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Inhibitory Competition Between Shape Properties in Figure–Ground Perception

Mary A. Peterson and Emily Skow
University of Arizona

Theories of figure–ground perception entail inhibitory competition between either low-level units (edge or feature units) or high-level shape properties. Extant computational models instantiate the 1st type of theory. The authors investigated a prediction of the 2nd type of theory: that shape properties suggested on the ground side of an edge are suppressed when they lose the figure–ground competition. In Experiment 1, the authors present behavioral evidence of the predicted suppression: Object decisions were slower for line drawings that followed silhouettes suggesting portions of objects from the same rather than a different category on their ground sides. In Experiment 2, the authors reversed the silhouette's figure–ground relationships and obtained speeding rather than slowing in the same category condition, thereby demonstrating that the Experiment 1 results reflect suppression of those shape properties that lose the figure–ground competition. These experiments provide the first clear empirical evidence that figure–ground perception entails inhibitory competition between high-level shape properties and demonstrate the need for amendments to existing computational models. Furthermore, these results suggest that figure–ground perception may itself be an instance of biased competition in shape perception.

Keywords: figure–ground perception, inhibitory competition, biased competition, familiarity, configural cues

A fundamental question in perception research is how do people perceive shapes? Shape perception is inextricably interwoven with *figure–ground perception.* Figure–ground perception occurs when adjacent regions of the visual field share an edge: In many circumstances, only one of the two regions is perceived as a shaped entity—a *figure.* The other region appears to continue behind the figure; this *ground* appears unshaped near the edge it shares with the figure.

Much of the literature on figure–ground perception has been concerned with identifying those properties that affect the likelihood that a region will be seen as figure. For instance, regions that are small, closed, convex, and/or symmetric are likely to be seen as figures (for a review, see Hochberg, 1971; Pomerantz & Kubovy, 1986; Rubin, 1958), whereas adjacent regions that are larger, open, concave, and/or asymmetric are likely to be seen as grounds. Because the Gestalt psychologists demonstrated that these properties affect figure–ground perception, they are called *Gestalt configural cues.* Contemporary researchers have identified other relevant properties. For instance, participants are more likely to see figures on the side of an edge where a portion of a familiar object (a *familiar configuration*) is sketched than on the opposite side (Peterson, Harvey, & Weidenbacher, 1991; for a review, see Peterson & Skow-Grant, 2003), and they are more likely to see the region below rather than above an edge as a figure (Vecera, Vogel, & Woodman, 2002).

An important yet neglected question is, how is figure–ground perception accomplished? Some computational models use inhibitory competition as a mechanism, but questions remain concerning what features compete. The extant behavioral and physiological evidence cannot adjudicate among these models. We review current models and proposals regarding the mechanisms of figure–ground perception and the relevant physiological and behavioral evidence. We then report on two experiments supporting a prediction derived from a proposal that the mechanism of figure–ground perception includes inhibitory competition between shape properties on opposite sides of an edge.

Computational Models, Physiological Evidence, and a Proposed Framework

Sejnowski and his colleagues (Kienker, Sejnowski, Hinton, & Schumacher, 1986; Sejnowski & Hinton, 1987) proposed the first competitive model of figure–ground perception. Their model included figure units separated by pairs of edge units facing in opposite directions (e.g., edge-left and edge-right units). Edge units facing in opposite directions inhibited each other but engaged in mutual excitation with figure units lying on their preferred side. In this early model, neighboring figure units responding to the same low-level features (e.g., color, luminance, or texture) engaged in mutual excitation. Kienker et al. (1986) used focused attention as a seed to increase the activity in one set of figure units and their associated edge units; these edge units suppressed edge

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Mary A. Peterson and Emily Skow, Department of Psychology, University of Arizona.

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Correspondence concerning this article should be addressed to Mary A. Peterson, Department of Psychology, University of Arizona, Tucson, AZ 85721. E-mail: mapeters@u.arizona.edu

units facing in the opposite direction, which in turn suppressed the figure units on the opposite side of the edge. The relatively enhanced activity in the figure units on one side of an edge was taken to realize figure assignment (see also Grossberg, 1994; Grossberg & Mingolla, 1993). Vecera and O'Reilly (1998, 2000) extended Kienker et al.'s model to account for Peterson et al.'s (1991; Peterson & Gibson, 1991, 1993, 1994a) effects of familiar configuration by using feedback from high-level neurons to increase the activity of the feature units lying on one side of an edge. It is important to note that the competitive models reviewed here assume that inhibitory competition occurs between edge units; none assume that competition occurs at high levels, even those that allow high-level effects (i.e., effects of attention or familiar configuration).

Lamme and his colleagues (e.g., Lamme, Rodriguez, & Spekreijse, 1999; Zipser, Lamme, & Schiller, 1996) reported physiological evidence for enhanced neural activity on the figural side of an edge. They found that the responses of V1 neurons are enhanced when a small, enclosed region (a figure) rather than a larger surrounding region (the ground) lies within their receptive fields (RFs). This enhanced figural activity is not evident until approximately 80–100 ms after stimulus onset; prior to that, the neurons with the highest firing rate are those with RFs containing the edge between the two regions. Although such results are consistent with models of figure–ground perception entailing inhibitory competition between edge units (e.g., Kienker et al., 1986; Sejnowski & Hinton, 1987; Vecera & O'Reilly, 1998, 2000), they are also consistent with other models, as discussed next.

Roelfsema, Lamme, Spekreijse, and Bosch (2002) modeled Lamme et al.'s (1999) physiological results, using lateral inhibition—rather than facilitation—between neighboring neurons responding to the same features. Neurons responding to the features filling the figure engage in mutual inhibition as do neurons responding to the features filling the adjacent ground; hence, early in processing, there is no enhanced figural activity. A model with lateral inhibition predicts that low-level neurons with RFs containing an edge will initially produce higher responses than those with RFs containing either the figure or the ground features, because the former are inhibited by neighbors on only one side, whereas the latter are inhibited by neighbors on both sides. Indeed, Roelfsema et al. were attempting to model both the initial edge response and the later enhanced figural activity observed by Lamme et al. To model the latter effect, Roelfsema et al. supposed that neurons at higher levels with larger RFs would also be responding to the features filling the figure and ground regions and that at some higher level there exists a neuron with an RF large enough to encompass the small figure. Neighboring neurons do not inhibit this high-level neuron because none of them respond to the figure features. The neighboring neurons still inhibit each other because they respond to the features filling the larger surround. At this level, the neuron with the figure in its RF has a higher response than its neighbors; this property enables it to release lower level neurons responding to the same (figure) features from lateral inhibition. In this way, Roelfsema et al.'s model produces an enhanced figure response in low-level neurons responding to the figure features relative to those responding to the ground features. Note that Roelfsema et al.'s model produces an enhanced figure response in low-level neurons using release from lateral inhibition at the feature level; they did not assume inhibitory competition between opposite-facing edge units. Roelfsema et al. hypothesized that their model could account for effects of familiar configuration through similar mechanisms.

As an alternative to the ways in which existing models account for effects of familiar configuration, Peterson, de Gelder, Rapcsak, Gerhardstein, and Bachoud-Lévi (2000; see Peterson & Skow-Grant, 2003, for a review) proposed that figure–ground perception entails inhibitory competition between shape properties on opposite sides of an edge rather than, or in addition to, competition between edge units or figure (feature) units. In Peterson et al.'s framework, the relevant shape properties include familiar configuration and the Gestalt configural cues. In this framework, shape properties on the same side of the edge cooperate, and those on opposite sides compete. *Ceteris paribus*, the more strongly cued side of the edge wins the competition and is seen as figure. Critically, Peterson et al. proposed that shape properties on the more weakly cued side of an edge are inhibited and suggested that this inhibition accounts, in part, for the patently unshaped nature of grounds near the edge they share with the figure. It is important to emphasize that none of the other models of figure–ground perception predict the inhibition of shape properties on the losing side of an edge; they simply predict an enhanced neural response to the features filling the figure. Evidence that shape properties on the losing side of an edge are inhibited would prove to be strong support for the proposal that competition between shape properties on opposite sides of an edge is one mechanism of figure–ground perception.

Behavioral Evidence Suggesting Inhibition of Shape Properties on an Edge's Ground Side

Previous experiments by Treisman and DeSchepper (1996) and Peterson and Kim (2001) can be taken to suggest that shape properties on the ground side of an edge are inhibited, as predicted by Peterson et al. (2000). Those previous experiments are open to alternative interpretations that do not entail inhibition, however. Accordingly, it is not yet clear whether figure–ground perception entails inhibitory competition at high levels where shape properties are represented. Yet, progress in understanding figure–ground perception in particular and shape perception in general requires an understanding of the mechanisms involved. In this section, we review the existing evidence and the controversy surrounding it.

Perhaps the first evidence suggesting that the potential shape on the ground side of a novel figure was suppressed was presented by Treisman and DeSchepper (1996). They asked their observers to judge whether two small enclosed white probe shapes with three straight edges and one curvilinear edge were the same or different (see Figure 1B). On experimental probe trials, at least one of the white shapes was the shape that had been suggested on the ground side of the edge of a black shape in the preceding prime trial. (The relevant shape in the prime trial was presented as part of a bipartite black-and-white display; a sample prime display is shown in Figure 1A.) On control probe trials, both white shapes were novel. Observers' response times (RTs) were longer for experimental than for control probes. Treisman and DeSchepper took their data to indicate that structural descriptions of both shapes potentially present in the bipartite prime display were established early in processing and that an ignore tag was attached to the description of the white shape adjacent to the black shape to which participants

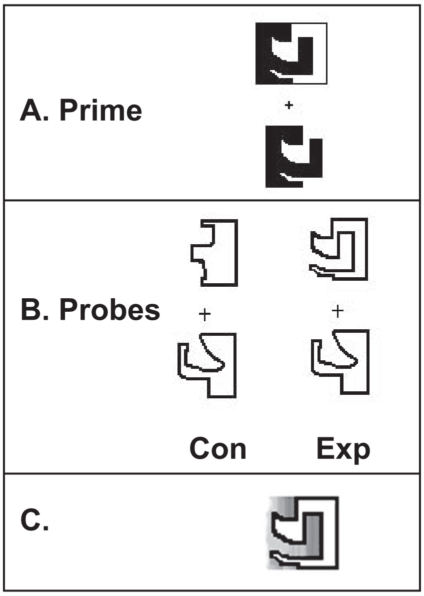

Figure 1. Panel A shows an example of a same-prime trial from Treisman and DeSchepper (1996), in which participants made a same–different judgment regarding black shapes above and below fixation. Treisman and DeSchepper presented their black-and-white stimuli on a gray background; hence, there was no need to outline the white region. The outline is used here because the figure is printed on white paper. Panel B shows examples of different-probe trials. The probe trial on the left depicts a control (Con) trial in which the articulated edges on the probe stimuli have never been seen before. The probe trial on the right illustrates an experimental (Exp) trial in which the articulated edge of the top probe stimulus was repeated from the prime display. Panel C shows the top experimental probe from the right side of Panel B, with shading used to illustrate how the experience of seeing the black region as a figure in the prime might compete with the small area and closure in the white region on probe trials.

responded. Treisman and DeSchepper were not investigating the mechanism of figure–ground perception; they made no proposals about inhibitory competition. They were investigating whether negative priming could occur for novel shapes. Nevertheless, their data are consistent with the prediction from Peterson et al.'s (2000) proposal that in the course of figure–ground perception, the shape properties on the ground side of an edge are inhibited.

Treisman and DeSchepper's (1996) results were criticized by a number of investigators. Some authors reported failures to replicate and claimed that negative priming could not be obtained for novel displays (e.g., Grison & Strayer, 2002; Strayer & Grison, 1999). Authors interested in figure–ground perception criticized Treisman and DeSchepper's findings for other reasons. Baylis and Cale (2001) also reported a failure to replicate with a task in which observers judged whether a single shape was symmetric or asymmetric; on experimental trials, the single shape was the shape suggested on the ground side of the previous shape, whereas on control trials it was a novel shape. Baylis and Cale argued that Treisman and DeSchepper's design required that observers actively ignore the ground shape in the prime, whereas their design did not and hence served as an uncontaminated test of figure–ground perception. These initial failures to replicate were followed by successful replications by Peterson and Lampignano (2003) and Peterson and Enns (2005) who, like Treisman and DeSchepper, used a same–different task but did not always use bipartite displays. However, Peterson and Lampignano pointed out that neither their results nor Treisman and DeSchepper's necessarily reflected inhibition of the shape on the ground side of the edge of the prime shape; these results might instead reflect competition from the immediately prior past experience of assigning the shape on the opposite side of the edge, as follows. Given that the curvilinear edge of the prime figure was repeated in the experimental probe stimulus in these experiments, perhaps past experience (which favors assigning the shape on the same side as in the prime) competes with cues that favor assigning the shape on the opposite side in the probe (small area and closure; see Figure 1C). Peterson and Lampignano reasoned that this increased competition might account for the increased response latencies on experimental compared with control probe trials. To test the competition time hypothesis, they manipulated the strength of the competition and found larger effects with increasing competition, consistent with a competition time interpretation. However, they pointed out that as long as the edge of the prime was repeated in the experimental probe shape, it was not possible to distinguish between Treisman and DeSchepper's original interpretation and the alternative competition time interpretation. (Note that in either case, the results show that a single past experience with a novel shape can influence figure assignment.)

Peterson and Kim (2001) used a task that did not involve repeating the edge of the prime in the probe shape to look for evidence that shape properties on the ground side of an edge are inhibited. Their prime shapes were small, enclosed, symmetric novel black silhouettes; a unique silhouette prime was exposed briefly on each trial and was followed immediately by a probe shape. The probe shapes were line drawings that portrayed either an object the observer was highly likely to have seen before (in either pictorial or tridimensional form; a *familiar object*) or a novel object from Kroll and Potter's (1984) set. (Sample stimuli are shown in Figure 2.) Participants' task was to judge as quickly and as accurately as possible whether the line drawing portrayed a familiar or a novel object; they did not respond to the silhouettes. The critical trials were those with familiar line drawings. On experimental trials, a portion of a familiar shape from the same basic-level category as the upcoming line drawing was sketched on the unbounded side (i.e., the ground side) of the edge of the silhouette; the edges of the silhouette and the line drawing were not identical (see Figure 2C). Of importance, the cues favoring figural status for the inside of the silhouette were stronger than the single familiar configuration cue on the outside, and observers perceived the small, enclosed, symmetric inside region as figure in both experimental and control silhouettes (as revealed by careful postexperiment questioning; see the *Method* section). On control trials, the edges of the silhouette prime were novel configurations on both the inside and the outside and bore no relation to the edges of the upcoming line drawing (see Figure 2D).

Peterson and Kim (2001) were interested in the time it took to correctly classify the familiar line drawings as a function of the preceding silhouette. They reasoned that, if the mechanism of figure assignment is inhibitory competition between shape properties on opposite sides of an edge, then the familiar configuration on the ground side of the experimental silhouettes should be inhibited when it loses the cross-edge competition and the figure is

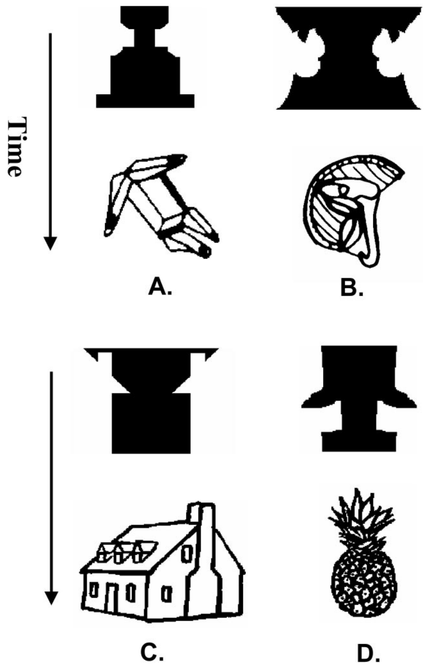

Figure 2. Panels A and B show examples of novel line drawing trials. The top row shows sample control silhouettes used in Peterson and Kim (2001). Both the inside and the outside of the edges of the control silhouette are novel configurations. The bottom row shows sample novel line drawings that followed the control silhouettes. Panels C and D show examples of familiar line drawing trials. The image on the left in the top row is a sample experimental silhouette. A portion of a familiar object is suggested along the outside of the silhouette's vertical edges (in this example, a portion of a house), whereas the inside is a novel shape like the control silhouettes. The top right shows a sample control silhouette. The bottom row shows sample familiar line drawings. The bottom left shows the line drawing following the experimental silhouette that portrays an object from the same basic-level category as the shape suggested on the ground side of the silhouette. The bottom right shows the familiar line drawing following a control silhouette.

perceived on the inside. If this inhibited configuration is among an ensemble of familiar configurations accessed by the upcoming line drawing, then RTs should be longer to verify that a line drawing is familiar when it follows an experimental versus a control silhouette. Peterson and Kim confirmed these predictions in two experiments, although they obtained evidence for inhibition only in participants who responded quickly. Competition-induced inhibition might be short lived when the silhouette is replaced by a line drawing, or it might be swamped in longer RTs by other components of the object decision RT, including motor components.

Behavioral evidence for inhibition of cues present on the ground side of an edge would constitute strong support for inhibitory competition between shape properties as a mechanism of figure–ground perception and could account, at least in part, for why grounds appear unshaped near the edges they share with figures. Unfortunately, Peterson and Kim's (2001) results are open to an alternative competition time interpretation because the experimental silhouette was the only silhouette where familiar configuration competed with cues favoring the inside of the silhouette as the figure. If it simply takes longer to resolve the cross-edge competition in experimental than in control silhouettes (because there is more competition) and response latencies to categorize the line drawings reflect the combined time needed to process the line drawing and the silhouette preceding it when the stimulus onset asynchrony (SOA) is short, then RTs would be longer on experimental than on control trials. Note that on the competition time account, the fact that the shape suggested on the outside of the experimental silhouettes was from the same basic-level category as the upcoming line drawing was irrelevant—the response to any line drawing shown shortly after an experimental silhouette would have been delayed.

Thus, whether Peterson and Kim's (2001) results show that competition is time consuming or that shape properties on the losing side of an edge are inhibited remains a question. Understanding the mechanism of figure–ground perception requires a resolution to this question. Evidence that it takes more time to resolve figure–ground perception in experimental than control stimuli could be easily accommodated by models that suppose that competition occurs between edge units or figure units and is merely modulated by top-down inputs (e.g., Kienker et al., 1986; Roelfsema et al., 2002; Vecera & O'Reilly, 1998, 2000). In contrast, evidence that the familiar configuration on the ground side of the prime silhouette is inhibited requires explanation in terms of inhibitory competition between shape properties, at least one of which—familiar configuration—is a high-level cue. Major changes to the current models would be required to include inhibitory competition between high-level shape properties rather than between edge units or low-level feature units. Of importance, elaboration of such a mechanism would provide a more complete picture of figure–ground perception. In the present experiments, we improved the design of Peterson and Kim's experiments by adding a new pair of conditions that allowed us to examine effects due to inhibition of shape properties on the unbounded side of the silhouette over and above effects due to competition. Our results require explanation in terms of competition between high-level shape properties.

Experiment 1

In Experiment 1, we tested the proposal that figure–ground perception operates by means of inhibitory competition between shape properties on opposite sides of an edge by examining the relative size of the difference between experimental and control RTs in two conditions: In one condition, the familiar configurations suggested on the ground side of experimental silhouettes were portions of objects from the same basic-level category as the subsequent line drawing; this was the same category–ground (SC–ground) condition. In the second condition, the familiar configurations suggested on the ground side of the experimental silhouettes were portions of objects from a different superordinate-level category as the subsequent line drawing; this was the different category–ground (DC–ground) condition. Control silhouettes with edges suggesting novel configurations on both the inside and the outside were used in each condition. Sample stimuli from these two conditions are shown in Figure 3. The same silhouettes were used in these two conditions; hence, competition was the same, and in both conditions, competition was greater for experimental than for control silhouettes. Thus, if increased competition is responsible for longer object decision RTs for line drawings that follow experimental silhouettes, then the size of the difference be-

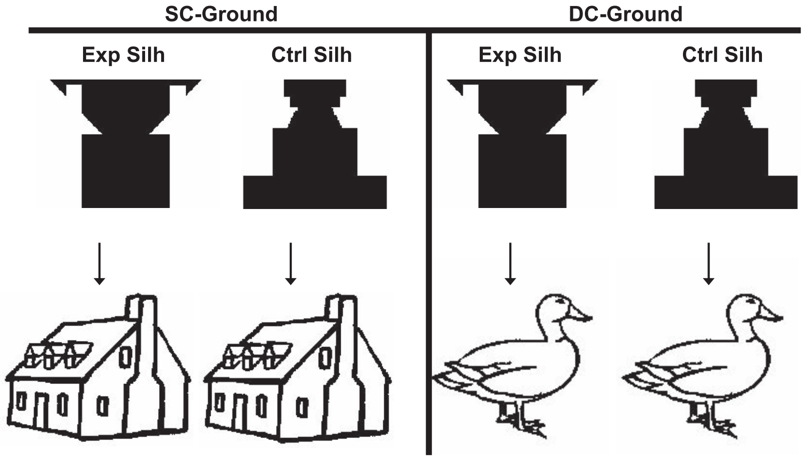

Figure 3. The left panel shows sample experimental and control trials in the SC–ground condition of Experiment 2. The right panel shows sample experimental and control trials in the DC–ground condition. Notice that the experimental and control silhouettes from the SC–ground condition are repeated; however, for this condition they each precede a line drawing of a familiar object from a different superordinate-level category than appeared in the SC–ground condition. SC = same category; DC = different category; Exp = experimental; Silh = silhouette; Ctrl = control.

tween experimental and control object decision RTs should be the same in the SC–ground and DC–ground conditions. In contrast, if inhibitory competition occurs between shape properties on opposite side of the edge, and the familiar configuration on the outside of the experimental silhouette edge is inhibited in both conditions, we expect inhibition to be evident in longer object decision RTs for line drawings of objects from the same basic-level category than for drawings from a different superordinate-level category. That is because familiar configurations accessed in the course of perceiving the silhouette and then suppressed are likely to be among those accessed to evaluate the familiarity of a line drawing in the same basic-level category but not in a different superordinate-level category. Inhibition of a subset of the configurations accessed by the line drawing would increase the time required for the representation of the line drawing to exceed a familiar-object decision threshold and hence would result in longer object decision RTs. (We are assuming an evidence accumulation model similar to those used for lexical decision; see Grainger & Jacobs, 1996). In other words, if the shape on the ground side of an edge is inhibited, we expect the difference between experimental and control object decision RTs to be larger in the SC–ground condition than in the DC–ground condition.

Experiment 1 comprises two experiments with identical conditions. We conducted two experiments to assess the reliability of our results, which were obtained in fast responses only (cf. Peterson & Kim, 2001).

Method

Participants. Participants were 163 undergraduate students (103 female; 81 in Experiment 1A and 82 in Experiment 1B) from the University of Arizona who completed this study for course credit. Each signed a consent form. All participants reported normal or corrected-to-normal visual acuity. Data from 1 participant were not analyzed in Experiment 1A because his error rate exceeded our criterion (>15%).

Stimuli and apparatus. Silhouettes were small, symmetric, enclosed black shapes subtending mean visual angles of 2.9° × 3.4° in height (H) and width (W), respectively. The vertical edges of control silhouettes ($N = 18$) were novel configurations along both the figure side (black side of the contour) and the ground side (white side of the contour), as shown in Figures 2A, 2B and 2D. The vertical edges of the experimental silhouettes ($N = 18$) were novel configurations along the black figure side but sketched familiar configurations suggesting a portion of a known shape along the white ground side, as shown in Figure 2C.

The line drawings included 36 drawings of novel objects from Kroll and Potter's (1984) set and 36 drawings of familiar objects. Some of the familiar objects were created for this experiment, and some were chosen from Snodgrass and Vanderwart's (1980) set. We divided the familiar line drawings into two sets of 18, Fam-A and Fam-B, matched for the frequency of the object's name, the number of symmetric versus asymmetric drawings, the number of living versus nonliving objects, the degree of curvature, and the height, width, and line thickness (heavy, medium, or thin) of the drawing. (See Appendix A for a list of the drawings.) Line drawings subtended mean visual angles of 3.0° H × 2.3° W.

For each familiar line drawing in set Fam-A, there was an experimental silhouette that suggested an object from the same basic-level category on the ground side of that edge (SC–ground). This was the experimental silhouette and line drawing pair in the SC–ground condition. (The shapes of the edges of the silhouette and the line drawing were different.) Each experimental silhouette was also paired with one line drawing in set Fam-B, but in this case the line drawing was of an object from a different superordinate-level category (DC–ground) than that suggested on the ground side of the silhouette (the pairing was across living and nonliving categories). This was the experimental silhouette and line drawing pair in the DC–ground condition. For instance, as shown in Figure 3, the silhouette suggesting a house on its ground side appeared before a line drawing of a house in set Fam-A (SC–ground condition) and before a line drawing of a duck in set Fam-B (DC–ground condition). Control silhouettes were paired with each familiar line drawing from each of the two sets as well; these were the control conditions for the SC–ground and DC–ground conditions (see Figure 3). Each of the experimental and control silhouettes was also paired with two different novel line drawings. There was no shape correspondence between the novel line drawings and the edges of the control silhouettes. Thus, each silhouette appeared four times and each line drawing appeared two times.

The experiment was conducted on a personal computer. Stimuli were presented on a 21-in. Sony monitor. Participants viewed the monitor from a distance of 96 cm, with their head position maintained by a chin rest. A custom-built button box with two horizontally arranged buttons was used to record participant's object decisions. Participants used a foot pedal to initiate each trial and to advance through the instructions. The presentation and response measurement software was DMDX (Forster & Forster, 2003).

Procedure. Instructions were presented on the computer screen; participants read them at their own pace. Participants were informed that their task was to distinguish as quickly and accurately as possible between line drawings of familiar objects (i.e., line drawings of objects that they had encountered in books or in reality before entering the laboratory) and novel objects (a set of line drawings created for laboratory use). They viewed examples of each type of line drawing. They were informed that on each trial, before the line drawing appeared they would see a brief exposure of a novel black silhouette. Participants were instructed to look at the silhouettes but not to respond to them.

Each trial began with a central fixation cross. Participants were instructed to look directly at it and to press the foot pedal when they were ready for the trial to begin. A black silhouette then appeared at fixation for 50 ms and was followed by a blank white screen (the interstimulus interval) for 33 ms. The target line drawing appeared 83 ms after the onset of the silhouette. Line drawings were exposed until participants responded or for 1,500 ms, whichever came sooner.

Participants indicated whether the line drawing portrayed a familiar or novel object by pressing one of two keys, using a finger on their dominant hand for the familiar-object response and a finger on their nondominant hand for the novel object response. Responses made within 1,500 ms after the line drawing appeared were recorded; otherwise, they were coded as errors. Following participants' responses (or 1,500 ms if no response occurred) a fixation cross for the next trial appeared.

Thirty-six practice trials followed the instructions. On these trials, participants categorized 18 familiar and 18 novel line drawings; all followed control silhouettes. None of the practice stimuli was used on experimental trials. If participants incorrectly categorized a line drawing during practice, the word *wrong* appeared for 1,250 ms on the screen; no feedback was given for correct responses. An experimenter remained in the room during the instructions and practice trials to answer questions. Data from the practice trials were not analyzed.

Participants were left alone in the room to complete 144 trials (72 with line drawings of novel objects and 72 with line drawings of familiar objects). The 72 trials with familiar line drawings were distributed as follows: 18 experimental SC–ground trials, 18 control SC–ground trials, 18 experimental DC–ground trials, and 18 control DC–ground trials. The 72 trials with novel line drawings included 36 in which a novel line drawing was paired with an experimental silhouette and 36 in which it was paired with a control silhouette. Trial types were randomly presented. No feedback was given on experimental trials.

Following the experimental trials and before debriefing, we asked participants a series of postexperiment questions to determine whether they had seen any of the shapes suggested on the outsides of the silhouettes. Participants were asked, in order, how easy it was for them to see the silhouettes, whether it became easier to see them as the experiment progressed, how much attention they paid to them, and whether the silhouettes allowed them to guess what type of line drawing would follow. Our participants responded that they focused on the line drawing task and did not pay much attention to the silhouettes; had they done so, they would have been probed further. During debriefing, the experimenter showed participants pictures of an experimental silhouette and then identified and traced the portion of the object suggested on the outside. Our procedure was to eliminate the data of any participants whose responses during questioning or debriefing suggested they had seen an object suggested on the outside of an experimental silhouette. This criterion was conservative in that it was likely to cause us to reject participants who did not really see the shape on the outside of the experimental silhouettes—but said they did because they believed they should have. In this experiment, none of our participants made any response that indicated they had seen a shape on the outside of the silhouette edge.

Data analysis methods. We analyzed the data in two ways. First, we calculated each participant's mean RT for line drawings following experimental and control silhouettes in each condition (SC– and DC–ground) and submitted these means to an analysis of variance (ANOVA) with two within-subjects variables (silhouette type: experimental vs. control; condition: SC– vs. DC–ground) and one between-subjects variable (experiment: 1A vs. 1B).

Second, because Peterson and Kim (2001) had observed slower RTs for line drawings following experimental rather than control silhouettes only in those observers who responded quickly, we calculated fast-half means for each participant.[1] Our design, in which each line drawing was presented twice—once following a control silhouette and once following an experimental silhouette—allowed us to yoke experimental and control RTs for the fast response analysis. For each condition (SC–ground and DC–ground), we first sorted by latency each participant's RTs to correctly classify the familiar line drawings following control silhouettes. We then performed a median split on each participant's RTs and calculated a control mean for each condition based on their fast-half responses. We chose to sort on the basis of control RTs because we expected shorter RTs on control than experimental trials, and our goal was to analyze participants' fastest responses. We reasoned that there would be some variability in the time individual participants needed to correctly categorize individual line drawings and that it would be best to test for short-lived inhibition in line drawings that participants could categorize quickly when no inhibition was expected to be present (i.e., on control trials). (It was not the case that some line drawings

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[1] We thank the reviewers of our original manuscript for suggesting that we analyze fast responses.

were uniformly easy to classify, and others were uniformly difficult; different participants responded quickly to different line drawings.) Next, we selected each participant's RTs to the same line drawings on experimental trials to which he or she had responded quickly on control trials and calculated a yoked experimental mean for that condition. If an error was made classifying a given line drawing in either the experimental or control condition, the RT to that line drawing was not considered in calculating either mean.

In the fast response analysis, RTs in the control condition were chosen on the basis of speed, whereas RTs in the experimental condition were not. Therefore, in the fast responses, main effects of silhouette type (experimental vs. control) are expected because of regression to the mean and are not considered theoretically important. Regression to the mean cannot account for a larger difference between experimental and control RTs in the SC–ground condition than in the DC–ground condition, however, whereas inhibitory competition can: If the familiar configuration on the ground side of the edge of the experimental silhouette is inhibited, we expect the fast responses of all participants to show a larger difference between experimental and control RTs in the SC–ground condition than in the DC–ground condition. We submitted fast response means to an ANOVA with two within-subjects variables (silhouette type: experimental vs. control; condition: SC– vs. DC–ground) and one between-subjects variable (experiment: 1A vs. 1B). If inhibition can be observed only in object decisions made quickly, then by examining fast responses in all participants, we should be able to observe the pattern characteristic of inhibition in our results, even if the pattern is not present in mean responses. (We did not compare fast responses to slow responses because we did not expect that a clearly different response pattern would emerge in slow responses.)

Results

Mean responses. The ANOVA on RTs for mean correct familiar-object decisions showed no significant effects (*F*s < 1.5, *p*s $>. 22$; see Table 1). An ANOVA that included line drawing type (familiar vs. novel) as an additional within-subject variable revealed that correct classification RTs were longer for novel than familiar line drawings, $F(1, 150) = 393.0$, $p < .001$, $\eta^2 = .711$. This difference was expected because novel objects often bear some resemblance to familiar objects; hence, participants take longer to reject them as familiar (Kroll & Potter, 1984). The same pattern of results was obtained for novel line drawings in the remaining experiments in this article. We had no predictions regarding the responses to novel line drawings. Novel line drawings were included so that observers had to make an object decision regarding the line drawings. Because tests of RTs for novel line drawings did not reveal anything of theoretical importance, we do not report analyses of responses to novel line drawings for the next experiment.

Error rates were low (3.6%). There was no evidence that participants made more errors in the DC–ground condition, where they responded faster than in the SC–ground condition (2.3% vs. 2.5%), $F(1, 160) = 1.8$, $p = .18$. We did not find evidence of a speed–accuracy trade-off in this or in any of the experiments in this article; hence, for the sake of brevity, we do not report error data for the remaining experiments.

Table 1
Mean Response Times (in ms) to Categorize Familiar Line Drawings Across Conditions in Experiment 1

	SC			DC			
Experiment	Exp silh	Ctrl silh	SC(E-C)	Exp silh	Ctrl silh	DC(E-C)	SC(E-C)–DC(E-C)
				Mean responses			
Exp 1 (A and B)							
M	533.7	530.2	3.5	525.6	525.5	−0.1	3.6
SE	5.2	5.5	3.1	4.9	4.7	2.3	4.0
Exp 1A							
M	532.7	528.4	4.3	525.1	528.0	−2.9	7.2
SE	7.2	7.5	4.1	7.1	6.6	3.5	5.7
Exp 1B							
M	534.7	532.2	2.6	526.2	523.5	2.7	−0.1
SE	7.5	8.0	4.6	6.7	6.6	3.1	5.7
				Fast responses			
Exp 1 (A and B)							
M	563.6	476.4	87.2	546.7	474.8	71.9	15.4
SE	6.2	4.5	3.9	5.8	4.3	3.7	5.3
Exp 1A							
M	563.6	474.3	89.3	545.4	473.2	72.2	17.1
SE	9.1	6.5	5.7	8.4	6.2	5.2	7.6
Exp 1B							
M	563.7	478.5	85.2	548.0	476.4	71.6	13.6
SE	8.5	6.3	5.4	8.2	5.9	5.4	7.4

Note. SC = same basic level category; DC = different superordinate level category; Exp silh = experimental silhouette; Ctrl silh = control silhouette; E = experimental; C = control.

Fast responses. The ANOVA conducted on fast correct familiar-object classification RTs showed no effects of experiment, $F(1, 160) = 0.07$, $p > .7$, nor were there any interactions involving experiment (Fs < 1, ps $> .6$). Thus, Experiment 1B replicated Experiment 1A. Therefore, we report the results averaged over Experiments 1A and 1B in the text, although we show both the averaged means and the means for the two experiments separately in Table 1.

As predicted, if the shape property on the ground side of the edge of the silhouette was inhibited, in fast responses the experimental minus control difference was larger in the SC–ground condition than in the DC–ground condition. This 15.4-ms difference was statistically significant as revealed by an interaction between silhouette type (experimental vs. control) and condition (SC– vs. DC–ground), $F(1, 160) = 8.5$, $p = .004$, $\eta^2 = .050$. As can be seen in Table 1, the interaction was due to differences in RTs on experimental trials not on control trials. Fast RTs on control trials were approximately equal for the SC– and DC–ground conditions, whereas on experimental trials, RTs in the SC–ground condition were longer than RTs in the DC–ground condition.[2]

Discussion

Peterson and Kim's (2001) results led us to expect that evidence of inhibition of the familiar configuration on the outside of the experimental silhouette would be obtained only in fast responses, and that is what we observed in Experiment 1. In the analysis of fast responses, but not in the analysis averaged over all responses, we observed a larger difference between experimental and control RTs in the SC–ground condition than in the DC–ground condition, as expected if the familiar configuration on the outside of the edge of the experimental silhouette was inhibited in the course of figure–ground perception. Similar effects were obtained in Experiments 1A and 1B; hence, the results are reliable.

In the fast responses, differences between experimental and control means are expected in both the SC– and the DC–ground conditions because we used the control condition to separate each participant's responses into fast and slow halves and then chose experimental RTs for the same line drawings to which they had responded quickly on control trials. This method necessarily produces longer RTs for experimental than control trials (because of regression to the mean). Effects due to regression to the mean are expected to be the same in the SC–ground condition and the DC–ground condition, however. The effects of inhibition are evident in the larger experimental minus control difference in the SC–ground than in the DC–ground condition. However, the regression to the mean does prevent us from asking whether competition slows object decision RTs; although the difference between object decision RTs in the DC–ground condition may reflect competition as well as regression to the mean, it is not possible to separate those effects. The present experiments were not intended to provide evidence that competition takes time; instead, they were designed to rule out the competition time hypothesis so that we could evaluate the inhibition hypothesis. The finding that the experimental minus control difference was larger in the SC–ground condition than in the DC–ground condition allows us to rule out competition time as well as regression to the mean as explanations for the SC–ground difference. Thus, the results of Experiment 1 are consistent with a prediction derived from Peterson et al.'s (2000) framework in which one mechanism of figure–ground perception is inhibitory competition between shape properties on opposite sides of an edge.

Experiment 2

An important question remains before the results of Experiment 1 can be taken as relevant to the mechanism of figure–ground perception: How can we be certain that the larger experimental minus control differences obtained in the SC–ground condition than in the DC–ground condition were not due to inhibition of return or negative priming—effects that have no bearing on the figure–ground mechanism? In Experiment 1, the silhouettes appeared only briefly before the line drawings and were not relevant to the object decision task; consequently, observers may have treated them as distractors and ignored them. Negative priming is typically found for ignored and/or briefly exposed stimuli (e.g., Milliken, Joordens, Merikle, & Seiffert, 1998): For instance, when participants ignore a distractor on one trial, they are often slower to respond to it when it is repeated as a target on a subsequent trial (DeSchepper & Treisman, 1996, Neill & Valdes, 1996). Similarly, inhibition of return can be observed when attention is first allocated to, and then removed from, an object (e.g., Kessler & Tipper, 2004; Morgan, Paul, & Tipper, 2005). Of course, in typical negative priming and inhibition of return experiments, the ignored stimuli are figures.

Suppose that because the silhouettes were ignored, every property associated with them (on both the figure side and the ground side of their edges) is inhibited. Even in such a case, we would not have been able to observe evidence of inhibition in any condition other than the SC–ground condition because that was the only condition where the line drawings and silhouettes were in the same basic-level category. Therefore, we cannot be certain whether longer RTs in the SC–ground than the DC–ground condition were obtained in Experiment 1 because the silhouettes were ignored or because of inhibitory competition between shape properties on opposite sides of an edge, as we have supposed. To adjudicate between these alternatives, in Experiment 2 we moved the familiar configurations from the ground side to the figure side of the edge of the experimental silhouettes and examined whether the same pattern of results was obtained under these conditions. If the pattern of results obtained in Experiment 1 reflects negative priming of all of the distracting silhouette's properties, rather than inhibition of the familiar configuration on the ground side of the silhouette's edge, then the same pattern of results is expected when the familiar configuration is sketched on the figure side of the edge. However, if the results of Experiment 1 reflect inhibitory competition between shape properties on opposite sides of an edge, then a different pattern of results should be obtained when the familiar configuration is sketched on the more strongly cued (figure) side of the silhouette edge rather than on the less strongly cued (ground) side. Indeed, one might even expect to find that responses are faster on experimental than control trials in an SC–figure condition than in a DC–figure condition: Other authors

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[2] No interaction between silhouette type and condition was observed in an ANOVA conducted on slow half responses ($F < 1$).

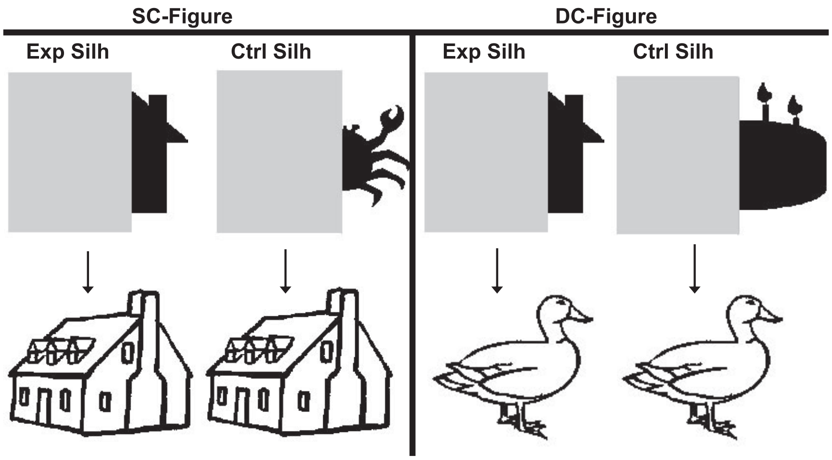

Figure 4. The left panel shows the SC–figure condition from Experiment 2. The right panel shows the DC–figure condition from Experiment 2. On experimental trials, the experimental silhouette from the DC–figure condition appeared before a line drawing of an object from a different superordinate-level category, a duck. The line drawing of the duck was repeated on control trials, but was then preceded by a silhouette portraying a birthday cake as a figure to preserve the requirement that on control trials, line drawings follow a silhouette portraying an object from a different superordinate category. SC = same category; DC = different category; Exp = experimental; Silh = silhouette; Ctrl = control.

have shown that responses are speeded to an object when it follows another object from the same basic-level category rather than an object from a different superordinate-level category (e.g., Dell'Acqua & Grainger, 1999). Evidence of facilitation in Experiment 2 would be further evidence against a negative priming or inhibition of return interpretation of the results of Experiment 1.

We attempted to make Experiment 2 as comparable as possible to Experiment 1, except for the change in figural status of the critical regions of the silhouettes. All of the silhouettes used in Experiment 1 portrayed novel shapes as figures; hence, as perceived figures, they did not induce differential response tendencies for line drawings of familiar versus novel objects. To maintain the feature that all silhouettes induced the same response tendency in Experiment 2, all of the silhouettes portrayed familiar objects as figures. (Sample figure silhouettes are shown in Figure 4.)[3] We presented the same 36 line drawings of familiar objects used in Experiment 1 in one of two conditions: an SC–figure condition or a DC–figure condition. On experimental trials, line drawings appeared after a silhouette portraying an object from the same basic-level category in the SC–figure condition and after a silhouette portraying an object from a different superordinate-level category in the DC–figure condition. For instance, as shown in Figure 4, a silhouette of a house would appear before a line drawing of a house on experimental trials in the SC–figure condition and before a line drawing of a duck on experimental trials in the DC–figure condition.

Each of the line drawings also appeared after a control silhouette. Control silhouette conditions were necessary for sorting the responses to the line drawings so that we could investigate whether the pattern evident in Experiment 2 participants' fast responses was the same as that evident in the fast responses in Experiment 1. The control figure silhouettes always portrayed objects from a different superordinate-level category from the line drawing.

Method

Participants. Participants were 89 undergraduate students (61 female) from the University of Arizona who completed this experiment for course credit. Each signed a consent form. All participants reported normal or corrected-to-normal visual acuity. Data from 1 participant were not analyzed because her error rate exceeded our criterion.

Stimuli and apparatus. Thirty-six figure silhouettes were created from a subset of the experimental silhouettes used in Experiment 1 by extracting the portion of the familiar configuration suggested on the ground side of the silhouette edge, coloring it black, and placing it on a white background. To hold approximately constant the portion of the familiar object sketched by the new figure silhouettes and the silhouettes used previously, and to close the figure silhouettes without adding any extrinsic edges to the region portraying the familiar object, we added vertically elongated gray rectangles 3.4° H × 1.8° W to the outside of each black figure. These rectangles were longer than the black figure silhouettes; hence, T junctions favoring the interpretation that they occluded the black figure silhouettes were formed where they met the black regions (see Figure 4). We divided the figure silhouettes into two sets (1 and 2). The design of Experiment 2 required that we replace the control silhouettes of Experiment 1 with silhouettes of familiar figures; these could not portray objects from the same basic-level category as any of the familiar line drawings. Hence, an additional set of 18 control figure silhouettes was created. A list of

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[3] We also conducted an experiment in which half of the silhouettes shown before both familiar and novel line drawings portrayed novel figures and half portrayed familiar figures. The pattern of results we obtained was similar to that found in Experiment 2. This other experiment and its results are reported briefly in the *Results* section.

the objects portrayed by the experimental and control figure silhouettes can be found in Appendix B. Control figure silhouettes matched the experimental figure silhouettes in terms of number of symmetric versus asymmetric objects, number of living versus nonliving objects, stimulus curvature (straight, curved, or combination of straight and curved lines), height, and width.

Figure silhouettes averaged 2.5° H × 6.6° W (measured from the outside edge of each gray rectangle). The gray rectangle appeared on the left for half of the figure silhouettes and on the right for the other half. Line drawings with a facing direction appeared with the object facing in the same direction as the object in the silhouette. Half of the line drawings with a facing direction faced left, and half faced right.

Thirty-six line drawings were used in this experiment; each portrayed an object from the same basic-level category as one of the experimental silhouettes. The line drawings were divided into two sets (1 and 2) matching the silhouette sets. All participants viewed all of the line drawings. For half of the participants, line drawings from Set 1 were in the SC–figure condition where they were preceded by Set 1 figure silhouettes that portrayed the same basic-level object on experimental trials and were preceded by control figure silhouettes on control trials. For these participants, line drawings from Set 2 were in the DC–figure condition where they were preceded by Set 1 figure silhouettes that portrayed an object from a different superordinate-level category on experimental trials and were preceded by control figure silhouettes on control trials. For the other half of the participants, line drawings from Set 2 were in the SC–figure condition, and line drawings from Set 1 were in the DC–figure condition.

The control figure silhouettes always portrayed objects from a different superordinate-level category from the line drawing; if the line drawing portrayed a living object, the silhouette portrayed a nonliving object, and vice versa. Because of this feature, it was impossible to maintain the same pairing of experimental and control silhouettes in both the SC– and DC–figure conditions. Consider the example shown in Figure 4. The familiar configuration on the ground side of the experimental silhouette suggests a nonliving object, a house. Therefore, the line drawing shown after the same silhouette in the DC–figure condition must portray a living object, in this case a duck. However, because the control silhouettes shown before the house in the SC–figure condition and before the duck in the DC–figure condition must portray objects from different superordinate-level categories, the control silhouette for the SC–figure condition must portray a living object (here, a crab) and the control silhouette for the DC–figure condition must portray a nonliving object (here, a birthday cake). Given that all between-condition comparisons were based on mean RTs and that yoking was done within rather than between the SC and DC conditions, this design difference between Experiments 1 and 2 should not affect the results.

Procedure. The procedures used in Experiment 2 were the same as those used in Experiment 1.

Data Analysis Methods

Mean responses. In Experiment 2, we were not attempting to rule out a competition interpretation for experimental minus control differences obtained in the SC–figure condition by subtracting differences obtained in the DC–figure condition; because the familiar configurations in the silhouettes were sketched by the silhouette figures, we expected little or no competition in any of the conditions. In fact, any experimental minus control differences obtained in the DC–figure condition were due to noise, because both the experimental and control silhouettes portrayed objects from a different superordinate-level category than the paired line drawing. Indeed, we included the DC–figure condition only so that we could compare the patterns obtained in fast responses in Experiments 1 and 2. In the analysis of mean responses, we were interested in testing whether the figure silhouettes facilitated responses to the line drawings by speeding responses to a line drawing of an object that follows a silhouette portraying another object from the same basic-level category rather than an object from a different superordinate-level category (cf. Dell'Aqua & Grainger, 1999). We performed two one-way ANOVAs to examine this question. The first ANOVA compared correct object decision RTs on experimental and control trials in the SC–figure condition. The second ANOVA compared correct object decision RTs on experimental trials in the SC–figure and the DC–figure conditions. Both ANOVAs compared correct object decision RTs in conditions where the silhouette figure portrayed a portion of an object from the same basic-level category as the line drawing (the SC–figure trials) to conditions where the silhouette figure portrayed a portion of an object from a different superordinate-level category from the line drawing (in the first ANOVA, the SC–figure control trials; in the second ANOVA, the DC–figure experimental trials). The comparison in the first ANOVA held constant the identity of the line drawing while the shape portrayed by the silhouette varied; the comparison in the second ANOVA held constant the identity of the figure in the experimental silhouettes while the identity of the objects portrayed by the line drawings varied (see Figure 4). In both ANOVAs, evidence for facilitation would take the form of faster object decision RTs on SC–figure trials than on trials in the comparison condition. We did not perform any comparisons involving the DC–figure control trials because such comparisons would not hold constant either the line drawing or the silhouette figure.

Fast responses. We analyzed fast responses in Experiment 2 only so that we could compare the pattern of results obtained with the pattern obtained in Experiment 1. Comparing the fast response patterns of Experiments 1 and 2 provides the best test of whether the results of Experiment 1 reflect negative priming or inhibition of return. If they do, we expect to see the same pattern replicated in the fast responses of Experiment 2. Accordingly, we sorted the RTs into fast responses following the same procedure used in Experiment 1. (For Experiment 2, we do not expect facilitation to be evident in fast responses; recall that our method of sorting necessarily produces longer RTs for experimental trials than for control trials. Our only interest in the fast responses of Experiment 2 was to compare them with fast responses in Experiment 1.)

Results and Discussion

Mean responses. An ANOVA on the SC–figure condition with silhouette type (experimental vs. control) as a within-subjects factor showed a main effect of silhouette type, $F(1, 84) = 3.928$, $p = .051$, $\eta^2 = .043$. The line drawings following experimental and control silhouettes in this condition were identical; nevertheless, participants' object decision RTs were on average 9 ms faster when the line drawings followed an experimental figure silhouette portraying an object from the same basic-level category rather than a control silhouette portraying an object from a different superordinate-level category (see Table 2). These are standard priming effects; as such, they are inconsistent with a negative priming/inhibition of return interpretation. We sought further evidence of priming in Experiment 2 by comparing experimental RTs in the SC–figure condition with experimental RTs in the DC–figure condition; in this condition, the silhouettes shown before the line drawings were identical, but the line drawings differed. This ANOVA too showed a main effect of condition, $F(1, 84) = 5.872$, $p < .02$, $\eta^2 = .065$: RTs were on average 10 ms faster in the SC–figure condition than in the DC–figure condition.

Similar results were obtained in two other experiments, not reported here. In the first of these experiments, we did not use control trials, just SC–figure and DC–figure trials. Once again, we found that participants accurately classified familiar line drawings faster when they followed SC–figure silhouettes than DC–figure silhouettes (difference = −12.4 ms), $F(1, 80) = 7.273$, $p = .009$, $\eta^2 = .083$. In the second of these experiments, half of the silhouettes shown before both familiar and novel line drawings portrayed novel figures, and half portrayed familiar figures. We found that this procedure induced response bias (i.e., participants were biased to say *familiar* following familiar silhouettes and were biased to say *novel* following novel silhouettes). Under those conditions, 25% of participants exceeded our error criterion. Participants who did not exceed our error criterion, however, correctly categorized familiar line drawings 13.3 ms faster when they followed SC–figure silhouettes rather than control silhouettes, a statistically significant difference, $F(1, 30) = 6.72$, $p = .015$, $\eta^2 = .18$, whereas their RTs to correctly categorize novel line drawings did not differ as a function of silhouette type, $F(1, 30) = 0.93$, $p > .34$. Together with the results of the present experiment, those two other experiments show that accurate familiar-object decisions are speeded following an SC–figure silhouette compared with a control silhouette. These findings in the mean responses are not what would be predicted by negative priming or inhibition of return.

Fast responses. As can be seen in Table 2, the pattern observed in the fast responses also failed to conform to a negative priming/inhibition of return interpretation. The pattern in the fast responses of Experiment 2 was different from the pattern obtained in Experiment 1. In Experiment 2, where familiar configurations were sketched on the figure side rather than the ground side of the silhouette edge, there was no interaction between silhouette type (experimental vs. control) and condition (SC–figure vs. DC–figure), $F < 1$, $p > .4$. The patterns of results obtained in the two experiments differed statistically, as shown by an interaction among experiment (1 vs. 2), silhouette type (experimental vs. control), and condition (SC vs. DC), $F(1, 166) = 6.443$, $p = .012$, $\eta^2 = .037$.

The finding of different patterns of results in the fast responses of Experiments 1 and 2 shows that the ground versus figure status of the familiar configuration in the silhouette made a difference. Thus, the differences observed in Experiment 1 cannot be attributed to either an inhibition of return or a negative priming account that does not take into account the ground versus figure status of the familiar configuration in Experiments 1 versus 2. The only account that predicts the different patterns obtained in fast responses of Experiments 1 and 2 is one that supposes that the familiar configuration was inhibited in Experiment 1 because it was suggested on the more weakly cued side of the silhouette edge, whereas it was not inhibited in Experiment 2 because it was one of many shape properties on the more strongly cued (figure) side of the silhouette edge.

General Discussion

We hypothesized that the mechanism of figure–ground perception entails inhibitory competition between shape properties and searched for this inhibition in longer RTs for object decisions regarding a line drawing of a familiar object shown after an experimental silhouette suggesting a portion of a familiar object along its ground side versus a control silhouette. Of importance, we included two pairs of experimental and control silhouettes. In the SC pair, the line drawing portrayed an object from the same basic-level category (SC–ground) as the shape suggested on the ground side of the experimental silhouette; in the DC–ground pair, the line drawing portrayed an object from a different superordinate-level category. As a baseline, we recorded responses to the same line drawings shown after control silhouettes lacking familiar configurations. The critical comparison was between differences in RTs to line drawings following experimental versus control silhouettes in the SC–ground condition versus the DC–ground condition because inhibition of a familiar configuration

Table 2
Mean Response Times (in ms) to Categorize Familiar Line Drawings Across Conditions in Experiment 2

	SC			DC			
Response type	Exp silh	Ctrl silh	SC(E-C)	Exp silh	Ctrl silh	DC(E-C)	SC(E-C)–DC(E-C)
Mean responses							
M	537.0	546.0	−9.0	547.8	550.1	—	—
SE	7.9	7.4	4.6	7.5	7.1	—	—
Fast responses							
M	569.1	491.2	77.9	574.9	490.6	84.3	−6.3
SE	8.5	5.7	5.7	7.7	5.8	4.9	7.2

Note. Dashes indicate differences in conditions that were not important in Experiment 2 (see main text for details). SC = same basic level category; DC = different superordinate level category; Exp silh = experimental silhouette; Ctrl silh = control silhouette; E = experimental; C = control.

should lengthen RTs for line drawings in the same basic-level category but not in a different superordinate-level category. Thus, inhibition should be evident over and above any experimental minus control RT differences in the DC–ground condition, which might have been due to competition alone or due to regression to the mean in the fast response analysis. In fast responses, we found that RTs were longer for line drawings following experimental than control silhouettes in the SC–ground condition and that this difference was larger than the experimental minus control difference in the DC–ground condition. This is exactly the pattern predicted if the mechanism of figure–ground perception entails inhibitory competition between shape properties. This effect was present in two experiments: Experiments 1A and 1B.

Experiment 2 ruled out an alternative interpretation of Experiment 1—that the effects reflected negative priming of all of the properties of the silhouette because it was irrelevant to the participants' task regarding the line drawings shown afterward. To test this alternative interpretation, we reversed the figure and ground status of the silhouettes, such that the familiar configuration lay on the more strongly cued side of the edge—the side that was expected to win the competition and be perceived as the shaped figure. The pattern of results obtained in the fast responses with SC– versus DC–figure silhouettes was different from the pattern obtained with SC– versus DC–ground silhouettes in Experiment 1, supporting our proposal that the pattern of results obtained in Experiment 1 was specific to suppression of properties on the ground side of the silhouette edges. In addition, we found evidence that the SC–figure silhouette had facilitatory effects on object decisions: RTs were faster following SC–figure experimental silhouettes than either SC–figure control silhouettes (where the same line drawing appeared following a silhouette portraying an object from a different superordinate-level category as the figure) or DC–figure silhouettes (where the SC–figure experimental silhouette appeared before a line drawing from a different superordinate-level category).

Evidence for inhibition of a familiar configuration on the ground side of a silhouette indicates that the mechanism of figure–ground perception entails inhibitory competition between shape properties. On the basis of empirical work, Peterson et al. (2000) proposed a framework involving inhibitory competition between shape properties. Yet, current computational models of figure–ground perception allow for inhibitory competition only between edge units (Vecera & O'Reilly, 1998, 2000) or between feature units (Roelfsema et al., 2002); they account for effects of familiar configuration on figure–ground perception as a top-down influence. Thus, the present results call for an amendment to current computational models of figure–ground perception. Indeed, we suggest that a biologically plausible model from a different realm might be adapted to account for our effects and for figure–ground perception in general.

A Biologically Plausible Competitive Model of Competition

We suggest that the current results might be understood as an instance of a type of competition that occurs at many levels of the visual system (i.e., V2, V4, TE, IT) and has been demonstrated in monkeys and in humans with a variety of methods (i.e., single cell recording, event related potentials, and functional magnetic resonance imaging). The competition is evident in the suppression of a neuron's response when more than one stimulus is present in its RF, even when one stimulus is a good stimulus in that it elicits a vigorous response when presented alone and the other is a poor stimulus in that it elicits little or no response when presented alone (e.g., Miller, Gochin, & Gross, 1993; Moran & Desimone, 1985; Rolls & Tovee, 1995). This competition has become known as *biased competition* because Desimone and Duncan (1995; Duncan, Humphreys, & Ward, 1997; Reynolds, Chelazzi, & Desimone, 1999; see Reynolds & Chelazzi, 2004, for a review) have shown that it can be biased or overcome by contrast, a bottom-up factor, or by attention, a top-down factor. For instance, if an animal attends to one of two stimuli within a neuron's RF, the neuron's response pattern changes to resemble the pattern obtained when only the attended stimulus is present. Critically, if the attended stimulus is the poor stimulus, the response to the good stimulus is suppressed (Chelazzi, Miller, Duncan, & Desimone, 1993). Likewise, if one shape is higher in contrast than the other, the neuron's response pattern resembles the response to the high-contrast stimulus alone, and the response to the other stimulus is suppressed. Notably, suppression is reduced when one of the stimuli lies outside the neuron's RF or when the stimuli are presented sequentially rather than simultaneously (Luck, Chelazzi, Hillyard, & Desimone, 1997; Moran & Desimone, 1985). The biased competition model has been used primarily to study effects of attention, often in visual search paradigms.

When Chelazzi et al. (1993) investigated biased competition in V4 or IT neurons, their stimuli were complex colored shapes or scenes. It is not possible to know, however, whether the competition they observed occurred between shapes per se or between ensembles of shape properties. The biased competition model and Peterson et al.'s (2000) framework can be seen as very similar if we assume that in both cases, the competition occurs between ensembles of the shape properties. Peterson et al. assumed further that shape properties on the same side of an edge cooperate and that shape properties on the opposite sides compete, such that, *ceteris paribus,* the between-ensemble competition is biased toward the stronger ensemble of shape properties. We assume that this bias toward certain shape properties is a bottom-up bias; even effects of familiar configuration can be mediated by feed-forward connections established by past experience (see Mozer, Zemel, Behrmann, & Williams, 1992; Peterson & Gibson, 1993; Peterson & Skow-Grant, 2003). Peterson et al. proposed that for figure–ground perception, the response to shape properties on the more weakly cued side of the edge is inhibited; this is similar to the suppression of the shape that loses the biased competition because of attention or contrast that was found by Desimone and his colleagues. With respect to figure–ground perception in particular, Peterson et al. suggested that the inhibition of shape properties (including familiar configuration) on the more weakly cued side of an edge accounts for the compelling phenomenological impression that grounds are shapeless near the edges they share with figures.

In circumstances where the biased competition model has been applied previously—visual search—unattended shapes are not phenomenally shapeless. How then do we account for these different phenomenal impressions with the same model? Indeed, the apparent shapelessness of grounds has been used to claim that figure–ground perception occurs at a unique processing or architectural stage that is earlier than access to memories of familiar configurations. We posit that the phenomenology of figure–ground perception is unique for a different reason—because the competing shape ensembles lie on opposite sides of the same edge, they necessarily lie within the RFs of an entirely overlapping set of neurons; that is, the shape ensemble on the inside of an edge lies in the RF of the same neurons as the shape ensemble on the outside of an edge. (This analysis assumes that the competition relevant to figure–ground perception occurs at a level where neuron's RFs are large enough to encompass the competing shape properties, including familiar configuration, which requires some minimum number of parts arranged in the proper spatial relationships.) When competing shapes lie within the RFs of the same neurons and are present simultaneously, Luck et al. (1997) have shown that competition and suppression are strongest. Because the two candidate shapes in figure–ground displays lie on opposite sides of a single edge, the probability is very low that the properties of the two candidate shapes lie in different RFs. When competition is resolved, the neurons with the edge in their RF signal the presence of a single shape only; the response to the other candidate shape is suppressed. Because there are no (or exceedingly few) neurons that respond to one ensemble of shape properties but not the other in figure–ground displays, there are no neurons that can contribute to the phenomenal impression of more than one shape. In contrast, in typical attention studies, the two shapes competing for attention are separated in space and, therefore, are represented in somewhat distinct populations of neurons. Hence, when attention resolves competition in favor of one shape in the neurons with both shapes in their RFs, there remain other neurons that can signal the presence of the second shape because there is no competing shape in their RFs. Even when different shapes are overlaid on top of each other in a visual display, at least some portions of their bounding contours do not overlap spatially. Therefore, they too are represented by somewhat distinct populations of neurons. The neurons with RFs containing portions of the bounding contour of only one of the shapes are not suppressed when attention is directed to one of the two overlapping shapes. Again, the response to the unattended shape is suppressed only in the neurons with both shapes in their RFs. Even compared with overlapping shapes, the suppression of the more weakly cued shape in figure–ground perception is extreme because essentially all shape properties lie within the same RFs. Consequently, suppression of the losing shape properties is complete and phenomenal shapelessness results. Thus, rather than construing figure–ground segregation as a unique stage of processing, this analysis places figure–ground segregation at one end of a continuum of phenomenal awareness determined by the spatial separation between shapes.

We propose that the competition that results in the inhibition we measured here occurs at midlevels of visual processing. Peterson (2003) showed that partial configurations are sufficient for effects of familiar configuration—a whole shape is not necessary—and hence that effects of familiar configuration might be mediated by posterior brain regions with RFs large enough to encompass partial, but not full, configurations. Thus, it is possible that competition between the Gestalt configural properties and familiar configuration occurs in posterior brain regions, such as V4. In addition to shape properties, other factors, such as contrast, attention, perceptual set, and fixation location, influence figure assignment (O'Shea, Blackburn, & Ono, 1994; Peterson & Gibson, 1994b; Peterson et al., 1991; Vecera, Flevaris, & Filapek, 2004). The latter three effects are likely mediated by input from the frontal cortex. A complete model of figure–ground perception must include additional bottom-up and top-down influences.

We are not the first investigators to see a relationship between the biased competition model and figure–ground perception. Keysers and Perrett (2002) suggested that figure–ground alternations might be an instance of competition, but they neither elaborated on nor explored their suggestion. Vecera (2000) drew a parallel between the two realms because both bottom-up and top-down factors influence figure–ground perception just as both bottom-up and top-down factors influence neural competition. However, Vecera relegated effects of familiar configuration to a top-down role and retained Vecera and O'Reilly's (1998, 2000) model in which figure–ground perception occurs at an earlier hierarchical level than access to (holistic) object memories. We propose that there is a deeper similarity between figure–ground perception and biased competition (a) by conceiving of figure–ground perception as competition between a set of neurons that include within their RFs the shape properties on both sides of an edge, (b) by proposing that the response to the shape properties on the more weakly cued side of an edge is inhibited, and (c) by hypothesizing that the complete suppression of the neural response to the more weakly cued shape properties under these circumstances accounts for the perceived shapelessness of grounds. The results reported in the present article indicating that familiar configurations on the losing side of an edge are inhibited are consistent with our deeper analysis.

Relationship to Previous Experiments

Peterson and Kim (2001). Experiments 1A and 1B in the present article adapted and improved the design originally used by Peterson and Kim (2001) and, in doing so, provided strong evidence that a familiar configuration on the ground side of an edge is inhibited. Peterson and Kim included only a pair of experimental and control trials similar to those we presented in the SC–ground condition (although they used different line drawings in the two conditions), and they reported that observers' object decision responses were slower for line drawings following experimental than control silhouettes. Because Peterson and Kim did not include a DC–ground condition as well as an SC–ground condition, it was not possible to know whether the pattern of responses they obtained reflected competition or inhibition or both. Effects of competition would be expected regardless of whether the line drawing was in the same basic-level category as the shape suggested by the familiar configuration on the ground side of the edge (i.e., in both DC–ground and SC–ground conditions), whereas effects of inhibition are expected only in the SC–ground condition, because it is only there that the inhibited familiar configuration is expected to be among the ensemble of configurations accessed to make an object decision regarding the line drawing. The pattern of results obtained in the fast responses of Experiments 1A and 1B is just the one expected if the response to a familiar configuration on the ground side of an edge is inhibited in the course of figure–ground segregation. Experiment 2 ruled out an interpretation of Experiment 1 that did not require that the familiar configuration be suggested on the ground side of the experimental silhouettes. In Experiment 2, we presented the familiar configuration on the figure side of the edge and found evidence of facilitation rather than inhibition.

Peterson and Kim (2001) found evidence of inhibition only in participants who responded quickly and only when they used a short (83-ms) SOA between the silhouette and the line drawing. In their Experiment 1, evidence for inhibition was found in the mean responses of all of their participants ($N = 22$) in the 83-ms SOA condition; it was not necessary to restrict analysis to fast responses. No evidence for inhibition was found in 200-ms or 350-ms SOAs. The participants in the 83-ms SOA condition of Peterson and Kim's Experiment 1 responded very quickly, perhaps because they had already responded to a number of other SOA conditions (the different SOA conditions were presented in a blocked Latin square design), and their RTs in the 83-ms SOA condition reflect the benefits of practice (indeed, RTs were shorter for later blocks than for earlier blocks). In Peterson and Kim's Experiment 2, SOA was a between-subjects variable, and participants ($N = 23$) had only a small number of practice trials before they participated in the 83-ms SOA condition. The RTs of participants in their Experiment 2 were substantially longer than those of participants in their Experiment 1, and they found no evidence for inhibition when they analyzed the mean responses of all participants. Because of the disparity between the RTs in the 83-ms SOA condition in the two experiments, Peterson and Kim chose to analyze the mean responses of only those Experiment 2 participants whose mean control RTs were equal to or less than an RT defined by the mean control RTs of the majority of participants (77%) in Experiment 1; they found evidence of inhibition in this restricted set of participants. Participants in our Experiments 1A and 1B had more practice before the experimental trials than participants in Peterson and Kim's Experiment 2 but had substantially less practice than participants in Peterson and Kim's Experiment 1. Indeed, their mean control RTs were long compared with those of participants in Peterson and Kim's Experiment 1 (530 ms vs. 498 ms), and the analysis of mean RTs showed no evidence of inhibition. Accordingly, we conducted a second analysis on means based on the fast half of each participant's responses. Our participants fast-half control means averaged approximately 475 ms; hence, they were short enough to reveal evidence for inhibition if it could be found only in fast responses. Indeed, the fast response analysis showed evidence of inhibition in the SC–ground condition. Thus, it appears that in this paradigm, inhibition is evident for only a short time. The fleeting nature of the inhibition measured in object decisions regarding a line drawing shown after the silhouette is not surprising. The line drawing appears after the silhouette disappears, so any inhibition of responses to the familiar configuration should be diminished by the presentation of a new task-relevant stimulus. Moreover, although activation of the familiar configurations that were inhibited when the silhouette was exposed constitutes a component of the object decision response, there are many other components as well, most of which are not expected to be inhibited. Note that the fact that inhibition can be measured only in fast responses and only when the silhouette/line-drawing SOA is short does not imply that inhibition would be short-lived were the silhouette still exposed and were the participants responding to it.

Treisman and DeSchepper (1996). Treisman and DeSchepper (1996) showed participants a bipartite black-and-white display with a curvilinear central contour suggesting a novel shape on both sides. The black-and-white regions of their displays were equal in area and—at least across displays—were equated for other configural cues relevant to figure assignment. Participants had a top-down set to see the figure on the black side of the edge because their task was to decide whether it was the same as or different from a second single black shape in the display (see Figure 1). For purposes of discussion, let the curvilinear edge define the facing direction of the black shapes in the first, prime, trial. On probe trials, participants made a same–different judgment regarding two white shapes facing in the opposite direction. On experimental probe trials, the curvilinear edge from the bipartite display was repeated as a bounding contour of a shape lying on the side that was seen as the ground on the prime trial. On control trials, the curvilinear edges used to construct the control probes were novel (see Figure 1). Treisman and DeSchepper found that accurate same–different judgments took longer on experimental than control probe trials. Like the present results, the results reported by Treisman and DeSchepper may reflect inhibition of the shape properties on the more weakly cued side of a shared edge, although we note that the authors did not interpret them this way: They took their data as evidence that negative priming could be obtained for novel shapes and reasoned that ignoring the ground shape on the prime trial caused an ignore tag to be attached to it such that when it was encountered on the probe trial, participants were slower to respond to it.

It is difficult to gauge to what extent Treisman and DeSchepper's (1996) results reflect the inhibition we have measured in our experiments, for a number of reasons. First, their interpretation does not speak to the focus of the current article—the mechanism of figure–ground perception. They were studying whether negative priming could be obtained for novel shapes; their choice of figure–ground displays seemed arbitrary. Second, it is not clear whether observers in Treisman and DeSchepper's experiments first saw the black region or the white region as a figure in the bipartite display shown on the prime trial. Had they seen the white region as the figure first and then reversed the perceptual organization to see the black region as the figure (which was necessary for their task), the differences obtained may have been due to reversal processes. Third, it is possible that Tresiman and DeSchepper's results reflect competition alone and not inhibition. Peterson and Lampignano (2003; Peterson & Enns, 2005) pointed out that when the bounding contour of the figure is repeated in probe trials, slowing might reflect competition from the immediately prior experience that the figure lies on the opposite side of the edge rather than an ignore tag or inhibition. For that reason, in the present experiments, participants' task on probe trials was to decide whether a line drawing portrayed a novel object or a real-world object, and we deliberately used line drawings with edges that were not identical to the edges of the silhouettes. This change in paradigm, along with the use of both SC–ground and DC–ground conditions allowed us to be more confident that our results reflected inhibition rather than competition.

Remaining Questions

Many other questions are raised by these experiments, both theoretical and practical. One important question regarding our theoretical interpretation is whether there is any converging evidence that figure–ground perception entails inhibitory competition between shape properties on opposite sides of an edge. Measuring electroencephalographs, Trujillo, Peterson, and Allen (2005, 2006; Trujillo, Allen, & Peterson, 2007) found evidence for early and late differences in the processing of experimental and control silhouettes. Specifically, the P100 ERP component was larger for experimental than control silhouettes. They interpreted this P100 difference as reflecting the suppression of the competing familiar configuration in experimental, but not control, silhouettes. Trujillo et al.'s (2005, 2006, 2007) observers responded directly to the silhouettes, further extending the tasks used to index inhibitory competition in figure–ground perception. In addition, Peterson and Salvagio (2007) found that context affects figure–ground perception in a manner predicted by the biased competition model (Beck & Kastner, 2005). Thus, ongoing work in our laboratory is continuing to explore the mechanisms of figure–ground perception and their relationship to shape perception and attention.

We turn now to practical/methodological questions raised by our experiments. First, can we be reasonably certain that observers did not see the shapes suggested on the ground side of the silhouette edges in Experiment 1? The silhouettes used in Experiment 1 were strongly biased toward the interpretation that the central black region was the figure, and nothing in our design directed participants' attention to the white surrounding region. To determine whether participants had seen the shapes on the ground side of the experimental silhouettes, we questioned them repeatedly at the end of the experiments and showed them examples of shapes suggested on the outside of black silhouettes. If anything, the demand character of our questions led participants to believe they *should* have seen the shapes on the outside of the silhouettes. We gave participants multiple opportunities to tell us they had seen the shapes on the outside of the silhouettes during the experiment, yet none of them reported seeing them.

The fact that we obtained a qualitatively different pattern of results in Experiment 2 than in Experiment 1 supports our assumption that observers in Experiment 1 did not consciously perceive the shapes suggested on the ground side of the silhouette edge. Cheesman and Merikle (1984) proposed that qualitative differences in patterns of results might distinguish between conscious and unconscious processes. According to our hypothesis, inhibition prevented the potential shape in the ground of the silhouettes used in Experiment 1 from being perceived consciously. The different patterns of results obtained in Experiment 1—where participants responded more slowly to line drawings that followed SC–ground experimental silhouettes—versus Experiment 2—where participants responded faster to line drawings that followed SC–figure experimental silhouettes—is consistent with our belief that participants did not consciously perceive the shapes on the outside of the silhouette in Experiment 1 but did consciously perceive the shape in the figure silhouette used in Experiment 2.

Second, could the presence versus absence of an occluder in Experiment 2 versus Experiment 1 account for the different pattern of results? The use of an occluder in Experiment 2 allowed us to present as a figure the same portion of a familiar shape that had been presented as a ground in Experiment 1. We considered it important to present the same portion of a familiar object in Experiment 2, where we expected facilitation, as we had in Experiment 1, where we expected inhibition. Had we presented more of the shape in Experiment 2, a different pattern of results might have been expected because more of the object was presented. We added the occluder because we did not want to introduce extrinsic edges to delimit the partial object given that it is known that extrinsic edges interfere with object recognition responses (Nakayama, Shimojo, & Silverman, 1989). Because there is no theoretical reason why an occluder should change the pattern of results from inhibition to facilitation, we do not believe that the different results obtained in Experiments 1 and 2 were due to the occluder in Experiment 2.

Third, was the determination of figure–ground necessarily completed while the silhouette was exposed in the present experiments? Lamme, Zipser, and Spekreijse (2002) claimed that for monkeys, a stimulus exposure duration of at least 70 ms before mask onset is necessary for a V1 index of figure–ground perception to be observed. Our exposures were only 50 ms but the line drawing did not appear until 33 ms after the silhouette disappeared (there was no mask). Although we cannot be certain that figure–ground perception was completed in our experiments, we can be certain that the silhouettes were processed far enough so that the familiar configuration accessed on the ground side of the silhouettes used in Experiment 1 was suppressed, whereas the same familiar configuration accessed on the figure side of the silhouettes in Experiment 2 was enhanced. The switch from suppression to facilitation of the familiar configuration may not occur at a discrete moment when figure–ground perception is accomplished. Instead, it may occur gradually as the cross-edge competition is arbitrated.

Further research into the mechanism of figure–ground perception will elucidate the questions raised by the present experiments, which are the first to show that figure–ground perception entails suppression of familiar configuration.

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Appendix A

Familiar Line Drawings Used in Experiment 1

Set Fam-A	Set Fam-B
anchor	axe
bell	bone
butterfly	boot
coffee pot	broom
dog	bunny
face	duck
faucet	frog
flower	grapes
guitar	hand
house	jet
lamp	light bulb
leaf	lobster
Mickey Mouse	mouse
seahorse	palm tree
teddy bear	pear
umbrella	pineapple
woman	rhinoceros
wrench	watering can

Appendix B

Stimuli Used in Experiment 2

Experimental silhouettes		Control silhouettes
Set 1	Set 2	
axe	anchor	apple
bell	bone	birthday cake
boot	bunny	bug
butterfly	duck	cactus
coffee pot	elephant	crab
dog	faucet	deer
eagle	flower	flag
face	foot	frog
grapes	house	giraffe
leaf	hydrant	key
light bulb	lamp	lizard
pine tree	Mickey Mouse	mug
rhinoceros	owl	sailboat
teddy bear	palm tree	snail
train	pineapple	star
umbrella	seahorse	toilet
woman	snowman	truck
wrench	watering can	windmill

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