Globally inconsistent figure/ground relations induced by a negative part

Sung-Ho Kim
Department of Psychology, Center for Cognitive Science,
Rutgers University, New Brunswick, NJ, USA

Jacob Feldman
Department of Psychology, Center for Cognitive Science,
Rutgers University, New Brunswick, NJ, USA

Figure/ground interpretation is a dynamic and complex process involving the cooperation and competition of a number of perceptual factors. Most research has assumed that figure/ground assignment is globally consistent along the entire contour of a single figure, meaning that the one side of each boundary is interpreted as figure along the entire length of the boundary, and the other side interpreted as ground. We investigated a situation that challenges this assumption, because local cues to figure/ground conflict with global cues: a “negative part,” a contour region that appears locally convex but that the global form requires be concave. To measure figure/ground assignment, we use a new task based on local contour motion attribution that allows us to measure border ownership locally at points along the contour. The results from two experiments showed that the more salient a negative part is, the more border ownership tended to locally reverse within it, creating an inconsistency in figure/ground assignments along the contour. This suggests that border ownership assignment is not an all-or-none process, but rather a locally autonomous process that is not strictly constrained by global cues.

Keywords: figure/ground, border ownership, negative parts, surface representation, contour curvature

Citation: Kim, S.-H., & Feldman, J. (2009). Globally inconsistent figure/ground relations induced by a negative part. *Journal of Vision, 9*(10):8, 1–13, http://journalofvision.org/9/10/8/, doi:10.1167/9.10.8.

Introduction

Figure/ground organization, the segmentation of an image into distinct figural and ground regions, is a critical step in visual processing. Figural regions are thought to perceptually “own” the common boundary separating them from ground regions, and to have well-defined shapes, while grounds are perceived as shapeless and continuing behind the figure (Koffka, 1935; Rubin, 1921). Figural assignment substantially influences later processing, as figures are more likely to be recognized, attended to, and acted upon than background regions (e.g., Driver & Baylis, 1996; He & Nakayama, 1992; Nakayama, Shimojo, & Silverman, 1989; Rock, 1983). Figure/ground assignment is also crucial for shape representation, as the sign of contour curvature (positive for convex, negative for concave) is defined relative to figure and ground, and the sign of curvature in turn influences the perception of three-dimensional surfaces (Attneave, 1971; Hoffman & Richards, 1984).

Figure/ground organization is a dynamic and complex process in which various factors cooperate or compete with one another to determine the ultimate percept. It is well known that the region that is more surrounded, smaller, more vertically oriented (Koffka, 1935; Rubin, 1921), more symmetrical (Bahnsen, 1928; Kanizsa & Gerbino, 1976), lower in the display (Vecera, Vogel, & Woodman, 2002), more convex (Kanizsa & Gerbino, 1976; Koffka, 1935; Stevens & Brookes, 1988), more familiar (Peterson & Gibson, 1993, 1994), and richer in high spatial frequencies (Klymenko & Weisstein, 1986) is more likely to be seen as the nearer, figural region.

In traditional approaches from the Gestaltists onwards, figure/ground organization has generally been assumed to occur in globally consistent manner along the whole contour of a figure, meaning that the figural assignments agree at all points along each boundary. Even in reversible figures, like Rubin’s (1915/1958) famous vase/face, where figure and ground can reverse, they do so in tandem and everywhere at once, so the interpretation is always globally consistent.

However, more recent theorists have suggested that figure/ground assignment can be influenced by local cues as well as global ones. Some modern computational models of figure/ground organization are based on local cue competition between local edge units on opposite sides for border ownership (Kienker, Sejnowski, Hinton, & Schumacher, 1986; Peterson, de Gelder, Rapcsak, Gerhardstein, & Bachoud-Lévi, 2000; Peterson & Skow, 2008; Vecera & O’Reilly, 1998). There is also behavioral evidence that figure/ground assignment can be influenced by local cues as well as global, configural, ones. Peterson et al. showed that some figural cues, such as familiarity (Peterson, 2003a) and (partial) closure (Peterson & Lampignano, 2003), can operate locally on portions of continuous contours. They interpreted these results in a framework of biased competition between configural cues on opposite sides of the boundary. Other evidence for

doi: 10.1167/9.10.8 Received January 15, 2009; published September 10, 2009 ISSN 1534-7362 © ARVO

local figural cues comes from studies on shape perception based on local contour geometry. Stevens and Brookes (1988) demonstrated that local geometry of contour curvature sign (convexity) and concave cusp are reliable figure/ground determiners. Hoffman and Singh (1997) argued that geometry of local curvature extrema determines the local saliency of shape parts, which in turn influences local figure/ground assignment. The presence of local figure/ground cues at operating independently at distinct points along a contour sets up the possibility of mutually inconsistent local figure/ground assignment. But this possibility has rarely been tested empirically.

We investigated a class of figures where local cues, such as closure, symmetry and convexity, to figure/ground conflict with global ones in a potentially inconsistent manner: *negative parts*. A negative part is a ground area mostly (but not completely) surrounded by an object, and which is perceived as having its own "shape," such as an indentation in the contour like a bay, or a bite taken from an apple. Hoffman and Richards (1984) classified parts into two categories based on the sign of curvature at their boundaries: positive parts, which are stretches of contour bounded by negative curvature extrema, and negative parts, which are bounded by positive extrema. All else being equal, figure/ground is assigned so that the most salient parts are figural (Hoffman & Singh, 1997). So if their shape is sufficiently "figural" (e.g., locally symmetric and convex) negative parts naturally set up a conflict between local figure/ground cues and the global bias to interpret interior as figure (so that the negative part would have to be ground).

In this study, we investigated the interpretation of border ownership, and thus figure/ground assignment, along the boundary of an object containing a negative part. Most previous studies on figure/ground organization have relied on explicit verbal report or two-alternative forced choice of the global interpretation of figural assignment between two adjacent regions. Such methods make it difficult to ascertain border ownership locally at specific, isolated points along a boundary, as we required in order to study the consistency of border ownership along the boundary. Moreover such methods are potentially susceptible to higher-level interpretations or extra-perceptual factors (Vecera, 2000; Vecera & O'Reilly, 1998; Vecera et al., 2002), and are generally not as quantitatively sensitive as we desired. Hence we sought a new method that (a) did not depend on direct verbal report of figure and ground, and (b) allowed figural status to be probed locally at specific points along a boundary.

To accomplish this, in the studies presented below we introduce an indirect but robust measure of local boundary ownership. Several studies have demonstrated that contour motion is perceptually owned by the figure rather than the ground (e.g., Barenholtz & Feldman, 2006; Barenholtz & Tarr, 2009; Duncan, Albright, & Stoner, 2000; Nakayama et al., 1989). The study by Barenholtz and Feldman (2006) also hinged on the fact that local motion (in their case, a single articulating vertex) is owned by the figure, in their study leading to a figure/ground inversion. Hence we reasoned that we could probe figure/ground status in an otherwise static figure by introducing a small local motion signal at an isolated point along the contour, and then asking the subject which side of the boundary appeared to be moving.

In the studies below, we presented subjects computer-generated animation sequences of a circular region including a "bay" or indentation (Figures 1a–1c), whose shape varied in a manner designed to modulate the degree to which it was perceived as a negative part. Somewhere along the boundary (in some trials within the bay, on others elsewhere along the boundary) there was a probe point that appeared to "vibrate" in place (undergo local periodic motion; see Figure 1d). We asked subjects which color appeared to be moving (the interior color or the exterior color), which as argued above reflects the perceived ownership of the boundary at the location of the probe point. Thus the subject's response indirectly but reliably reflects the perceived border ownership at the given point on the contour.

Using this methodology, Experiment 1 establishes that figure/ground tends to invert locally inside a negative part, to a degree that depends on the geometry of the negative part and thus its salience. Experiment 2 shows that if surface layer information which disambiguates depth ordering is given more overtly, by an occlusion cue, the local figure/ground reversal observed in Experiment 1 disappears. Taken together, our study suggest that many local and global cues combine and compete to produce an ultimate percept that may not be globally consistent. Negative parts constitute a particularly acute case where local factors combine to combat the overall global preference for interior as figure, leading to a globally inconsistent figure/ground assignment.

Experiment 1: Measuring border ownership inside and outside a negative part

Experiment 1 tested how border ownership might vary locally along the contour of an object with a negative part. We showed subjects computer-generated animation sequences of a circular region including a bay, with a vibrating probe point as described above located somewhere on the boundary (see Figure 1). Figure 1d gives a magnified view of the only varying part in animation sequences, two alternating frames of a probe composed of one cycle of small triangle wave. Locally, the boundary is rotationally symmetric about its central point, meaning that both sides have exactly the same local geometry, and is thus perfectly ambiguous in terms of figure and ground. When set in motion the point thus gives an impression of

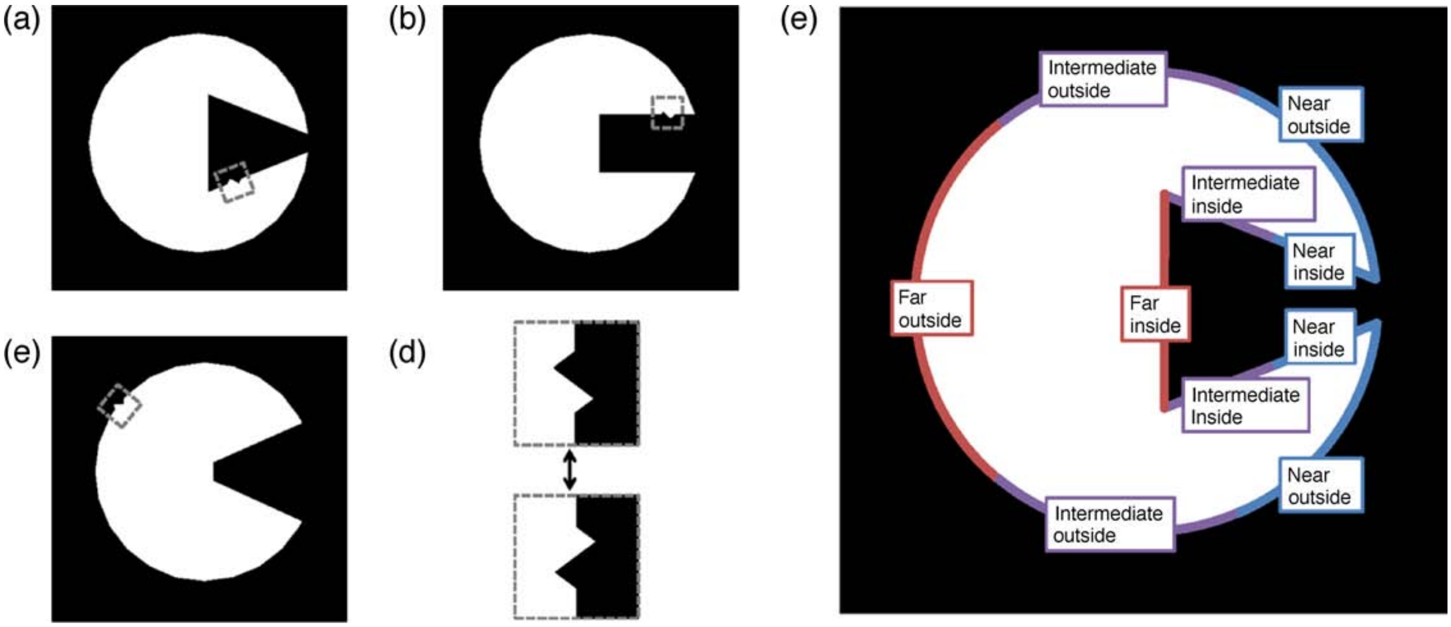

Figure 1. (a)–(c) Examples of displays used in Experiment 1. The gray dotted window refers to a probe point (in real displays, gray dotted windows were not presented). Moving probes (inside gray dotted windows) were randomly assigned along the contour. (a) A medium size stimulus with small entrance. (b) A medium size stimulus with medium entrance. (c) A medium size stimulus with large entrance. (d) Magnified diagrams of two alternating probe sequences. (e) Six positions of the moving probe along the boundary either inside or outside the bay, and either near, far, or intermediate in distance from the bay boundary: far outside, intermediate outside, near outside, near inside, intermediate inside, and far inside. For animated versions, see the Supplementary materials.

local vibration, which will be attributed to whichever side is interpreted as figure. More specifically, the probe has a zig-zag shape with two "tips" pointing in opposite directions, one of which will be interpreted as convex, and the other concave; which is which depends on the figural assignment. When the display is in motion, whichever tip is perceived as convex is perceived as rapidly moving back and forth. By design the entire probe is very small, so this motion is perceived as a rapid vibration attributed to the figural side. The subject's response thus provides a measure of the local figural assignment.

We sought to use this method to assess figural assignment along the boundary within a negative part, comparing it to figural assignment along the same boundary outside the negative part. To modulate the strength of the expected effect, we varied the geometry of the bay in such a way as to modulate its part salience and thus the degree to which it would in fact be perceived as a negative part. Specifically, we used a trapezoidal bay shape (Figure 1), varying size of the opening relative to the rest of the bay. Smaller openings (more nearly closed bays) have more sharply curved cusps at their boundaries, conveying a higher degree of salience to the negative part (Hoffman & Richards, 1984; Hoffman & Singh, 1997), and thus, we expected, a greater degree of figural inversion relative to the rest of the shape.

Moreover, we were interested in tracking border ownership over the entire boundary of the shape, in order to study the transition between the negative part and the rest of the shape. To this end we placed probe points at a variety of positions along the boundary, from deep within the negative part, to points near the cusp, to points far outside the negative part (Figure 1e). The key question here is whether any alteration of figural happens smoothly over an extended ratio of contour, or, alternatively, abruptly at the cusp.

Summarizing the logic of the experiment, we sought to test for the possibility of inconsistent figure/ground assignment along the length of an object's border. Our subjects were asked simply which color appeared to have moved, as a way of indirectly asking which region perceptually owned the vibrating probe point. What is really moving, of course, is not either area but the common border between them. But if the motion of the border is perceptually owned by the figure, as we have argued, subjects will attribute the motion to the side they perceive as figure. This allows our experiments to assess figural status at each point along the boundary independently.

Method

Participants

Eleven Rutgers University undergraduates participated for course credit, and they were naïve to the purpose of the experiment.

Stimuli

Stimuli were computer-generated animation sequences consisting of a pair of two alternating frames of 50 ms presented consecutively 7 times, so total duration was 700 ms for the entire animation sequence. Each animation frame consisted of a black or white polygon (approximately circular) with a "bay" (Figure 1). The central shape was presented white against black background on half of the trials and black against white on the others (counterbalanced and crossed with other factors). The central polygon was originally a 24-sided polygon, measuring approximately 7.2° × 7.2° in visual angle, but there introduced a bay, an arm of the background penetrating far into the polygon. A bay can be placed on the left side of the polygon or the right. There were three bay size conditions, large, medium, and small, in which the length between the innermost side and the entrance was respectively 4.6°, 3.5°, and 2.3°, and bay area was respectively about 34.7, 12.7, and 7.1 square degrees. We also manipulated the shape of the bay by varying the ratio between the innermost side and the entrance, with keeping the area of a bay the same regardless of the shape within the same level of the bay size factor. The ratio between the inner side and the entrance was 1:5 (large entrance), 1:1 (medium entrance), or 5:1 (small entrance), such that as the ratio is larger, entrance of a bay was more enclosed, making the bay more salient (Figures 1a–1c).

A moving probe was constructed by interpolating one cycle length of small triangle wave (amplitude 0.2°, one cycle 0.8° in visual angle) on the contour of an otherwise smooth polygon (Figure 1d). In two alternating frames, the probe was positioned at the same point of the contour, but only the curvature polarity of the triangle wave was reversed, so in animation sequences a probe is perceived as vibrating in place. The moving probe was placed either inside or outside the bay, and either far, intermediate, or near in distance from the bay boundary, resulting in six positions: far outside, intermediate outside, near outside, near inside, intermediate inside, and far inside (Figure 1e). The position used on each trial was determined randomly. The purpose of this manipulation was to allow us to probe figure/ground assignment locally at points that were either inside the negative part, or elsewhere along the contour, and more generally track the percept as it (potentially) changed along the contour. The probe was always interpolated on locally straight contour segments between each neighboring vertex pair, but not on vertices.

Design and procedure

Subjects sat in a dark room at a distance of approximately 57 cm from the monitor. The animation stimuli were generated and presented by an Apple G4 computer connected to a 17 inch monitor (1152 × 864 pixels at 80 Hz). Each subject completed 16 practice trials, followed by 432 trials divided in three blocks of 144 trials each, i.e., 2 [repetition] × 2 [color] × 2 [bay orientation] × 3 [bay shape] × 3 [bay size] × 6 [probe position]. All conditions were interleaved and the order of presentation of the trials was randomized for each subject. They were encouraged to take breaks if necessary at the end of each block. Each trial was initiated with presenting the plus sign (+) at the center of the screen. When subjects pressed the space bar, the plus sign disappeared and animation sequences were presented. After the animation finished, the last frame kept still until subjects responded. They were asked to decide which color appeared to be moving between white and black. The participants were to press the key "c" when black color appeared to be moving, and the key "m" when white did.

The dependent measure to be analyzed in this and the subsequent experiment was the proportion of "exterior moving" responses, that is, the proportion of responses that the color of the outside area (black in trials of white polygon stimuli, or white in trials of black polygon) appears to have moved.

Results and discussion

The subjects' exterior moving response rate was analyzed as a function of color, orientation, and three experimental factors of bay shape, bay size, and probe position. Analysis of Variance showed no main effect between left-sided bay and right-sided bay conditions, $F(1, 10) = 1.044$, $p = 0.33$. There was a significant effect of the figure/ground color, $F(1, 10) = 6.17$, $p = 0.03$, with a higher exterior moving response in the black figure/white ground (28.2%) condition than in the white figure/black ground condition (18.4%). However, color did not yield any significant interaction with any of three experimental factors, so, in the analysis of three experimental factors, all color and orientation conditions were pooled.

ANOVA did not yield a significant difference among three bay size conditions, $F(2, 20) = 1.016$, $p = 0.38$, and the mean exterior moving response in each large, medium, and small size condition was 23.9%, 23.9%, and 22.0%, respectively. However, there were significant effects of the other two experimental factors (Figure 2). The effect of bay shape was significant, $F(2, 20) = 10.030$, $p = 0.01$. Means for a small, a medium, and a large entrance were respectively 28.8%, 22.2%, and 18.9%, so the narrower the entrance of a bay compared to the innermost side, the more subjects responded that the exterior color appeared to have moved. The effect of the probe position was also significant, $F(2, 20) = 10.030$, $p = 0.01$. The proportion of exterior moving response was higher when the probe was positioned inside the bay than when it was outside; means for far outside, intermediate outside, near outside, near inside, intermediate inside, and far inside conditions were respectively 15.4%, 16.4%, 15.5%, 31.2%, 31.4%, and 29.8%. There were almost no differences among the three inside positions, nor among the three outside positions, but there was a sharp increase at the transition of probe

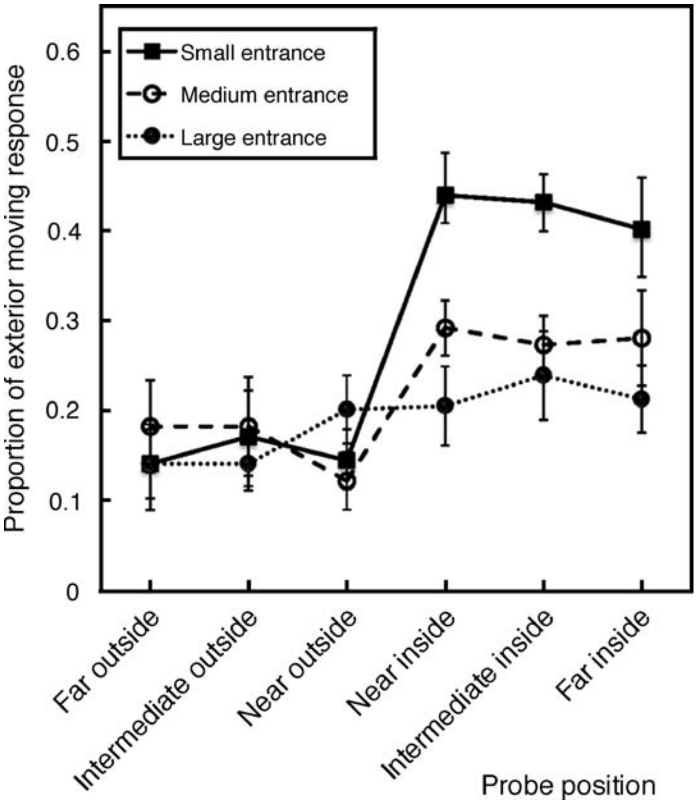

Figure 2. Results from Experiment 1. Proportion of exterior moving responses for the three bay shapes over the six probe positions. Error bars in this and all following graphs represent ± one standard error.

position from outside to inside of a bay, as is seen in Figure 2. Post-hoc analysis revealed that no pairwise differences within the inside-bay conditions were significant, nor within the outside-bay conditions ($p > 0.05$), but every comparison between any inside condition and any outside condition was significant ($p < 0.03$).

The interaction between bay shape and probe position was also significant, $F(10, 100) = 4.736$, $p < 0.001$. When the probe was positioned outside the bay, there was no effect of bay shape. But, when the probe was inside the bay, the exterior moving response rate was higher when the bay opening was smaller (more nearly closed) and so the saliency of a bay was increased. This demonstrates that contour ownership tends towards local reversal inside a negative part, at least when the negative part is salient. In fact, the effect is surprisingly categorical when the negative part is salient. As can be seen in Figure 2, in the small-entrance condition (most salient negative part) the exterior moving response rate is uniformly higher inside the bay than it is outside, as if the local figure/ground assignment makes an abrupt transition at the entrance of the bay. This categorical effect is still visible but diminished in the medium-entrance condition, but absent in the large-entrance condition, suggesting that the large-entrance bay does not function as a negative part.

It should be noted that the exterior moving response never exceeded 50% in any condition, so this tendency does not completely overturn the global preference for interior as figure. But the tendency suggests that contour ownership assignment is not necessarily globally consistent, contrary to the usual assumption. Rather, figure/ground organization is influenced by local mechanisms and is not constrained to yield a globally consistent result (Hoffman & Singh, 1997; Peterson, 2003a; Peterson & Lampignano, 2003; Peterson & Salvagio, 2008), allowing a local tendency towards contour ownership reversal within a salient negative part.

Experiment 2: Border ownership reversal without depth reversal?

As mentioned above, in figure/ground organization depth and figural assignment are usually understood to be tightly connected, so that the figural side is always perceived as both closer to the observer and shaped by the common contour. In Experiment 1, we measured border ownership inside and outside negative parts, and found a tendency towards border ownership reversal inside a negative part. But what about depth assignment when border ownership is locally reversed? We did not measure relative depth assignment *per se,* so we cannot conclude anything about depth assignment inside negative parts. One possibility is that depth assignment and contour ownership would be tightly coupled, consistent with the traditional Gestalt assumption that the figural side and the nearer side are necessarily one and the same. Another possibility is that contour ownership and figural depth assignment might be dissociable. Unlike other forms of ground, negative parts have quasi-figural status and some degree of shape status, so it might be that negative parts are at ground depth, but unlike other ground areas own the common contour.

In Experiment 2, to test these possibilities, we added a bar occluded by the central polygon to serve as a clear cue to depth ordering. In Experiment 1, if local contour ownership reversal was accompanied by depth reversal inside negative parts, an occluded bar should suppress the possible depth reversal inside a negative part, because the occluded bar induces a strong percept that the central polygon is in front of it, so figural depth inside a negative part is incompatible with the occlusion cue. If depth reversal had been concomitant with contour ownership reversal inside parts in Experiment 1, when an occluded bar was added, exterior moving response to a moving probe inside a bay should be decreased compared to that in Experiment 1. Conversely, if contour ownership is dissociated from figural depth inside a negative part, an occluded bar would have no effect on local contour ownership reversal within the bay.

Method

Participants

Twelve new Rutgers University undergraduates participated for course credit, and they were naïve to the purpose of the experiment.

Stimuli and procedure

Stimuli and probe motion were generated as in Experiment 1, and the equipment and procedure were also identical to those in Experiment 1. The only difference in this experiment is that a gray bar (length 14.5 deg) occluded by the polygon is introduced to suppress the possible depth reversal inside a negative part. We used three occluded bar types, defined by the position of the bar relative to the moving probe: no-bar, a bar far from the probe (far-bar), and a bar near to the probe (near-bar; see Figure 3). The no-bar display was the same as the display used in Experiment 1. In a far-bar display an occluded bar behind the central polygon was positioned to the remote side from a moving probe, so that when a moving probe was inside the bay an occluded bar was always outside the bay and vice versa. In a near-bar display, the bar was always near a moving probe by about 1.0° visual angle, from a probe to the nearest contour point of a bar, regardless of the position of a moving probe.

The three bar types were blocked to ensure that the desired depth ordering was consistently perceived, and the block order was counterbalanced across subjects. Each blocked condition was composed of 216 trials, i.e., 2 [color] × 2 [orientation] × 3 [bay shape] × 3 [bay size] × 6 [probe position], and preceded by 16 practice trials. In each block, all conditions were crossed and the order of presentation of the trials was randomized for each subject.

Result and discussion

Data were analyzed individually for each subject as a 3-factor, repeated measures ANOVA. The factors were bar type, bay shape, and probe position. As in Experiment 1, bay shape and probe position yield significant effects on exterior moving response, $F(2, 22) = 5.520$, $p = 0.011$, and $F(5, 55) = 5.007$, $p = 0.001$, respectively. As in Experiment 1, the interaction between bay shape and probe position was significant, $F(10, 110) = 2.341$, $p = 0.015$. The main effect of bar type did not reach significance, $F(2, 22) = 1.854$, $p = 0.18$. But the interaction between bar type and bay shape was significant, $F(4, 44) = 3.000$, $p = 0.028$ (Figure 4a). When the bay entrance was large or medium, there were no significant differences among the three bar positions ($p > 0.05$). But when the entrance was small, the condition in which we found the largest figure/ground reversal in Experiment 1, there was a significant effect of the bar position, $F(2, 22) = 3.735$, $p = 0.04$. That is, the combination of conditions that produced the largest reversed border ownership effects in Experiment 1 was most affected by the position of the bar in Experiment 2. To confirm this interpretation, we separated out the small entrance condition, and examined the interaction between the probe position and the bar type (Figure 4b), which was significant, $F(10, 110) = 2.189$, $p = 0.023$. Summarizing, in the three conditions where the probe was presented outside the bay, there was no effect of the presence or position of an occluded bar, presumably because there was no tendency towards figure/ground reversal. But in conditions where we expected a tendency to reverse figure/ground, i.e. where the probe was inside a bay with a narrow entrance, the presence and position of the bar has a significant effect. When the bar is near the probe, suppressing the depth reversal, contour ownership (as revealed by the probe) follows suit.

Figure 3. Three displays types used in Experiment 2. (a) No-bar display, equivalent to the displays used in Experiment 1; (b) Near-bar display, where an occluded bar behind the central polygon was positioned on the same side as the moving probe; that is, behind the bay when the probe was inside the bay (as pictured), or on the other side of the shape when the probe was outside the bay. On these trials the bar was always about 1.0° visual angle separated from the moving probe. (c) Far-bar display, where the bar was on the other side of the shape when the probe was inside the shape (as pictured), or behind the bay when the probe was outside the bay.

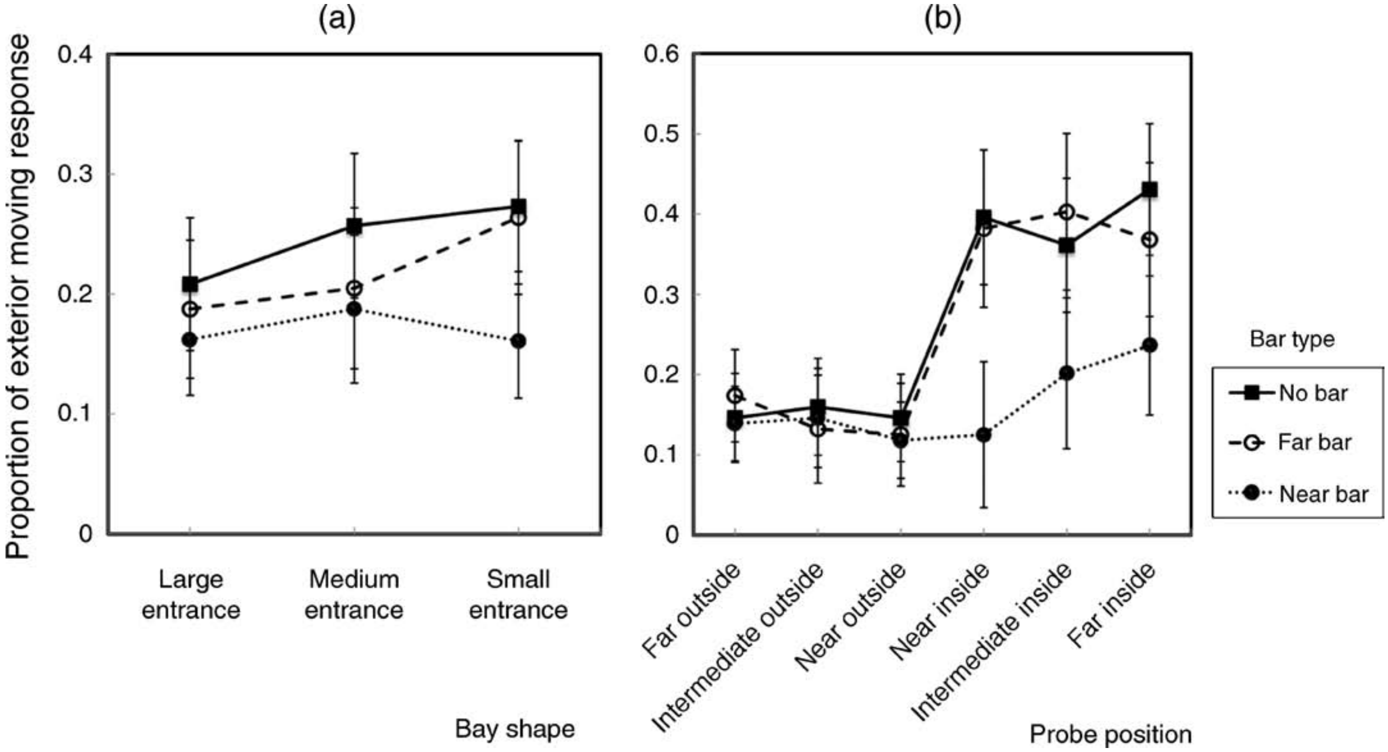

Figure 4. Results from Experiment 2. (a) Proportion of exterior moving response for three bar types (no-bar, far-bar, near-bar) over the three bay shapes. (b) Proportion of exterior moving response for three bar types over the six probe positions, for small-bay-entrance condition only.

These results show that the depth-ordering cue of an occluded bar exerted sufficient effect on figure/ground organization so that in a near bar display participants responded more that a moving probe belonged to inner area which looked closer to them than outer area of background. That is, in a 'near-bar' display the exterior moving response was suppressed, and so the local border ownership reversal disappeared. This result suggests that the contour ownership reversal observed in Experiment 1 was accompanied by depth reversal, so when depth reversal is suppressed, contour ownership reversal is also suppressed. In contrast, in the far-bar display the results were similar to those in the no-bar display; the occluded bar far from the bay exerts little effect on figure/ground within the bay. The tendency towards contour ownership reversal inside a negative part is a genuinely local effect, in the sense that it is not affected by depth cues outside the negative part. This suggests that global figure/ground organization is probabilistically defined by combinations of local and global of local cues, and is not constrained to yield a globally consistent result.

General discussion

Figure/ground organization is a dynamic and complex process in which various factors cooperate or compete with one another. Most research on figure/ground organization has assumed that it occurs in globally consistent manner along the whole contour of a figure, and has focused on identifying these Gestalt configural factors that allow one entire region to appear as the figure and another to appear as the ground. However, we have found that figure/ground assignment can be influenced not only by a combination of global cues but also by local cues that may differ from place to place along a single contour.

Given that most previous studies on figure/ground organization have been based on the influence of border ownership on the global interpretation of figural assignment, to understand border ownership locally at specific, isolated contour points we introduced a new task based on local contour motion attribution. In this study, we investigated the interpretation of border ownership within a negative part. The results from two experiments showed that subjects' probe motion attribution was modulated by both the position of the moving probe (inside vs. outside the negative part) and the saliency of negative parts. We found a tendency towards border ownership reversal locally inside a negative part, which suggests that border ownership assignment is not an all-or-none process, but rather locally autonomous and graded process that is not strictly constrained by global configural cues.

Validity of the motion probe ownership task

Is our motion probe ownership task a good measure of local figure/ground assignment? The vast majority of studies on figure/ground organization have relied on explicit verbal reports of figure/ground. Those subjective reports can be affected by extra-perceptual, top-down factors, such as spatial attention, experimental instruction, and observers' strategies (Driver & Baylis, 1996; Rubin, 1921; Vecera, 2000; Vecera & O'Reilly, 1998; Vecera et al., 2002). As a subjective measure, our task also has potential susceptibility to extra-perceptual factors. However, because it is indirect, and does not overtly ask subjects to consider figure, ground, or depth relations, it seems relatively immune to subjective expectation about those factors, such as that they be globally consistent.

At the same time, there is good reason to think that local motion attribution tracks figural status. Several studies have demonstrated that contour motion is perceptually owned by the figural surface rather than background (e.g., Barenholtz & Feldman, 2006; Barenholtz & Tarr, 2009; Duncan et al., 2000; Nakayama et al., 1989). Hence we reasoned that local motion ownership is the consequence of figural border ownership of the local contour point, and this makes it a reasonable candidate as an indirect measure of figural border assignment.

To more completely validate the method, further studies are required to assess whether the method is sensitive to the various configural cues known to play a role in determining figural status. Such a project is beyond the scope of this paper, but as a tentative step in that direction, we examined from our Experiment 1 data a possible modulation on figure/ground assignment due to the lower region cue (Vecera et al., 2002). Vecera et al. (2002) proposed that there is a tendency, when a display segments into distinct upper and lower regions, to interpret the lower region of a display as figure and the upper as ground. In our displays, with the exception of "far outside" and "far inside" contours that were vertical, each probe position falls on the boundary between and upper and a lower region (see Figure 1e), allowing to assess whether our task corroborated Vecera et al.'s principle. In trials where a probe was presented outside the bay, there was no significant effect of the contour position factor, apparently due to a floor effect (very low exterior moving response rate). However, when the probe was inside a negative part, there was a significant tendency for the lower region to be perceived more often as figural, as measured by the motion probe response (p = .023). We also broke the effect down by bay shape, to examine which bay shape condition most contributes to this tendency (Figure 5b). The effect was largest in the medium-entrance condition, where the boundaries are horizontal, so the division between upper and lower regions would be most clear (Figure 5a). That is, especially with horizontal boundaries, lower regions were more likely to be gauged figural by our task than were upper regions, consistent with Vecera's claim. For at least one known cue, then, the probe motion ownership task corroborates a known effect.

Another complicating issue is the timing of the motion probe. Our displays remained on the screen statically following the 700 msec motion sequence, until response.

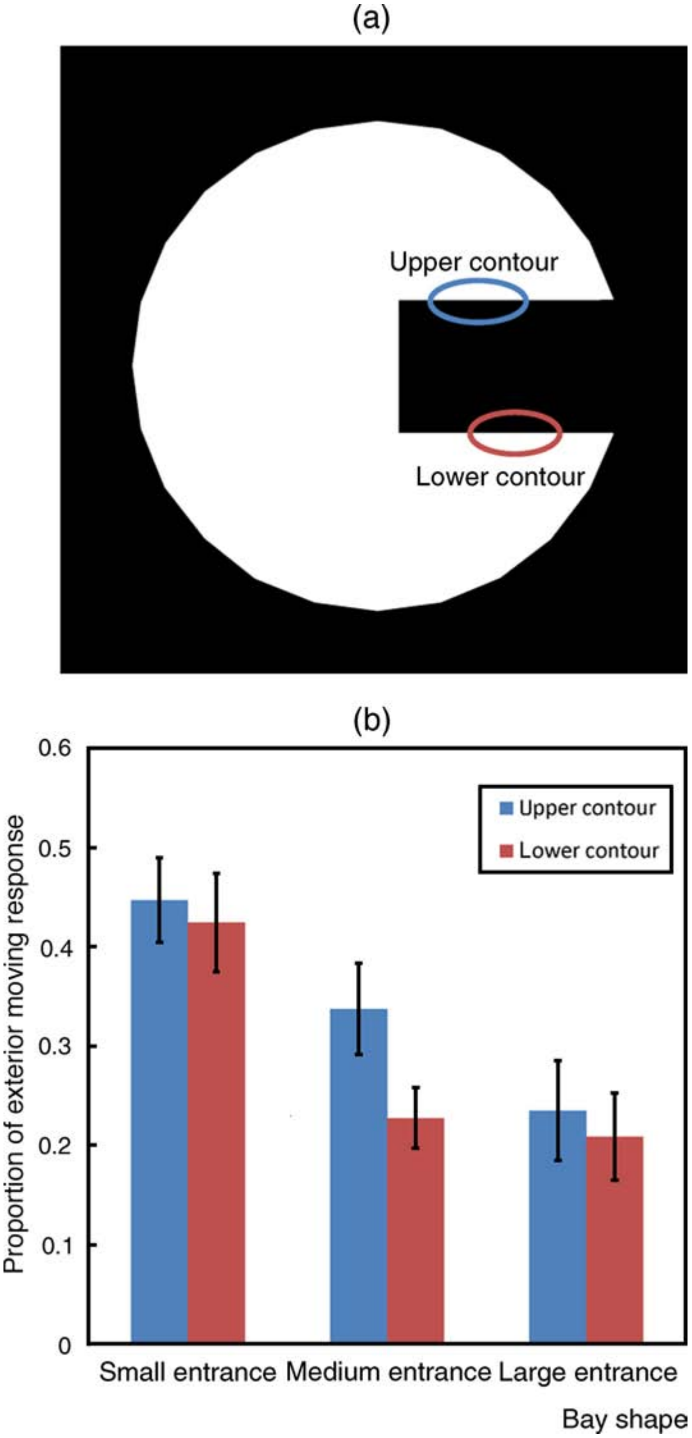

Figure 5. (a) Upper and lower contour inside a bay with medium entrance. Notice that the bay area is the lower area relative to the upper contour, and the upper area relative to the lower contour. (b) Proportion of exterior moving response for probes on upper and lower contours inside a bay and for three bay shapes.

Given the dynamics of local cue competition, it is entirely possible that the percept is in flux over this period, potentially resulting in variations in the percept over the course of processing. As an initial step towards understanding such potential timing factors, we analyzed performance in Experiment 1 as a function of response time. We divided subjects into two groups on the basis of whether their mean RTs were faster or slower than the overall mean RT (six subjects for fast RT group and five for slow RT group), and analyzed their responses. (One trial exceeded 22 minutes and was excluded.) There was no group difference, $F < 1$, nor were there any significant two-way or three-way interactions between the group factor and bay shape or probe position. In future experiments, we hope to explore the timing of the motion probe attributions more systematically, but these results suggest that the nature of our effect does not depend substantially on the timing of responses.

A continuum of contour closure

Gestalt psychologists took special notice of the fact that a contour forming a closed or almost closed figure is not simply perceived as a line on a homogeneous background, but as the boundary of a surface or region (Kanizsa & Gerbino, 1976; Koffka, 1935). A closed contour divides an image into an inside (figure) and an outside (ground), and many if not all shape properties, such as the sign of curvature, convexity/concavity, and medial axes, are defined relative to the assignment of figure (Baylis & Driver, 1995; Hoffman & Richards, 1984). Accordingly, contour closure enhances the perception of shape in a number of ways, e.g. enabling objects to pop out from distracters (e.g., Elder & Zucker, 1993, 1994; Kovacs & Julesz, 1993; Mathes & Fahle, 2007). Elder and Zucker (1993, 1994) in particular showed that the concept of contour closure in shape perception is not an all-or-none property, but defined in graded manner as "continuum of contour closure," finding that even mostly (but not perfectly) closed targets enjoy enhanced detectability relative to open ones.

Gillam (1975) also provided evidence for a continuum of contour closure, showing that under ambiguous motion of line segments in depth, subjects' percept of common motion among line segments monotonically increases as the gap between them is decreased. Once contour closure exceeds some threshold, a partially closed contour produces almost the same degree of perceived common motion of as a completely closed contour. Peterson and Lampignano (2003) further demonstrated that partial closure can serve as a figural cue. They showed that when a gap between two articulated edges of two objects is small enough, partial closure cue of ground side between the two objects can compete with other configural cues on an object side for the border shared by ground and the object. It implies that closure is not necessarily a global cue, but can work as a local cue.

Thus it is natural that the "degree of figurehood" of a negative part would follow from its degree of closure, as we found: we observed higher rates of exterior boundary ownership when the bay's opening was smaller and thus the negative part more closed.[1] That is, indentations that are more closed are interpreted more as figures and less as grounds. Thus the continuum of contour closure found by Elder et al. and Gillam apparently extends to negative parts.

Neurophysiological evidence concerning border ownership and depth

As discussed earlier, border ownership is closely connected with figural depth in figure/ground organization. The fact that the tendency towards figural reversal disappears in the vicinity of the occlusion cue dictating depth ordering, as we found in Experiment 2, suggests that the tightly coupled relationship between figural depth and figural border assignment is consistently conserved at each "local" point along the contour, even if figure/ground relation is not "globally" consistent along the contour. This relates directly to studies of the neural representation of border ownership and relative depth.

Recent neurophysiological studies (Lamme, 1995; Lee, Mumford, Romero, & Lamme, 1998; Qiu & von der Heydt, 2005; von der Heydt, Qiu, & He, 2003; Zhou, Friedman, & von der Heydt, 2000; Zipser, Lamme, & Schiller, 1996) have found cells sensitive to border ownership in cortical areas V1, V2 and V4, suggesting a local neural representation of figure/ground assignment broadly consistent with the local (rather than global) determination we found in Experiment 1. Zhou et al. (2000) showed that some orientation selective neurons in V2 responded with different strength to the same edge of a square figure defined by luminance contrast, depending on the side of the figure to which the edge belonged, suggesting neural encoding of unilateral border ownership. In addition, many of these cells combine side-of-figure selectivity with selectivity for the depth order of surfaces, defined by binocular disparity cues (Qiu & von der Heydt, 2005) or by dynamic occlusion cues (von der Heydt et al., 2003), in a manner that is consistent with three-dimensional object perception. This observation suggests that neuronal side-of-figure selectivity to two-dimensional images is tightly connected to three-dimensional surface interpretation of the given images, consistent with psychophysical observations that border ownership assignment is modulated by three-dimensional depth order (e.g., Nakayama et al., 1989), and broadly consistent with the tight coupling between depth and figural assignment we found in Experiment 2.

What do those neurophysiological studies suggest about the possibility of mutually inconsistent border ownership induced by negative parts that we have observed? Of course, neural responses to border ownership in V2 cells may not correspond closely to the phenomenal or psychophysically assessed percept of figure/ground. Nevertheless, the links between our results and these studies of neural coding are suggestive and consistent. Zhou et al. (2000) used a C-shaped figure, roughly comparable to the medium-entrance bay in our studies, to investigate border ownership coding under conflicting cues such as convexity, L junction, and closure. The inner contour of the C in their studies corresponds to the interior of a negative part in our displays. Though a completely reversed side preference was not observed in any cells for the inner contour of the C, more than half of the cells with significant side-of-figure preference for simple convex (square) figures did not exhibit any side preference (to either side) for the inner contour of the C—suggesting that the coding of the shape's interior as figure was weaker there than it would be on a "normal" convex boundary. This weakening of side preference along the inner contour of the C is broadly consistent with our psychophysical finding that the default assignment of interior as figure significantly weakens inside a negative part.

Further studies are required to understand the neural processes underling inconsistent border ownership assignment inside negative parts in two-dimensional display without any depth cues. Negative parts that are almost enclosed, like those in our small entrance condition, are an extreme case of conflict between multiple global and local cues like convexity, L junction, and closure. Closure in particular is doubly related among global and local cues: contour closure of whole objects with negative parts conflicts with the partial closure of the negative part itself. We expect that neural border ownership assignment is determined not by a single all-or-none process but by a combination of multiple mechanisms employing various available cues.

A continuum of negative parts

The primary goal of our study was to investigate border ownership inside negative parts. We observed a tendency towards border ownership reversal inside negative parts in Experiment 1. However, suppression of this border ownership reversal by addition of a depth-ordering cue in Experiment 2 suggests that this tendency is not purely the effect of border ownership per se, but rather accompanied by figural depth reversal. These results showed that when border ownership reverses, the resulting interpretation of the negative part is not as an empty bay, but rather as a surface extending from the background and over (occluding) the circular object (Figure 6a). This interpretation is no longer consistent with a simple figure occluding a simple background, but now involves at least three distinct depths.

The proportion of subjects' exterior moving responses to the moving probe inside negative parts with small entrance in Experiment 1 (over 40%) implies the presence of competition between the two percepts of a negative part of the otherwise circular region (Figure 6b) in case of exterior moving response, and a positive part of the background occluding a circular region (Figure 6a) in case of interior moving response. When there were no detectable depth-ordering cues, two percepts were competing as in Experiment 1. To disambiguate those competitive precepts, depth-ordering cues such as binocular disparity (Nakayama, He, & Shimojo, 1995), "accretion-deletion" defined by motion (Kaplan, 1969), or occlusion are needed, as shown in Experiment 2.

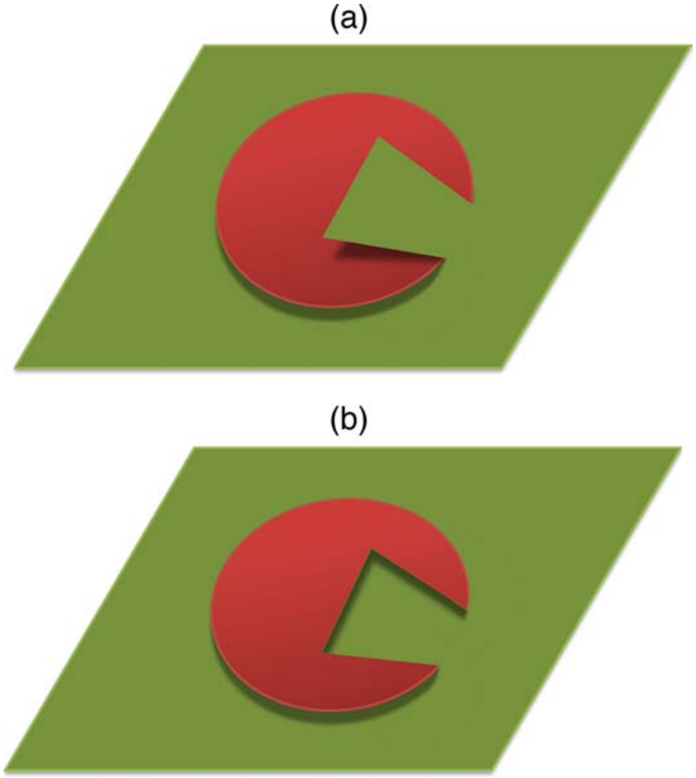

Figure 6. Two competing percepts of a bay. (a) A bay as a positive part of background (an arm of the background) in figural depth occluding a circular object. (b) An empty bay as a negative part.

One important topic that relates to the competitive figure/ground status of almost enclosed areas is the perception of holes. Recently the perception of holes (cutouts in a surface) has generated a great deal of discussion in the literature on figure/ground organization (see Bertamini, 2006; Palmer, Davis, Nelson, & Rock, 2008; Nelson & Palmer, 2001, for a review of issues concerning holes). A region perfectly enclosed by a surrounding area has two possible interpretations: as a convex object or as an empty hole. As in the case of negative parts, if enough depth cues are given, perfectly enclosed areas are eventually seen as empty ground (i.e., holes) instead of solid objects, but subjects can still recognize their shape similarly to their complement objects, seemingly violating the classical Gestalt assumption of unidirectional border ownership. In this connection, researchers have argued about whether holes are quasi-figures or ground areas (e.g., Casati & Varzi, 1994; Feldman & Singh, 2005; Palmer, 1999; Peterson, 2003b; Subirana-Vilanova & Richards, 1996; but Bertamini, 2006; Bertamini & Croucher, 2003; Bertamini & Hulleman, 2006; Bertamini & Mosca, 2004; Hulleman & Humphreys, 2005). Several proposals have sought to explain why and how people perceive the shape of holes (Bertamini, 2006; Palmer et al., 2008).[2]

The present study implies that an almost, but not completely enclosed area in a two dimensional display can also have two competing percepts. If the contour of a negative part is owned by the surrounding area, but not by the negative part itself, given sufficient depth-ordering cues, its shape might be perceived as quasi-triangular or trapezoidal. If so, the negative part would be in the same situation as a hole. There is indeed evidence that negative parts behave similarly to holes in shape perception. Bertamini (2006) shortly reported his observation that observers made similar responses to both holes and negative parts (in his term, objects with missing regions) in a similarity judgment task. A recent study by Kim (2008), to compare visual working memory (VWM) capacity for objects having holes or bays to that for objects with their complements, also suggest that contour features of negative parts are encoded in VWM in a way that is similar holes, but different from other ground areas. By modifying Xu's (2002) beachball-like stimuli, he constructed colored circles with oriented, bar-shaped, holes or bays, and also manipulated the color of holes and bays so that empty hole/bay and filled hole/bay displays were employed. His result showed that there were no differences in change detection performance between empty holes and filled holes, as well as between empty bays and filled bays—suggesting that contour features of both holes and bays require the same encoding load as their complement solid bars.

In those respects, negative parts can be seen as lying on a continuum with holes at one extreme and convex figures at the other, modulated by degree of closure as defined in a graded manner (Elder & Zucker, 1994). As closure is a graded property, negative part status is likewise a graded property that depends on the geometry of the shape indentation.

Conclusion

Our study suggests that in figure/ground organization many local and global cues combine and compete to produce an ultimate percept (Fowlkes, Martin, & Malik, 2007; Peterson & Lampignano, 2003; Peterson & Salvagio, 2008), which may not be globally consistent even if it favors one side as a figure. Negative parts provide a simple context in which such inconsistent border assignment manifests itself, as measured by our motion probe ownership task. Negative parts in effect constitute a "battleground" between competing local and global figural cues. As such they may provide an excellent opportunity to study the neural and computational processes involved in figure/ground assignment, and more broadly to understand cooperation and competition between local and global perceptual cues more generally.

Acknowledgments

Supported by NIH EY15888 to J.F. We are grateful to Eileen Kowler, Manish Singh, Steve Palmer, and an anonymous reviewer for many helpful comments.

Commercial relationships: none.

Corresponding author: Sung-Ho Kim.
Email: sungho4@eden.rutgers.edu.
Address: Department of Psychology, Center for Cognitive Science, Rutgers University, New Brunswick, NJ, USA.

Footnotes

[1] There are actually at least two different factors involved here that influence the "degree of figurehood" of negative parts related to closure: the size of the opening *per se,* and the magnitude of the turning angles at the two sharp positive maxima of the opening formed by intersection between the inner and outer contour. These two variables can obviously be manipulated independently to a large extent, though we have done so here. In our experiments smaller openings (more nearly closed bays) always had more sharply curved cusps at their boundaries, to convey a higher degree of salience to the negative part.

[2] The shape properties of holes form a large topic beyond the scope of this study. We briefly mention two relevant hypotheses concerning the perceived shape of holes. Bertamini (2006) suggested that people can recognize the shape of holes through the lock-and-key match between holes and their complement objects. When the visual system analyses the contour curvature of a shape, it registers the sign of both sides of the shape as being completely opposite, thus implying that the two sides analyzed are complementary. Palmer et al. (2008) explained observers' percept of the shape of holes by assuming at least two distinct levels of shape processes: an early process of local figure/ground organization, and a late process of global shape description. Exactly how these ideas relate to partially closed regions such as negative parts is unclear without further research.

References

Attneave, F. (1971). Multistability in perception. *Scientific American, 225,* 61–71. [PubMed]

Bahnsen, P. (1928). Eine Untersuchungüber Symmetrie und Asymmetrie bei visuellen Wahrnehmungen. *Zeitschriftfür Psychologie, 108,* 129–154.

Barenholtz, E., & Feldman, J. (2006). Determination of visual figure and ground in dynamically deforming shapes. *Cognition, 101,* 530–544. [PubMed] [Article]

Barenholtz, E., & Tarr, M. J. (2009). Figure–ground assignment to a translating contour: A preference for advancing vs. receding motion [Abstract]. *Journal of Vision, 9*(5):27, 1–9, http://journalofvision.org/9/5/27/, doi:10.1167/9.5.27.

Baylis, G. C., & Driver, J. (1995). One-sided edge assignment in vision: 1. Figure–ground segmentation and attention to objects. *Current Directions in Psychological Science, 4,* 140–146.

Bertamini, M. (2006). Who owns the contour of a visual hole? *Perception, 35,* 883–894. [PubMed]

Bertamini, M., & Croucher, C. J. (2003). The shape of holes. *Cognition, 87,* 33–54. [PubMed] [Article]

Bertamini, M., & Hulleman, J. (2006). Amodal completion and visual holes (static and moving). *Acta Psychologica, 123,* 55–72. [PubMed] [Article]

Bertamini, M., & Mosca, F. (2004). Early computation of contour curvature and part structure: Evidence from holes. *Perception, 33,* 35–48. [PubMed]

Casati, R., & Varzi, A. C. (1994). *Holes and other superficialities*. Cambridge, MA: MIT Press.

Driver, J., & Baylis, G. C. (1996). Edge-assignment and figure–ground segmentation in short-term visual matching. *Cognitive Psychology, 31,* 248–306. [PubMed]

Duncan, R. O., Albright, T. D., & Stoner, G. R. (2000). Occlusion and the interpretation of visual motion: Perceptual and neuronal effects of context. *Journal of Neuroscience, 20,* 5885–5897. [PubMed] [Article]

Elder, J., & Zucker, S. (1993). The effect of contour closure on the rapid discrimination of two-dimensional shapes. *Vision Research, 33,* 981–991. [PubMed]

Elder, J., & Zucker, S. (1994). A measure of closure. *Vision Research, 34,* 3361–3369. [PubMed]

Feldman, J., & Singh, M. (2005). Information along contours and object boundaries. *Psychological Review, 112,* 243–252. [PubMed]

Fowlkes, C. C., Martin, D. R., & Malik, J. (2007). Local figure–ground cues are valid for natural images. *Journal of Vision, 7*(8):2, 1–9, http://journalofvision.org/7/8/2/, doi:10.1167/7.8.2. [PubMed] [Article]

Gillam, B. (1975). The evidence for "closure" in perception. *Perception & Psychophysics, 17,* 521–524.

He, Z. J., & Nakayama, K. (1992). Surfaces vs. features in visual search. *Nature, 359,* 231–233. [PubMed]

Hoffman, D. D., & Richards, W. A. (1984). Parts of recognition. *Cognition, 18,* 65–96. [PubMed]

Hoffman, D. D., & Singh, M. (1997). Salience of visual parts. *Cognition, 63,* 29–78. [PubMed] [Article]

Hulleman, J., & Humphreys, G. W. (2005). Differences between searching among objects and searching among holes. *Perception & Psychophysics, 67,* 469–482. [PubMed] [Article]

Kanizsa, G., & Gerbino, W. (1976). Convexity and symmetry in figure–ground organization. In M. Henle (Ed.), *Vision and artifact*. New York: Springer.

Kaplan, G. A. (1969). Kinetic disruption of optical texture: The perception of depth at an edge. *Perception & Psychophysics, 6,* 193–198.

Kienker, P. K., Sejnowski, T. J., Hinton, G. E., & Schumacher, L. E. (1986). Separating figure from ground with a parallel network. *Perception, 15,* 197–216. [PubMed]

Kim, S.-H. (2008). Encoding the shape of holes in visual working memory. Poster presented at *Object Perception, Attention, and Memory Conference*. Chicago, IL.

Klymenko, V., & Weisstein, N. (1986). Spatial frequency differences can determine figure–ground organization. *Journal of Experimental Psychology: Human Perception and Performance, 12,* 324–330. [PubMed]

Koffka, K. (1935). *Principles of Gestalt psychology*. New York: Harcourt.

Kovacs, I., & Julesz, B. (1993). A closed curve is much more than an incomplete one: Effect of closure in figure–ground segmentation. *Proceedings of the National Academy of Sciences of the United States of America, 90,* 7495–7497. [PubMed] [Article]

Lamme, V. A. (1995). The neurophysiology of figure–ground segregation in primary visual cortex. *Journal of Neuroscience, 15,* 1605–1615. [PubMed] [Article]

Lee, T. S., Mumford, D., Romero, R., & Lamme, V. A. F. (1998). The role of the primary visual cortex in higher level vision. *Vision Research, 38,* 2429–2454. [PubMed] [Article]

Mathes, B., & Fahle, M. (2007). Closure facilitates contour integration. *Vision Research, 47,* 818–827. [PubMed] [Aticle]

Nakayama, K., He, Z., & Shimojo, S. (1995). Visual surface representation: A critical link between lower-level and higher-level vision. In S. Kosslyn, & D. Osherson (Eds.), *Visual cognition: An invitation to cognitive science* (pp. 1–70). Cambridge, MA: MIT Press.

Nakayama, K., Shimojo, S., & Silverman, G. H. (1989). Stereoscopic depth: Its relation to image segmentation, grouping, and the recognition of occluded objects. *Perception, 18,* 55–68. [PubMed]

Nelson, R., & Palmer, S. E. (2001). Of holes and wholes: The perception of surrounded regions. *Perception, 30,* 1213–1226. [PubMed]

Palmer, S. (1999). *Vision science: Photons to phenomenology*. Cambridge, MA: MIT Press.

Palmer, S., Davis, J., Nelson, R., & Rock, I. (2008). Figure–ground effects on shape memory for objects versus holes. *Perception, 37,* 1569–1586. [PubMed]

Peterson, M. A. (2003a). Overlapping partial configurations in object memory: An alternative solution to classic problems in perception and recognition. In M. A. Peterson, & G. Rhodes (Eds.), *Perception of faces, objects, and scenes: Analytic and holistic processes* (pp. 269–294). New York: Oxford University Press.

Peterson, M. A. (2003b). On figures, grounds, and varieties of amodal surface completion. In R. Kimchi, M. Behrmann, & C. Olson (Eds.), *Perceptual organization in vision: Behavioral and neural perspectives* (pp. 87–116). Mahwah, NJ: LEA.

Peterson, M. A., de Gelder, B., Rapcsak, S. Z., Gerhardstein, P. C., & Bachoud-Lévi, A. (2000). Object memory effects on figure assignment: Conscious object recognition is not necessary or sufficient. *Vision Research, 40,* 1549–1567. [PubMed]

Peterson, M. A., & Gibson, B. S. (1993). Shape recognition inputs to figure/ground organization in three dimensional grounds. *Cognitive Psychology, 25,* 383–429.

Peterson, M. A., & Gibson, B. S. (1994). Must figure–ground organization precede object recognition? An assumption in peril. *Psychological Science, 5,* 253–259.

Peterson, M. A., & Lampignano, D. W. (2003). Implicit memory for novel figure–ground displays includes a history of cross-border competition. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 808–822. [PubMed]

Peterson, M. A., & Salvagio, E. (2008). Inhibitory competition in figure–ground perception: Context and convexity. *Journal of Vision, 8*(16):4, 1–13, http://journalofvision.org/8/16/4/, doi:10.1167/8.16.4. [PubMed] [Article]

Peterson, M. A., & Skow, E. (2008). Inhibitory competition between shape properties in figure–ground perception. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 251–267. [PubMed]

Qiu, F., & von der Heydt, R. (2005). Figure and ground in the visual cortex: V2 combines stereoscopic cues with Gestalt rules. *Neuron, 47,* 155–166. [PubMed] [Article]

Rock, I. (1983). *The logic of perception*. Cambridge, MA: MIT Press.

Rubin, E. (1921). *Visuell wahrgenommene figuren*. Kobenhavn, Denmark: Gyldendalske Boghandel.

Rubin, E. (1958). Figure and ground. In D. Beardslee, & M. Wertheimer (Ed. and Trans.), *Readings in perception* (pp. 35–101). Princeton, NJ: Van Nostrand (Original work published in 1915).

Stevens, K. A., & Brookes, A. (1988). The concave cusp as a determiner of figure–ground. *Perception, 17,* 35–42. [PubMed]

Subirana-Vilanova, J. B., & Richards, W. A. (1996). Attentional frames, frame curves and figural boundaries: The inside/outside dilemma. *Vision Research, 36,* 1493–1501. [PubMed]

Vecera, S. P. (2000). Toward a biased competition account of object-based segregation and attention. *Brain and Mind, 1,* 353–384.

Vecera, S. P., & O'Reilly, R. C. (1998). Figure–ground organization and object recognition processes: An interactive account. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 441–462. [PubMed]

Vecera, S. P., Vogel, E. K., & Woodman, G. (2002). Lower region: A new cue for figure–ground assignment. *Journal of Experimental Psychology: General, 131,* 194–205. [PubMed]

von der Heydt, R., Qiu, F. T., & He Z. J. (2003). Neural mechanisms in border ownership assignment: Motion parallax and gestalt cues [Abstract]. *Journal of Vision, 3*(9):666, 666a, http://journalofvision.org/3/9/666/, doi:10.1167/3.9.666.

Xu, Y. (2002). Encoding color and shape from different parts of an object in visual short-term memory. *Perception & Psychophysics, 64,* 1260–1280. [PubMed] [Article]

Zhou, H., Friedman, H. S., & von der Heydt, R. (2000). Coding of border ownership in monkey visual cortex. *Journal of Neuroscience, 20,* 6594–6611. [PubMed] [Article]

Zipser, K., Lamme, V. A., & Schiller, P. H. (1996). Contextual modulation in primary visual cortex. *Journal of Neuroscience, 16,* 7376–7389. [PubMed] [Article]