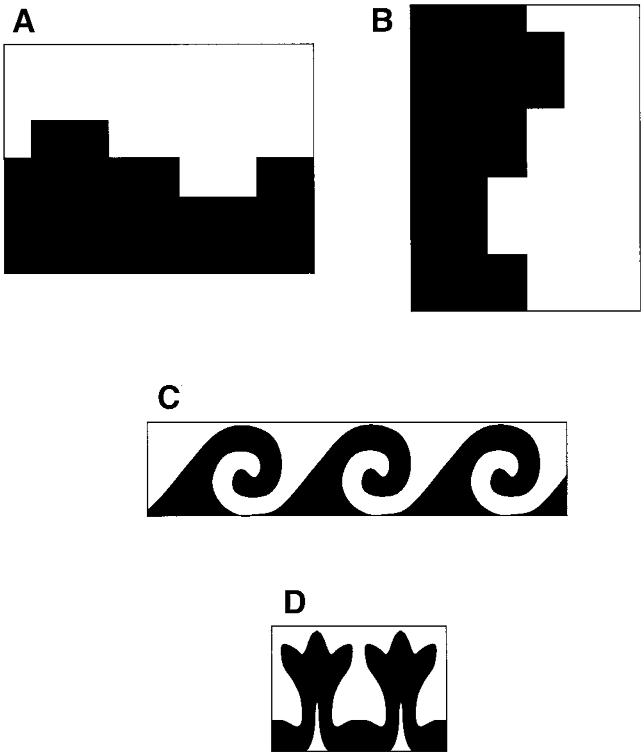

Figure 2. Lower-region cue to figure–ground assignment. A: Upper–lower display, in which most viewers perceive the lower (black) region as the foreground figure. B: Left–right control display, in which either region can be perceived as figure. Color versions of these figures can be viewed at http://www.psychology.uiowa.edu/Faculty/Vecera/lab/lower_region.html. C: Metzger-Ehrenstein display, which appears to show a lower-region effect, although the black, lower region may appear to be the figure because it looks like a familiar pattern—ocean waves. Familiarity, not lower region, can explain why the black region appears as figure in this display. From *Gesetze des Sehens* (p. 37), by W. Metzger, 1953, Frankfurt, Germany: Waldemar Kramer. Copyright 1975 by Waldemar Kramer. Adapted with permission. D: Koffka's display, which also appears to show a lower-region effect. However, the white lower region in Koffka's display contains a single component (region), whereas the black region has two components. Further, the white region has more salient parts than the black region, allowing the white region to appear as figure. Lower region need not be discussed to explain why the white region appears as figure in Koffka's display. From *Principles of Gestalt Psychology* (p. 186), by K. Koffka, 1935, New York: Harcourt, Brace. Copyright 1935 by Wadsworth, an imprint of the Wadsworth Group, a division of Thomson Learning. Reprinted with permission.

review), these visual field differences may influence figure–ground assignment.

The second possibility relates to a possible connection between figure–ground assignment and pictorial depth perception cues. As noted earlier, there are several consequences of figure–ground assignment. Most relevant, figures, because they are perceived as occluders, are typically perceived as being closer to a viewer than the background. Thus, figure–ground assignment involves a depth assignment in which the figure is perceived as being closer to the viewer than the ground. The intimate connection between figure–ground assignment and depth perception suggests that pictorial depth segregation cues may influence figure–ground assignment and, further, that gestalt figure–ground cues may be viewed more generally as monocular depth cues (see also Grossberg, 1997; Palmer, 1999; Palmer, Nelson, & Brooks, 2001). One pictorial depth cue is of particular importance to the lower-region phenomenon. *Relative position* is a pictorial depth cue in which the distance of an object can be inferred from its distance from the horizon. In real-world scenes, regions below a horizon line will be physically closer to the viewer than regions above the horizon line; this regularity in visual scenes can be used to determine depth relationships in pictorial representations of scenes. Thus, the location of a region relative to the shared contour may influence figure–ground assignment: Relative position influences the perception of distance which, in turn, influences figure–ground relationships. The lower-region cue may reflect an environmental regularity in which nearby objects appear more frequently below a horizon line, thereby connecting pictorial depth cues with figure–ground assignment. In the following experiments, we document the lower-region effect and determine the likely cause of this effect.

Experiments 1 and 2

In the first two experiments, we empirically established lower region as a cue to figure–ground assignment. Participants in these experiments viewed figure–ground displays that contained two abutting regions similar to those shown in Figures 2A and B; participants were asked to report which of the two regions appeared as the foreground figure. In both experiments, there were two display types, black–white displays (one region white and one region black) and red-green displays (one region red and one region green and of approximately equal luminance). We manipulated display type to ensure that the lower-region effect was not restricted to a particular contrast or color combination. In Experiment 1, the displays were visible until participants responded; in Experiment 2, we presented the displays for 150 ms to ensure that the lower-region effect was not due to preferential eye movements to the lower region.

Method

Participants. Eighteen University of Iowa undergraduates with normal or corrected vision volunteered for course credit. There were 6 participants in Experiment 1 and 12 in Experiment 2.

Stimuli. Participants viewed figure–ground displays similar to those shown in Figures 2A and B. The displays measured 9.7° of visual angle on the short side and 12.9° on the long side. The displays were created by varying the central, shared contour such that the regions on either side of the contour were equal in area. Thus, the two regions were equated on the gestalt cue of area; convexity also was approximately equal between the two regions because equating area required us to balance convexity on one side of the contour with convexity on the other side of the contour. The middle of the contour between the two colored regions was positioned at fixation to prevent participants from fixating on only one of the regions.

We chose four randomly generated contours on the basis of the results of a pilot study, which demonstrated that the two regions were equally likely to be perceived as figure when the regions appeared to the left and right of each other. These four contours were used to create 128 different displays. Each contour had four different versions, which were created by flipping the contours across both their horizontal axis and their vertical axis. Each of these four versions had two orientations; the central contour was oriented vertically in the left–right control displays and horizontally in the upper–lower displays. Finally, the color scheme and placement of the colors were counterbalanced such that half of the displays were black–white displays and half were red–green displays. In low-contrast red–green displays, one region was red (luminance of 14.72 cd/m^2) and the other was green (luminance of 14.54 cd/m^2); in black–white displays, one region was black and the other was white, for maximal contrast. For every contour, each of the colors appeared on the left region in half of the displays and each of the colors appeared on the lower region in half of the displays.

Procedure. Participants were instructed to report the color of the region that first appeared to be the figure. Prior to testing, each participant was shown Rubin's (1915/1958) face–vase figure to illustrate the principle of figure–ground assignment. Participants were told that either the faces or the vase, but not both, could be perceived as lying in the foreground and would appear to be closer than the other region. Participants were asked to try to perceive both the faces and the vase as figure in alternation. All of the participants appeared to understand the principle of figure–ground assignment.

Trials began with a 500-ms fixation cross (0.55° by 0.55°). A figure-ground display then appeared. Displays were visible until participants responded (Experiment 1) or were presented for 150 ms (Experiment 2), a duration too brief to permit eye movements to either region. Following responses, there was a 200-ms intertrial interval. The *Z* key was used to report red or black as figure, and the *?/* key was used to report green or white as figure. There were 128 randomly presented trials in Experiment 1 and 256 in Experiment 2.

Results and Discussion

Table 1 shows the average frequency with which regions were perceived as figure in Experiments 1 and 2. We computed the percentages of trials in which participants reported the left region as figure in the left–right control displays and the lower region as figure in the upper–lower displays. If the lower region biased figure–ground assignment, then the lower region should have been perceived as figure above chance (50%) levels. Regions in left–right displays should have been perceived as figure at near-chance levels because the regions were equated on other figure–ground cues. Because our preliminary analyses indicated that contrast (red–green displays versus black–white displays) had no systematic effect on the results, all ts < 1, the analyses that we report below collapse across display contrast.

In Experiment 1, the lower region was perceived as figure on 79.0% of the trials, a value that was above chance, $t(5) = 4.1$, $p < .01$. In Experiment 2, the lower region was perceived as figure on 71.7% of the trials, a value that also differed from chance, $t(11) = 4.0$, $p < .005$. Regions in the left–right control displays showed no systematic figural preference; the left region was reported as figure on 51.3% and 57.3% of the trials in the respective experiments, ts < 1.

Table 1
Mean Percentage of Trials in Which Lower or Left Regions Were Perceived as Figure in Experiments 1 and 2

	Experiment 1		Experiment 2	
Display	Upper–lower displays	Left–right displays	Upper–lower displays	Left–right displays
Red–green (low contrast)	76.8 (13.0)	51.1 (13.2)	72.3 (8.4)	56.0 (12.0)
Black–white (high contrast)	81.3 (13.0)	51.4 (13.2)	71.1 (8.4)	58.6 (12.0)

Note. Data are reported as means, and 95% within-subject confidence intervals are given in parentheses.

These results indicate that viewers have a strong preference to see lower regions as figure; no figural preference exists in left–right displays. This lower-region preference was found for both black–white and red–green displays, and neither color combination had a systematic effect on the left–right displays. Further, the lower-region effect is not due to within-trial eye movements toward the lower region. When the displays were presented too briefly to permit eye movements (150 ms), the lower-region preference remained.

The results of Experiments 1 and 2 corroborate the informal observations made by Ehrenstein (1930), Metzger (1953), and Koffka (1935) using more tightly controlled displays and a more rigorous paradigm than the “look at the figure and see the effect” procedure typically used by Gestalt psychologists. However, although our results provide empirical confirmation of the lower-region effect on figure–ground assignment, one limitation of Experiments 1 and 2 is that the lower-region preference may be caused by a top-down effect of familiarity. The display shown in Figure 2A can be interpreted as a familiar scene—a city skyline—just as Metzger’s (1953) display (Figure 2C) could be viewed as containing a familiar scene (ocean waves). As noted earlier, familiar regions are more likely to be perceived as figures than less familiar regions (Peterson, 1994, 1999; Rock, 1975) because object representations stored in visual memory can influence figure–ground assignment in a top-down manner (Vecera & O’Reilly, 1998, 2000).

To demonstrate that the lower-region preference is a bottom-up, or data-driven, cue for figure–ground assignment, we created two new stimulus sets that were less likely to have a familiar shape in the lower region of the display. One set of stimuli was created by dividing a circle into two regions with a curved line, as shown in Figure 3A, similar to the displays created by Rock and Kremen (1957). When viewed with regions in the upper and lower positions (Figure 3B), the two regions appear to form stalactites hanging from the ceiling or stalagmites rising from the floor.[1] The other set of stimuli was created by dividing a square into two regions separated by a regularly repeating contour that looked like a box joint on a piece of furniture (Figure 3C). When these displays were rotated (Figure 3D), they looked like interdigitating teeth. For both stimulus sets, there was no a priori reason to assume that the lower region was a more familiar shape than the upper region.

Experiments 3 and 4

Method

Participants. The participants were 24 University of Iowa undergraduates who had normal or corrected vision and who received course credit for their time. There were 12 participants in each experiment.

Stimuli. In Experiment 3, participants viewed figure–ground displays similar to those shown in Figures 3A and B (stalactites–stalagmites), and in Experiment 4, participants viewed displays similar to those shown in Figures 3C and D (repeating teeth). The stalactite–stalagmite stimuli measured 4.7° in circumference and were created by bisecting the circle with an irregular contour. The contour was created such that (a) the two regions would be of approximately equal area and (b) any deep convexity into one region was matched with a deep convexity into the other region. These two constraints allowed us to minimize the role of area and convexity as figure–ground cues. We created four contours using these constraints, and these four contours were used to create 128 different displays. Each contour had four different versions, which were created by flipping the contours across both their horizontal axis and their vertical axis. Each of these four versions had two orientations; the central contour was oriented vertically in the left–right control displays and horizontally in the upper–lower displays. Finally, the color scheme and placement of the colors were counterbalanced such that half of the displays were black–white displays and half were red–green displays. For every contour, each of the colors appeared on the left region in half of the displays and each of the colors appeared on the lower region in half of the displays. The color combinations were identical to those used in Experiments 1 and 2.

The repeating-teeth stimuli measured 9.7° on each side. The areas of the two regions were identical, as were the convexities. There were only eight displays in this stimulus set: a left–right display with red on the left or green on the left, a left–right display with black on the left or white on the left, an upper–lower display with red in the lower half or green in the lower half, and an upper–lower display with black in the lower half or white in the lower half.

Procedure. The procedure was identical to that used in Experiment 1.

Results and Discussion

Table 2 shows the average frequency with which regions were perceived as figure in Experiments 3 and 4. We again computed the percentages of trials in which participants reported the left region as figure in the left–right control displays and the lower region as figure in the upper–lower displays; these percentages were compared to chance (50%) levels.

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[1] We thank Steve Lindsay for suggesting these terms for our stimuli.

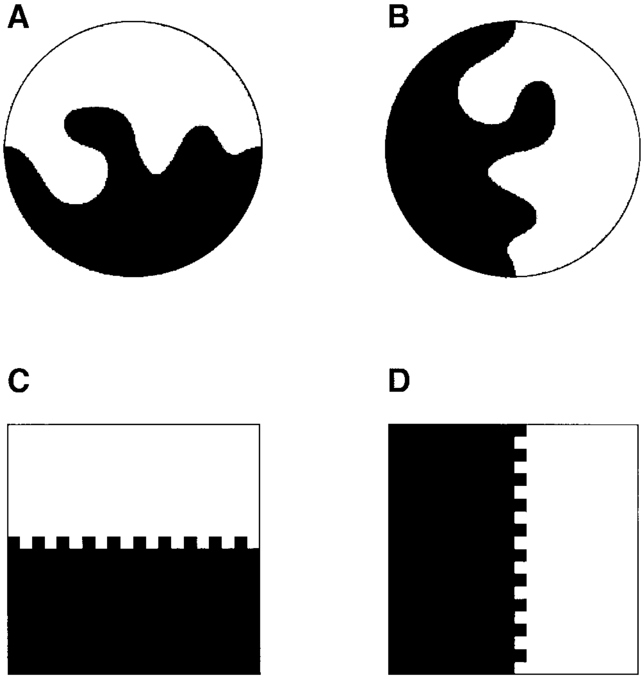

Figure 3. Examples of the stalactite–stalagmite stimuli used in Experiment 3 (A and B) and the repeating-teeth stimuli used in Experiment 4 (C and D).

In Experiment 3, the lower region was perceived as figure on 60.6% of the trials, a value that was above chance, $t(11) = 2.33$, $p < .05$. In Experiment 4, the lower region was perceived as figure on 73.5% of the trials, a value that also differed from chance, $t(11) = 2.82$, $p < .05$. Although there appeared to be a smaller lower-region preference with the stalactite–stalagmite stimuli than with the repeating-teeth stimuli, this difference was not significant, $t(22) = 1.4$, *ns*.

Regions in the left–right control displays showed no systematic figural preference; the left region was reported as figure on 52.6% and 56.4% of trials in Experiments 3 and 4, respectively ts < 1.5, *ns*. As in Experiments 1 and 2, there were no systematic effects of contrast (black–white vs. red–green), indicating that the lower-region preference was not influenced by this variable.

The results of Experiments 3 and 4 replicate our finding that viewers have a strong preference to see lower regions as figure. Importantly, we observed the lower-region preference in two new stimulus sets that were less likely to be interpreted as having a familiar lower region. Top-down familiarity biases, which are known to influence figure–ground assignment, do not appear to be the sole cause of the lower-region preference. We would not want to imply, however, that familiarity could not modulate the data-driven lower-region preference. The lower-region bias might be reduced if a familiar object appeared in the upper portion of a display.

Although our first four experiments present solid evidence for a lower-region preference in figure–ground assignment, these results only concern the initial perception of figure and ground. However, figure–ground assignment is bistable in that figural assignment can be reversed; the figure can become ground and vice versa, as in Rubin's (1915/1958) famous face–vase figure. Displays containing salient cues for discriminating figure from ground lead to more stable percepts with fewer perceptual reversals (see Peterson & Hochberg, 1983, for relevant results). Therefore, we investigated the dynamic aspects of the lower-region preference. Participants viewed figure–ground displays for a longer period of time (30 s) and provided continuous reports of figure–ground organization. If lower region is a true figure–ground assignment cue, then lower regions should be more stable figures: Lower regions should be perceived as figures for longer durations than upper regions and should be less prone to figure–ground reversals than left–right displays. We tested these predictions in Experiment 5.

Experiment 5

Method

Participants. Ten University of Iowa undergraduates with normal or corrected vision volunteered for course credit.

Stimuli. The stimuli were the red–green displays used in Experiments 1 and 2. Half of the displays contained upper–lower regions and half contained left–right regions.

Procedure. The participants were given general instructions regarding figure–ground assignment by viewing Rubin's (1915/1958) face–vase figure, as in Experiments 1 and 2; participants were also informed of figure–ground reversals and how these reversals often occur spontaneously. As before, all participants appeared to understand the principle of figure–ground assignment and how figure and ground can reverse.

Participants viewed 64 displays for 30 s each and gave continuous reports of the perceived figural region (red or green) by pressing one of two buttons. We measured the duration each region was reported as figure and the number of figure–ground reversals.

Table 2
Mean Percentage of Trials in Which Lower or Left Regions Were Perceived as Figure in Experiments 3 and 4

	Experiment 3 (stalactites–stalagmites)		Experiment 4 (repeating teeth)	
Display	Upper–lower displays	Left–right displays	Upper–lower displays	Left–right displays
Red–green (low contrast)	59.6 (7.1)	54.1 (2.9)	74.2 (13.0)	54.9 (6.8)
Black–white (high contrast)	61.7 (7.1)	51.0 (2.9)	72.9 (13.0)	57.8 (6.8)

Note. Data are reported as means, and 95% within-subject confidence intervals are given in parentheses.

Results and Discussion

In upper–lower displays, participants perceived the lower region as figure 84.5% of the time (± 4.2, the 95% within-subject confidence interval), a value that was above chance, $t(9) = 13.0$, $p < .0001$. Further, there were significantly fewer reversals for the upper–lower displays ($M = 2.5$) than for the left–right displays ($M = 4.2$), $t(9) = 2.7$, $p < .03$. In the left–right displays, there was a slight bias for perceiving the right region as figure (a bias opposite that observed in Experiments 1 and 2). On average, participants perceived the right region as figure 53.8% (± 2.5) of the time, a value that was slightly above chance, $t(9) = 2.5$, $p < .05$. This rightward bias was caused by 2 participants. Omitting these 2 participants from the analyses reduced the rightward bias to 51.9% (± 1.7), a value that did not differ from chance, $t(7) = 1.8$, $p > .10$, but left intact the lower-region bias at 86.1% (± 4.2), a value that remained above chance, $t(7) = 14.5$, $p < .0001$. These results further support the lower-region cue for figure–ground assignment: Lower regions are more stable figures than upper regions and left–right regions. Lower regions are perceived as figure longer than any of the other regions. Further, upper–lower displays, in which the lower region is typically perceived as figure, undergo fewer figure–ground reversals than left–right displays.

Having demonstrated the lower-region effect on figure–ground assignment in five experiments, we next examined the source of this lower-region preference. Why are lower regions preferred as figure over upper regions or regions in control displays? One possible answer is that the lower-region effect is not caused by figure–ground assignment per se but is caused by another, later visual process. Visuospatial attention may be another source for the lower-region preference. In some situations, voluntary visuospatial attention can influence figure–ground assignment (Driver & Baylis, 1996). Spatial attention may be a candidate process for the lower-region preference because of attentional differences that exist between the upper and lower visual fields. The resolution of attention appears to be greater in the lower visual field than in the upper visual field when multiple stimuli are present in one of the two fields (He, Cavanagh, & Intriligator, 1996). Thus, because our lower regions fall entirely within the lower visual field, our results may reflect the effects of voluntary spatial attention, not figure–ground assignment. Viewers may be more likely to direct voluntary spatial attention to the lower field than to the upper field or to the left or right fields. We addressed this possibility in Experiment 6 by using an opposed-set procedure that allows different figure–ground assignment cues to either cooperate or compete with one another (Peterson & Hochberg, 1983). Using an opposed-set procedure, Peterson and Hochberg (1983) demonstrated that both stimulus cues (e.g., occlusion cues) and viewers' intentions (which region viewers were asked to attend to) influenced form perception and the perception of relative depth.

In Experiment 6, we asked participants to selectively attend to one region in a display and to try to perceive that attended region as figure. Because the left–right displays do not contain any gestalt cues to bias figure–ground assignment, only the attentional bias created by our instructions should influence figure–ground assignment. However, because the upper–lower displays contain a potential cue for distinguishing figure from ground, we can determine whether attention, lower region, or both influence figure–ground assignment. The critical condition in Experiment 6 is that viewers were asked to direct voluntary visuospatial attention to the upper region; in this condition, attention and the lower-region cue compete for determining which region is perceived as figure. If voluntary visuospatial attention is the cause of the lower-region effect, then asking viewers to direct attention to the upper region should abolish the lower-region preference in figure–ground assignment. Viewers would perceive the attended upper region, not the unattended lower region, as figure. However, if the lower-region cue continued to influence figure–ground assignment when attention was directed to the upper region, then viewers should report the unattended lower region as figure. Of course, both the lower-region cue and visual attention may influence figure–ground assignment.

Experiment 6

Method

Participants. Ten University of Iowa undergraduates with normal or corrected vision participated for course credit.

Stimuli. The stimuli were those used in Experiment 5.

Procedure. The procedure was similar to that of Experiment 5, except that during each 30-s trial, participants were instructed to attend to either the red or the green region in the figure–ground display; across all trials, the red region and the green region were to be attended equally. The participants were asked to try perceiving each region as figure while giving continuous reports as to which region appeared as figure. Participants also were told that figure–ground may reverse and that the attended region may not always be perceived as figure. As in Experiment 5, we measured the proportion of time each region was reported as figure.

Results and Discussion

The percentage of the 30-s trial that participants reported perceiving the attended or unattended region as figure is shown in Figure 4. Each region that participants were asked to attend to is plotted separately. Inspection of Figure 4 shows that when participants were asked to attend to the left, right, or lower region, the attended region was perceived as figure more often than the unattended region. However, when viewers were asked to attend to the upper region, the unattended lower region was perceived as figure more often than the attended upper region. These observations were investigated further with statistical analyses.

For the upper–lower displays, we first examined whether there was an overall preference for seeing the lower region as figure irrespective of the attention instructions. Overall, the lower region was perceived as figure more frequently than the upper region, $t(9) = 5.2$, $p < .001$. Note that this analysis includes the trials in which the lower region was to be unattended (because the participants were asked to attend to the upper region).

Using the left–right displays as a baseline condition for the attention effect, we next examined whether attended upper regions differed from attended left and right regions. If attention is the cause of the lower-region preference observed in Experiments 1 to 5, then attending to an upper region should allow this region to be perceived as figure as often as attending to a left or a right region. However, we found that attention had a significantly smaller effect when it was directed to upper regions than when it was directed to either left or right regions, $t(9) = 3.9$, $p < .005$. That is, attended upper regions were

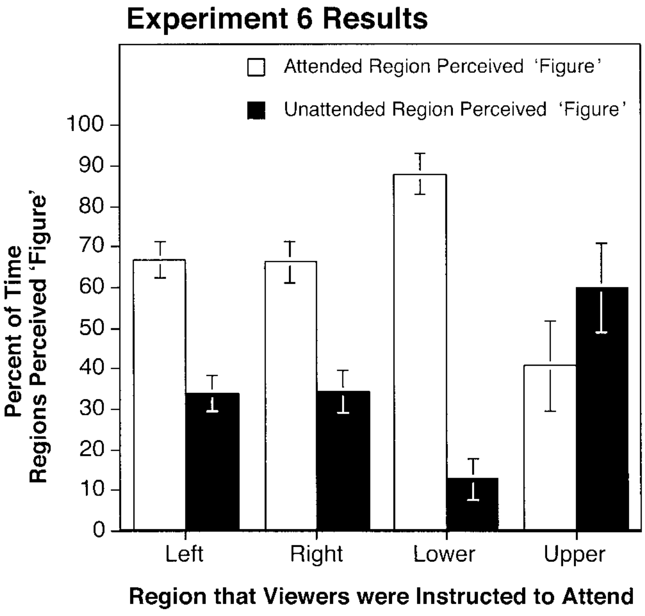

Figure 4. Results from Experiment 6, in which voluntary visuospatial attention was directed to a region in a figure–ground display. The difference between the corresponding bars defines the effect of attention on figure–ground assignment. In left–right control displays and when attention is directed to a lower region, attention influences figure–ground assignment (i.e., the attended region is perceived as figure). In contrast, when attention is directed to an upper region, the attention effect reverses relative to the other conditions—the unattended lower region is perceived as figure more frequently than the attended upper region. Error bars are 95% within-subject confidence intervals for each condition compared against chance (50%).

perceived as figure for less time (40.4%) than attended left or right regions (66.1%). Further, attended upper regions were perceived as figure for less time (40.4%) than attended lower regions (87.6%), $t(9) = 5.2$, $p < .001$.

The results of Experiment 6 suggest that voluntary spatial attention is not the sole cause of the lower-region figural preference. When attention and lower region are placed in competition with one another by asking participants to attend to the upper region, the unattended lower region continues to be perceived as figure. Of course, one could argue that our attention manipulation was relatively weak and might not have competed effectively against the lower-region cue. Importantly, the results from left–right displays provide a manipulation check. In the left–right control displays, participants were able to use voluntary visuospatial attention to influence figure–ground assignment. In the left–right displays, the attended region was perceived as figure more often than the unattended region, $t(9) = 7.3$, $p < .0001$, demonstrating that in the absence of other figure–ground cues, such as a lower region, attention can bias figure–ground assignment. This latter conclusion is consistent with the results of other studies of attention and figure–ground processes (Driver & Baylis, 1996).

These results show that viewers reported the lower region as figure more frequently irrespective of whether the lower region was attended or unattended, indicating that voluntary attention alone does not cause the lower-region preference. Of course, we would not want to argue that spatial attention does not or cannot play a role in figure–ground assignment. The results from our left–right control displays and from other studies (Driver & Baylis, 1996) indicate that spatial attention can influence figure–ground assignment. There are likely to be many influences on figure–ground assignment, some from image-based information (i.e., gestalt cues, including lower region) and some from higher-level visual processes (e.g., spatial attention or object representations; for further discussion, see Vecera, 2000; and Vecera & O'Reilly, 1998, 2000).

Having ruled out voluntary attention as the source of the lower-region preference, we can now return to the question of why lower regions appear to be more figure-like than upper regions. As we noted above, there are at least two possible sources for the lower-region preference. On the one hand, because the lower regions in Experiments 1 to 6 all fall below the fixation point within the lower visual field, the lower-region preference also may reflect processing differences between the upper and the lower visual fields. On the basis of the perceptual processing differences between the upper and the lower visual fields (for examples, see also He et al., 1996; Previc, 1990; and Rubin, Nakayama, & Shapley, 1996), the lower-region preference may be caused by the visual field location. Any region falling below the fixation point in the lower visual field may be more figure-like than regions falling above the fixation point in the upper visual field. On the other hand, the lower-region preference may emerge because the lower region falls below a horizontal horizon line. Because figures are occluders and are perceived as lying closer to a viewer, figure–ground assignment involves a depth assignment. Thus, pictorial depth segregation cues, such as relative position, may influence figure–ground assignment. A complete understanding of the lower-region preference requires an understanding of the source of the preference and how "lower" is defined (relative to the visual field or relative to the horizon line).

In Experiment 7, we investigated the cause of the lower-region preference by presenting the figure–ground display entirely above or entirely below a central fixation point. If the lower-region preference is due to differences between the upper and the lower visual fields, then moving a figure–ground display into the lower field should allow both regions to be perceived as figure and moving the entire display into the upper field should allow neither region to appear figure-like. However, if the lower-region preference is due to the relative position depth cue, then the lower region should be perceived as figure irrespective of whether the stimulus display appears entirely in the upper or the lower visual field. In the latter scenario, the lower region always falls below the horizontal horizon line, irrespective of whether the display falls within the upper or the lower visual field. Of course, testing between these two alternatives requires that the entire figure–ground display fall within the upper or the lower visual field. If the participants made any eye movements from the central fixation point, then the stimulus would not be confined to a single visual field. To ensure that participants maintained fixation, we recorded eye position and eye movements and adopted strict criteria for excluding a trial or a response from the final analysis.

Experiment 7

Method

Participants. Five University of Iowa undergraduates with normal or corrected vision served as participants and were paid $8 per hour.

Stimuli. The stimuli were identical to the upper–lower displays from Experiment 5, with two changes. First, the displays could appear 4.2° either above or below the fixation point, placing the entire display within the upper or the lower visual field. Second, the displays were 80% their size in Experiment 3. We reduced the display size so that the display would appear only in the upper or the lower visual field.

Procedure. The procedure was similar to that of Experiment 5, with two exceptions. First, eye position was monitored with electro-oculogram recordings. Two small electrodes were placed lateral to the left and right eyes to monitor horizontal eye position, and two electrodes were placed above and below the left eye to monitor vertical eye position and blinks. This procedure allowed us to reject any trials or responses contaminated by blinks, large eye movements ($>1°$ of visual angle), or changes in fixation position greater than 0.2° of visual angle. Second, there were 96 trials, each 10 s long. The trial length was reduced from 30 s to allow participants time to rest and blink their eyes between trials.

Trials and responses were rejected on the basis of two conservative criteria. If an eye movement or blink occurred either 200 ms before a trial began or 800 ms after a trial ended, the entire trial was excluded from the analyses. For an eye movement or blink that occurred during a 10-s trial, any key press responses that occurred 500 ms either before or after the eye movement or blink were excluded from the final analyses. These stringent criteria minimized any contributions of eye movements or changes in fixation to the data. Adopting more stringent criteria (e.g., excluding an entire trial that included an eye movement) would have left us with few data points per participant and would have reduced statistical power.

Results and Discussion

Eye movements that occurred before or after a trial excluded 12.7% of the trials, and eye movements that occurred within trials excluded 24.4% of the responses. When the stimulus appeared in the lower visual field, participants perceived the lower region as figure for 79.5% (± 10.6) of the 10-s trials, a value that was above chance (50%), $t(4) = 5.5$, $p < .01$. When the stimulus appeared in the upper visual field, participants perceived the lower region as figure for 78.3% (± 12.6) of the 10-s trials, a value that also was above chance, $t(4) = 4.4$, $p < .02$. As is evident from these results, the placement of the figure–ground display in either the upper or the lower visual field did not influence the lower-region preference. There was no statistical difference between participants' lower-region preferences in the upper and the lower visual fields, $t(4) < 1$. These results indicate that "lower" is defined relative to the stimulus configuration, specifically, the horizontal horizon line. The region that appears below the horizon line is the region that is perceived as figure. The lower-region preference appears to be invariant across visual fields. Of course, we would not deny processing differences between the upper and the lower visual fields (Previc, 1990), although visual field differences do not appear to account entirely for the lower-region preference.

Although the foregoing studies consistently demonstrated a lower-region bias, there is one remaining issue that we must address. All of our studies relied on explicit reports of figural perception; that is, the participants were asked to report which region appeared to be the foreground figure. So that participants could perform this task, we informed participants about figure–ground assignment by showing them the face–vase figure. Such explicit reports are potentially problematic because they may involve cognitive processes, such as decision processes, in addition to basic figure–ground processes. Also, informing participants about figure–ground processes may alter the way in which those processes are deployed; for example, Rock and colleagues (Girgus, Rock, & Egatz, 1977; Rock & Mitchener, 1992) showed that perceptual reversals, such as those that we studied in Experiment 5, may occur only in participants who are informed about such reversals. Thus, although we did not inform participants about the lower-region preference, informing participants about figure–ground perception more generally may have caused them to perform figure–ground assignment in a manner uncharacteristic of the routine, everyday performance of figure–ground assignment.

In our final experiment, we investigated the lower-region preference by using a visual short-term memory matching task that does not require participants to be instructed about figure–ground perception. This task, recently used by Driver and Baylis (1996) to study figure–ground assignment, is depicted in Figure 5. Participants are shown a figure–ground display and, after a short delay, are shown two shapes in a matching display. The participants' task is to determine which of the two shapes in the matching display appeared in the figure–ground stimulus. In our displays, the two shapes in the matching display test either the left or the right region (in left–right displays) or test either the upper or the lower region (in upper–lower displays). Previous research showed that figures (e.g., a symmetric region) are matched faster and more accurately than grounds (e.g., an asymmetric region) (Driver & Baylis, 1996). We hypothesized that matching performance would not differ between left and right regions but that matching would be faster and more accurate for lower regions than for upper regions.

Experiment 8

Method

Participants. The participants were 12 University of Iowa undergraduates with normal or corrected vision; the participants received course credit for their time.

Stimuli. The stimuli were similar to those used in Experiments 1 and 2, although the displays in this experiment involved new stimuli. We created these new stimuli by first dividing the shared contour into 16 equal regions. We randomly assigned each region to contain a convexity from one region or from the other region, with the constraint that eight of the convexities be assigned to each region to ensure equal convexity on both sides of the shared contour. Because the convexities had equal area when assigned to each region, the total areas of both regions were also equal. A sample figure–ground display is shown in Figure 5, which also depicts the procedure used in Experiment 8. These new stimuli were less likely to be perceived as a city skyline than the stimuli developed in our earlier studies.

We generated 12 random contours. There were eight versions of each contour, corresponding to the red–green color combination (red on left or right; red in upper or lower) and the orientation of the display (left–right or upper–lower); thus, there were 96 total stimuli. Each display measured 8.3° on each side, and the red–green color values were those used in our previous studies.

Procedure. The visual short-term memory matching task is depicted in Figure 5, which shows the order and duration of each event in a trial. Participants viewed a figure–ground display and were asked to remember

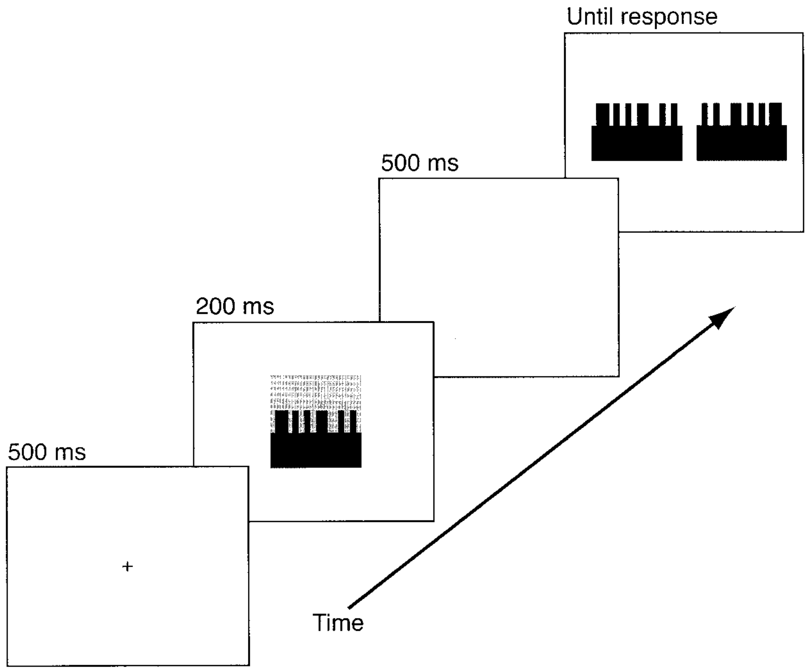

Figure 5. Visual short-term memory matching task used in Experiment 8 to study figure–ground processes without explicitly informing participants of figure–ground effects.

the two regions for a test that occurred 500 ms later. We made no mention of figure–ground assignment; participants were instructed to respond as quickly and as accurately as possible. Each participant received 384 trials, collapsed as follows. For each of the 96 stimuli, the two regions were probed equally. In the probe displays, the correct responses were on the left side and the right side equally often. Participants received a short break after every 96 trials. Before beginning the experimental trials, participants received 96 practice trials that were not analyzed. The display types (left–right or upper–lower) were intermixed throughout the experiment.

Results and Discussion

Any reaction time (RT) over 3,000 ms was excluded from our analyses, as were RTs from incorrect trials. We computed median RTs for the probe trials. The RTs were analyzed with a two-factor repeated-measures analysis of variance with display type (upper–lower and left–right) and region probed (upper, lower, left, or right) as factors. The results appear in Figure 6, which shows that participants were faster in matching lower regions than upper regions; participants did not show any difference in matching left or right regions.

As suggested by Figure 6, there was a main effect of display type, $F(1, 11) = 33.04$, $p < .0001$, indicating that participants were faster in matching regions from left–right displays (1,133 ms) rather than upper–lower displays (1,330.1 ms). There was no overall effect of the region probed, $F(1, 11) < 1$. Most important, these two factors interacted with one another, $F(1, 11) = 6.26$, $p < .03$, indicating that there was figural preference for matching in the upper–lower displays but not the left–right displays. This interpretation was supported by planned comparisons. In the upper–lower displays, the lower displays were matched faster than the upper displays (1,312.8 ms vs. 1,347.5 ms, respectively), $t(11) = 2.7$, $p < .03$. There was no significant difference in matching left or right regions (1,155.3 ms vs. 1,110.7 ms, respectively), $t(11) = 1.55$, *ns*.

An analysis of the error data, shown in the lower panel of Figure 6, showed a pattern similar to that of the RT data. There was an effect of display type, $F(1, 11) = 45.39$, $p < .0001$, with fewer errors for left–right displays (20.9%) than for upper–lower displays (27.2%). There was an effect of region probed, with lower and left regions having fewer errors than upper and right regions (22.1% vs. 26%, respectively), $F(1, 11) = 7.52$, $p < .02$. There was a trend toward a significant interaction, $F(1, 11) = 3.0$, $p < .12$. Planned comparisons revealed fewer errors for matching lower regions (24.3%) rather than upper regions (30.1%), $t(11) = 3.4$, $p < .006$. There was no difference in errors for matching left regions (19.9%) and right regions (21.9%), $t(11) = 1.0$, *ns*.

The results from the visual short-term memory matching task support the existence of a lower-region preference in figure–ground assignment. Lower regions are matched faster and with fewer errors than upper regions; no such preference exists in the left–right control displays. This lower-region preference emerges when no explicit mention of figure–ground is provided to the participants.

One curious finding was that left–right control displays were responded to more quickly and with fewer errors than upper–lower displays. However, recall that in Experiment 7 we demonstrated that the lower-region preference is based on first extracting a horizon line from the display. There is no such horizon line in the control displays, a fact that might allow the control displays to be processed more quickly overall than the upper–lower displays. Our left–right control displays provide an excellent control over image

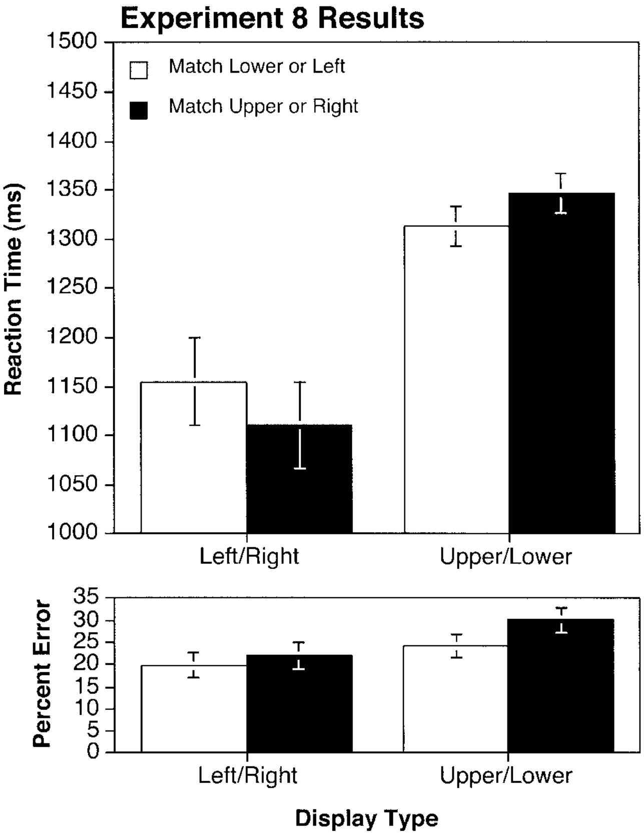

Figure 6. Results from Experiment 8. Participants were faster in matching lower regions than upper regions, and there was no difference in matching left or right regions. These results suggest that the lower-region preference can be observed without explicitly mentioning figure–ground assignment. Error bars are 95% within-subject confidence intervals.

characteristics such as area and convexity, but they do not control for horizon line differences. Another possible reason for this difference is that displays that contain figure–ground cues might be processed more slowly than completely ambiguous figure–ground displays. Some evidence for this notion comes from Driver and Baylis's (1996) Experiment 4, in which they found that displays containing two symmetric regions were matched more slowly than displays containing two asymmetric regions (i.e., an ambiguous display). Such a result is consistent with the processing dynamics of interactive computational models, which can exhibit less stable processing as additional constraints are added to a display or scene (see Hinton & Lang, 1985; Mozer, Zemel, Behrmann, & Williams, 1992; and Vecera & O'Reilly, 1998). Adding the lower-region cue might provide an additional constraint on the interpretation of a display, and it would likely take a recurrent network longer to implement this constraint during processing relative to a control display that has fewer constraints on the interpretation.

General Discussion

Our results support the existence of a new cue to figure–ground assignment, adding to the list of cues initially proposed by Gestalt psychologists. Regions that fall in the lower portion of a figure–ground display are more likely to be perceived as figure than regions in the upper portion. This lower-region preference probably is not due to an attentional bias and appears to reflect the influence of relative position—a pictorial depth cue—on figure–ground assignment. Lower region, like the well-known gestalt cues of symmetry, area, and convexity, may be based on environmental regularities that the visual system can use for figure–ground assignment. Although some Gestalt psychologists may have known about the lower-region preference for figure–ground assignment (Ehrenstein, 1930; Koffka, 1935; Metzger, 1953), as with many of the demonstrations of Gestalt psychologists, strong empirical evidence for this preference was lacking. Our results not only empirically establish the lower-region preference in figure–ground assignment but also point to the source of the preference.

Many issues arise concerning this lower-region preference. As Palmer (1999) noted, the gestalt cues for perceptual organization and for figure–ground assignment are ceteris paribus rules, rules that predict grouping or figure–ground assignment only when no other cues are present. With the exception of Experiment 6, in our experiments we attempted to negate the effects of the other gestalt figure–ground cues in order to study only the lower-region preference. The problem with eliminating other cues is that our results may lack ecological validity and may not generalize to real-world scenes that contain multiple figure–ground cues. We are sensitive to the limitations of ceteris paribus rules and have started to investigate the relationship between the lower-region preference and other gestalt figure–ground cues. For example, in work that is in progress, we have found that the lower-region cue can overcome the gestalt cue of convexity: A concave lower region appears more figure-like than a convex upper region. There are many observations in the perception literature that have pitted grouping and figure–ground cues against one another (e.g., see Kaniza, 1979; Kaniza & Gerbino, 1976; Palmer, 1992; Palmer & Rock, 1994; and Pomerantz & Kubovy, 1986). However, the primary limitation with these approaches (including our own preliminary observations) is that the specific parameters of the grouping or figure–ground cues are arbitrary. For example, Kaniza and Gerbino (1976) presented a figure which shows that convexity can override symmetry in figure–ground assignment; convex regions are preferred as figure over symmetric regions. However, the amount of convexity can be manipulated (Hoffman & Singh, 1997), and the convexity in Kaniza and Gerbino's (1976) figure may have been more salient than symmetry. Such studies need to manipulate a wide range of parameters of both cues (e.g., a wide range of convexities and a wide range of symmetries). This example highlights the fact that no current theory of figure–ground assignment provides a rigorous explanation of how different cues combine or compete with one another (see Kubovy & Holcombe, 1998; and Kubovy & Wagemans, 1995, for quantitative accounts of perceptual grouping with proximity).

Another issue that arises is whether lower region is defined with a retinal (viewer-centered) coordinate frame or an environmental coordinate frame. Although the results of Experiment 7 indicate that the lower region might be defined in terms of an environmental position (i.e., the lowest region in the display), Experiment 7 only demonstrates that "lower" is relative to the central contour in the display. The central contour itself could be defined as horizontal in terms of viewer-centered orientation or environmental (or gravitational) orientation. Research under way suggests that the lower region appears to be defined in viewer-centered coordinates, not environmental coordinates: If viewers rotate their heads 90° and view Figures 2A and B, the left–right display appears to exhibit a lower-region preference, although the regions remain to the left and right of each other when defined relative to the environment or gravity (Vecera, 2002).

In addition to the more specific issues just discussed, our results have implications for and connections to the broader study of figure–ground assignment. For example, although developmental studies have investigated the completion of occluded objects (e.g., Spelke, 1990), there has been no direct study of figure–ground assignment with displays comparable to the displays used to study figure–ground processes in adults. Our finding that the lower-region preference is connected to pictorial depth cues suggests that figure–ground assignment may develop concurrently with sensitivity to pictorial depth cues. Previous research has suggested that young infants are sensitive to occlusion cues at about 7 months of age (Granrud & Yonas, 1984), and occlusion is a well-known pictorial depth cue. Figure–ground assignment may emerge at the same time during infancy if occlusion cues and other pictorial information are associated with figure–ground assignment.

Several recent neurophysiological studies of figure–ground assignment are relevant to our findings. Neurons in the primary visual cortex (area VI) appear to be sensitive to figure–ground relationships on the basis of the gestalt cue of area; neurons whose receptive fields lie on a figure respond with greater frequency than those whose receptive fields lie on the ground (Lamme, 1995; Zipser, Lamme, & Schiller, 1996). This figural superiority for V1 neurons is demonstrated with several different cues for figure–ground assignment, including area, luminance, and binocular disparity (Zipser et al., 1996). Further, neurons in V1 are also sensitive to the edge assignment produced by figure–ground assignment (Zhou, Friedman, & von der Heydt, 2000). Our results would suggest that the primary visual cortex also might be sensitive to the relative position of a figural region and edge assignment, a prediction that could be tested in future neurophysiological studies.

Perhaps the most general question regarding our results is why lower regions have a figural preference. Although we have explained the lower-region preference as arising from the relative position of a region in a display, we do not have an understanding of why relative position might influence depth segregation and, in turn, figure–ground assignment. An ecological consideration of figure–ground assignment (Palmer, 1999) might provide an understanding of why some sources of visual information, such as area or symmetry, influence figure–ground processes. The primary function of figure–ground assignment is to determine which regions correspond to probable intrinsically shaped objects (figures) and which regions are the accidentally shaped regions between objects (backgrounds). Foreground figures possess stable, nonaccidental properties that reflect a situation in the external world (as opposed to reflecting a property that arises from a viewer's accidental viewpoint; see Lowe, 1985, 1987). Figure–ground cues might therefore reflect an environmental situation that allows viewers to determine the most likely objects or shapes in a scene. For example, symmetric regions are more likely to be perceived as figures than asymmetric regions because the most probable interpretation of the scene is for a symmetric object to occlude an asymmetric background.[2] Although a background region (i.e., the space between objects) could be symmetric, this situation is less likely than either (a) the symmetric region being a foreground figure or (b) the background region being asymmetric. There is evidence that environmental regularities can influence contour grouping (e.g., Geisler, Perry, Super, & Gallogly, 2001), and we would argue that such regularities also could influence figure–ground assignment.

Lower regions may have a figural preference because they, too, offer the most parsimonious interpretation of a visual scene. In most natural scenes, regions below a horizon line are physically closer to the viewer than regions above the horizon line. Relative position influences the perception of distance which, in turn, influences the interpretation of occlusion, edge ownership, and figure–ground relationships. The regularities present in natural scenes are used when viewing depictions of scenes (i.e., paintings or photographs), giving rise to the pictorial depth cue of relative position. Thus, the lower-region preference may reflect an environmental regularity in which nearby objects appear more frequently below horizon reference points, thereby connecting pictorial depth cue with figure–ground assignment (see Grossberg, 1997, for a discussion). In general, pictorial depth perception cues may act as figure–ground cues, and figure–ground cues may act as pictorial depth perception cues (Palmer et al., 2001). Our lower-region cue can be added to the list of recently discovered image cues (Klymenko & Weisstein, 1986; Lee & Blake, 1999; Palmer, 1992; Palmer & Levitin, 1998; Palmer & Rock, 1994) that, along with the original gestalt cues, are used in interpreting and organizing visual scenes in a bottom-up, data-driven manner.

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[2] As Steve Palmer pointed out to us, some visual scenes might contain regularities that appear to oppose gestalt cues for figure–ground assignment. For example, the gestalt cue of area may be a problematic case because regions that are closer to a viewer tend to have larger retinal images than regions that are more distant. This ecological fact appears to run counter to the area cue, in which smaller regions tend to be perceived as figure. We are making a statistical argument and would not deny the possibility that some images could appear to contradict gestalt cues. A statistical regularity view would lead us to predict that such contradictory images would be less likely to occur than images in which the foreground figure was retinally smaller than the background. (Imagine a person walking up a flight of stairs; the person would cast a smaller retinal image than the background stairs.)

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