Perceptual Organization in a Brief Glance:
The Effects of Figure Size, Figure Location, and the Attentional Focus

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Abstract

Observers judged both the possibility and amount of depicted depth in briefly exposed possible and impossible figures of three sizes—large, medium, and small. Observers viewed these figures in one of two presentation conditions, either intermixed or blocked by size, conditions that were designed to manipulate the width of attentional focus. Two types of impossible figures were used, one in which the top and bottom corner were depicted from inconsistent viewpoints, another in which only one of the four corners was inconsistent with the other three. The retinal locus of the inconsistent corners was varied. Three major findings were obtained. First, estimated depth and apparent possibility were not completely overlapping variables; hence, theories must be specific about the perceived variables which they intend to predict. Second, the extraction of structural details signaling both possibility and depth was disrupted for small figures when the attentional focus was tailored for larger figures. Thus, object perception can be affected by the amount of processing resources within the attentional focus. Third, object-wide information was not utilized for either type of judgment. Implications for global and local theories of perceptual organization are discussed.
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A critical problem for any theory of form perception is that the percept of an object and the physical object are not isomorphic. The rectangular version of the Penrose and Penrose (1958) impossible figure shown in Figure 1a is one frequently discussed demonstration of this phenomenon. Figure 1a is "impossible" because the two corners on the right are depicted from a point of view (i.e., above and to the left) that is inconsistent with the point of view from which the two corners on the left are depicted (i.e., below and to the right). A closed rectangular object can be viewed from a single vantage point on a single occasion; hence the depicted tridimensional object is "impossible." Nevertheless, there are many reports that this figure appears to depict a closed rectangular tridimensional object (Hochberg, 1968, 1981; Pomerantz & Kubovy, 1986).

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Insert Figure 1 about here
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Drawings of impossible figures raise a serious problem for "minimum principle" accounts of form perception, which propose that the perceived organization of a figure will be the "simplest" organization, as determined on the basis of an object-
wide, or "global," computation (Boselie & Leeuwenberg, 1986; Buffart, Leeuwenberg, & Restle, 1981; Leeuwenberg, 1971). Since 1968, Hochberg has argued that interpreting impossible figures as flat line drawings would be globally simpler than interpreting them as depictions of tridimensional objects because the latter interpretation necessarily entails global inconsistency, whereas the former does not. Hochberg took the perceived tridimensionality of the impossible figures as evidence that the perceptual organization fitted to an object need not be based on a global simplicity-driven analysis of the object, but instead can derive from an analysis of locally attended or fixated object parts.

Debates regarding globally-induced versus locally-induced organization remain unresolved. One reason for the lack of resolution is that none of the theories has specified precisely those aspects of perceived organization to which their predictions apply. For example, it is not clear whether minimum principles are intended to predict apparent impossibility or apparent tridimensionality (e.g., see Boselie & Leeuwenberg, 1986; Peterson & Hochberg, 1989). Nor is it clear whether these two perceived properties must covary, or whether they can be dissociated: When impossible figures appear tridimensional, do they necessarily appear possible, or can they appear impossible and yet tridimensional, as Draper (1978) has implied? If impossible figures appear to depict tridimensional objects, do
they do so as convincingly as possible figures do, or does the simultaneous perception of impossibility reduce the depicted depth (i.e., the apparent distance from front to back)?

For the most part, impossible figures have remained demonstration figures: Very little research has used these figures to address questions regarding locally- versus globally-driven perceived organization, although theories of both human and machine vision have used impossible figures as proving grounds (e.g., Boselie & Leeuwenberg, 1986; Cowie, 1988; Hochberg, 1968; Huffman, 1971; Peterson & Hochberg, 1989). We contend that a closer examination of how observers perceive these figures may prove useful to an understanding of perceptual organization.

Another reason for the lack of resolution between global and local theories of perceptual organization is that the debate has allowed no middle ground. Theories of global organization such as structural information theory (Leeuwenberg, 1971; Buffart, Leeuwenberg, & Restle, 1981; Boselie & Leeuwenberg, 1986) predict which will be the simplest organization after an analysis of object-wide information; whereas research demonstrating locally-induced organization has typically defined "local information" as that carried by small subregions of an object. In fact, certain attributes of perceived organization may entail information of a more global nature than is often included in conditions of narrowly-focused attention.
Consider, for example, the altered Necker cube shown in Figure 1b. In Figure 1b, depth cues of the shading and occlusion in one region of the cube (point 1) indicate that it is facing downward and to the left. The depth information is not uniformly dense across the entire object, however: When considered in isolation, the region around point 2 is orientation-neutral. Peterson and Hochberg (1983, 1989; Hochberg & Peterson, 1987; Peterson & Gibson, 1991) showed observers both two-dimensional (2D) and three-dimensional (3D) altered Necker cubes and directed observers to fixate and/or to attend to either point 1 or point 2. Observers then reported continually throughout 30-sec trials about whether the cube appeared to be facing downward and to the left or upward and to the right. The results showed that the depth cues present at point 1 effectively determined the perceived organization when observers fixated on or attended to that region, but not when they fixated or attended to point 2.

In these previous studies, it was clear that the perceived orientation of the cube was governed more by fixated or attended local regions of the cube than by more determinate but unfixated regions of the cube. Other aspects of perceived organization may have been governed by information of a more global nature (cf. Cowie, 1988), however. For example, the interpretation of the connected wires (in the 3D case) or lines (in the 2D case) as a "cube" may have been governed by more global analysis.

Moreover, the region over which information is integrated
may be influenced by attentional allocation (Peterson & Hochberg, 1989). The empirical work demonstrating that perceived organization does not necessarily depend on global integration across the object has typically employed instructions to focus attention narrowly. Spatial attention is not always directed to a small region in the visual field, however. It is often distributed quite broadly (Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Jonides, 1983). Moreover, the processing resources available within the attentional focus may vary with its size. Recently, Eriksen and his colleagues (Eriksen & St. James, 1986; Eriksen & Yeh, 1985) have proposed that a constant supply of processing resources is distributed equally across the region over which attention is focused. Hence, when attention is focused narrowly, processing resources are highly concentrated; when attention is focused broadly, the processing resources devoted to any given region decrease.

It is possible that the narrowly-focused attention conditions in the Hochberg and Peterson experiments fostered piecemeal perception because information excluded from the attentional focus was attenuated or inhibited (LaBerge & Brown, 1989; Peterson & Gibson, 1991), and, consequently, its influence on perceived organization was reduced (Peterson & Gibson, 1991). Although it might be quite common for some parts of an object to fall outside the focus of attention, it may also be common for an entire object to fall within the focus of attention. One
question is whether mismatches between the object and the percept arise only in the former case or whether they arise in the latter case as well.

The Experiments

In the experiments presented here, we asked observers to judge the depth (Experiment 1) and the possibility (Experiment 2) of objects depicted by drawings of impossible and possible figures under two conditions of attentional distribution. Our aims were threefold:

First, we were interested in testing whether observers can distinguish between possible and impossible figures that are exposed only briefly. It has been shown that observers can identify impossibility when the entire figure is shown for a long time or when the individual corners are shown consecutively with a sufficiently long interval between the corners (Cowan & Pringle, 1978; Hochberg, 1968). It is not clear whether those judgments rely on integrating the viewpoints of individually attended or fixated corners, however. If figural impossibility can only be detected by integrating across successive glances, as Hochberg (1968; 1981) has argued, then observers should not be able to distinguish between possible and impossible figures that are exposed for durations too short to permit eye movements. Another reason for testing performance in brief exposure conditions is that proponents of globally-driven perceptual theories (e.g., Boselie & Leeuwenberg, 1986) have questioned
whether the evidence in support of locally-driven theories which has been obtained during 30-sec trials (e.g., Hochberg & Peterson, 1987; Peterson & Gibson, 1991; Peterson & Hochberg, 1983, 1989; Peterson, 1986) pertains to initial organization.

Our second aim was to establish (a) whether possible and impossible figures constructed from the same corners appear to depict equal amounts of figural depth, and (b) whether observers' judgments regarding possibility show the same pattern as their judgments regarding amount of depicted depth. Advocates of both local and global theories of perceptual organization have tended to consider claims about apparent possibility and apparent tridimensionality as interchangeable. Nevertheless, there is no evidence to suggest that these two variables are synonymous.

Third, we were interested in whether the width of observers' attentional focus affects their judgments regarding possibility and/or tridimensionality. If so, we will have identified a new condition in which mismatches between objects and percepts can arise. In this case, if perceptual organization varies as a function of the size of the attentional focus, it will be because of variations in the supply of processing power within the attentional focus rather than because of the exclusion of structural details from the focus of attention.

General Method

We manipulated the area over which spatial attention was distributed by varying the size of our stimulus figures. Small,
medium, and large versions of possible and impossible figures were presented in trial blocks that either included stimuli of only one size (blocked presentation condition) or that included stimuli of all three sizes (mixed presentation condition). In both presentation conditions, the figures were presented briefly in one of five locations—either centered on the observer's fixation point, or located in one of the four quadrants of the display. Large figures occurred somewhere within a 4.5 x 5.8 deg region centered on fixation; medium figures within a 3.0 x 4.4 deg region; and small figures within a 2.0 x 3.0 deg region.

The impossible figures were drawn so that the viewpoints of either one or two corners were inconsistent with the viewpoints of the remaining corners. The inconsistent corners could be located near or far from the observer's fixation point. We expected that observers would distribute their attention widely enough to optimize performance on the largest stimuli they expected to see on a given block of trials. Hence, because large figures were intermixed with medium and small figures in the mixed presentation condition, observers in that condition were expected to distribute their attention over the widest area they deemed necessary to make judgments about the large figures on all trials. Consequently, the size of their attentional focus would be quite large on all trials, and the processing power within the focus would consequently be low. On the other hand, because large figures were viewed in separate blocks from the small and medium
figures in the blocked presentation condition, observers in that condition were expected to distribute their attention widely enough to include the large figures only on the trial block on which they viewed the large stimuli; they could narrow their attentional focus for the trial blocks on which they viewed medium sized stimuli, and could narrow their attentional focus further for trial blocks on which they viewed small stimuli. Consequently, the processing power within the focus of attention would increase as the size of the figures decreased.

Because the size of the local viewpoint features (i.e., the corners) decreases as the size of the figures decreases, the processing power required to identify corner viewpoints correctly may increase as figure size decreases. In that case, judgments of possibility or tridimensionality made by observers in the blocked condition might not vary with size, because the adjustments in the size of the attentional focus from block to block might compensate for any changes in the size of the viewpoint features. However, judgments of possibility or tridimensionality made by observers in the mixed presentation condition might vary with figure size because the processing resources within the widest condition of attentional focus may not be sufficient to extract the structural details from the small and medium sized figures within the allotted time. If this result is found, that would imply that even with widely distributed attention, perceptual organization need not reflect
all the structural details present in the physical object.

Experiment 1

In Experiment 1, we examined observers' judgments regarding the depth of the objects depicted by briefly exposed possible and impossible figures that had been constructed from the same set of corners. Observers received no warning that the stimulus set included possible and impossible figures.

Method

Subjects. The subjects were 48 college students from the State University of New York at Stony Brook who participated in this experiment to satisfy a research participation requirement for an introductory psychology course. All had vision that was normal or corrected to normal. Half of the subjects were randomly assigned to the blocked presentation group; the other half were randomly assigned to the mixed presentation group.

Stimulus Materials and Apparatus. The set of figures we used is shown in Figure 2. Corners that appeared as parts of possible figures also appeared as parts of impossible figures, and vice versa. (The corners of the possible and impossible figures used in our experiments were drawn from the same set. Therefore, observers should not be able to distinguish between possible and impossible figures by identifying single corners.) Because this set of figures was originally designed for an iconic memory experiment in which observers reported whether individual corners of briefly exposed figures were depicted from "above" or
from "below" (Peterson & Shyi, 1989), the possible and impossible stimuli were equated for number of "above" and "below" corners, as we described next.

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Insert Figure 2 about here

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One half of both the possible and impossible figures were constructed from four corners all of which were viewed from either above or below. Because all four corners were viewed from the same above/below orientation, we will refer to these subsets of possible and impossible figures as P4 and I4 figures, respectively. The I4 figures were rendered impossible by the fact that a single corner was depicted from a right/left viewpoint that was inconsistent with the viewpoint of the remaining corners. For our purposes, that meant that detecting the impossibility of I4 figures depended on detecting the inconsistency of the viewpoint of a single corner. The retinal location of that corner varied with the location in which the figures were displayed. Consequently, analyses of performance with I4 figures as a function of presentation location can reveal whether or not judgments have utilized object-wide information. (It should be noted that we are not suggesting that detecting the impossibility of I4 figures requires an object-wide analysis, however. In fact, noting the viewpoint inconsistency of the two corners on the left would suffice to mark the impossibility of I4
The other half of both the possible and impossible figures were drawn so that the top corners were viewed from below and the bottom corners were viewed from above. Because only two corners were viewed from the same above/below orientation, we will refer to these subsets of possible and impossible figures as P2 and I2 figures, respectively. The possibility of the P2 figures was preserved by maintaining the same right/left viewpoint for all corners. Hence, the P2 figures were depicted from an eye-level perspective shifted to the left or right of center. The I2 figures were rendered impossible by switching the right/left perspective along with the above/below perspective. Detecting the impossibility of the I2 figures depended on detecting the inconsistency between any top-bottom pair of corners. Consequently, reports about the impossibility of I2 figures should not vary with presentation location because the inconsistencies between the top and bottom corners should be equally perceptible in all presentation locations.

Large figures were 9.4 cm long and 6.5 cm high, subtending a visual angle of 2.9 x 2.0 deg at the viewing distance of 185 cm. Medium figures were three-quarters the size of the large figures, subtending a visual angle of 2.2 x 1.5 deg; and small figures were half the size of the large figures, subtending a visual angle of 1.5 x 1.0 deg. All figures were drawn white on black on a CRT screen with a P3 phosphor. Stimulus presentation and
response recording were controlled by an Apple IIe microcomputer in conjunction with a Rogers' A6 Timer/Driver card. The experimental room was dimly illuminated at .12 ftl, and the luminance level of the CRT screen was .09 ftl. A grey cardboard, 24 cm in depth, was wrapped around the screen to eliminate reflections from the room light and to keep subjects fixation on the screen.

Procedure. Subjects participated in the experiment individually. Prior to the experimental trials, they were shown a P4 figure as an example of the type of figures they would be viewing. Next, they were instructed that they were to judge the apparent depth of the objects depicted by pictures such as these using a ten-point scale. They were instructed to use the number "1" to indicate that the object appeared to be flat and the number "10" to indicate that the depicted object appeared to be as deep as the cube shown in Figure 1c. They were to use the numbers between "1" and "10" to describe depicted objects with depths between those two extremes.

On each experimental trial, a "4" (accompanied by a low-frequency tone) was first displayed in the center of the screen. Subjects were instructed to fixate the cross and then to press the space bar on the keyboard. Immediately following the space bar push, one of the stimulus figures was presented for 150 ms in one of five locations: either in one of the four quadrants of the screen or centered on the location that had previously held
the fixation point. Following stimulus offset, subjects were prompted to judge the depth of the depicted object. Two seconds elapsed between the subject's response and the beginning of the next trial.

Each figure was presented once in each size in each of the four quadrants and twice in the center location for a total of 144 trials. The trials were divided into 3 blocks of 48 trials. For the mixed presentation group, figures of all three sizes were randomly mixed in each block. For the blocked presentation group, figures of different sizes were presented in separate blocks, with order of presentation counterbalanced across subjects.

All subjects were told that the stimulus figures would be of three different sizes. They were also shown three rectangles, cut from a white cardboard that represented the actual sizes of figures. Subjects in the blocked presentation group were reminded of the size of figures that they were about to see prior to the onset of each block of trials. Before the actual blocks of trials began, all subjects received 12 practice trials, randomly selected from a combination of stimulus size and presentation location.

Results and Discussion

The main effect of figure type was significant, $F(3, 138) = 22.83$, $MSe = 7.49$, $p < .001$. As can be seen in Figure 3, the possible figures were judged to depict deeper objects than the impossible figures ($Ms = 6.73$ and $5.67$, respectively) in both
presentation conditions, although overall, the objects were judged to be quite deep ($M = 6.20$). The interaction between figure type and presentation condition was also significant, $F(3, 138) = 3.59$, $MSe = 7.49$, $p < .02$. Observers reported that P2 figures depicted more depth than P4 figures did in the blocked presentation, $F(1, 23) = 6.97$, $MSe = 0.52$, $p < .02$, but not in the mixed presentation condition, $F < 1$, and that I4 and I2 figures appeared to depict objects with approximately equal depth in both presentation conditions (both $p$'s > .2). Hence, although briefly exposed impossible figures clearly did not appear to be flat, they did not appear to depict objects as deep as those depicted by possible objects.

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Insert Figure 3 about here
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There was also a significant interaction between size and presentation condition, $F(2, 92) = 5.25$, $MSe = 11.28$, $p < .01$. As can be seen in Figure 4, apparent depth did not vary with figure size in the blocked presentation condition, $F < 1$, when observers were able to adjust the size of their attentional focus optimally for each figure size. In the mixed presentation condition, however, large figures (of all types) appeared to depict deeper objects than small and medium figures, $F(1, 23) = 10.80$, $MSe = .49$, $p < .005$, and $F(1, 23) = 9.30$, $MSe = 2.46$, $p < .01$, respectively, and medium figures appeared to depict more
depth than small figures, $F(1, 23) = 7.14$, $MSE = .86$, $p < .02$. Hence, when the medium and small figures were seen under conditions in which attentional resources were distributed optimally for large figures, they appeared to be flatter than the large figures did. Hence, the perceived depth of these figures decreased as the processing power within the attentional focus decreased.

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Insert Figure 4 about here

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These findings also seem to rule out an alternative explanation which argues that subjects may have maintained an intermediate sized attentional distribution. With an intermediate size the density of processing resources may be adequate for processing efficiently both medium and small figures, whereas the processing of large figures can be accomplished by taxing the fringe area surrounding the attentional focus (Eriksen & St. James, 1986). Were this the strategy adopted by the subjects, it is not clear, however, why small and medium figures should appear to depict flatter objects than large figures. Given the optimal supply of processing resources (Eriksen & St. James, 1986), an intermediate sized attentional focus should be most suited for extracting information from medium figures and as a result subjects ought to rate medium figures as depicting more depth than either
the small or large figures, or at least to rate medium figures as depicting approximately equal depth as large figures. (Recall that when subjects knew in advance the size of the figures, they rated all figures as equally deep regardless of their sizes.) Neither was obtained in the experiment.

Another alternative is that, as Posner, Synder, and Davidson (1980) alluded, subjects' strategy may have been maintaining and moving a narrowly focused attentional beam (i.e., spotlight) to inspect the figure upon its appearance, and the difference between the blocked and mixed presentation conditions can be attributed to the additional spatial uncertainty of the figures in the latter condition. However, it is not clear how such an interpretation would deal with the fact that large figures appeared to depict deeper objects than medium and small figures. Presumably it should predict (a) a main effect of size with small figures depicting more depth than either medium or large figures because the larger the figure was the more spatial uncertainty it inherited; (b) the main effect of size manifesting in both the blocked and the mixed presentation conditions with differences in size exacerbated by the additional spatial uncertainty in the mixed condition. Neither prediction was confirmed in the experiment.

The data revealed no difference between performance with stimuli exposed in the two locations in the left hemifield or the two locations in the right hemifield. Consequently, in what we
report below, we describe the location effects in terms of left visual field (LVF), right visual field (RVF), and center locations.

Both the main effect of location and its interaction with figure type were found significant, $F(2, 92) = 7.27$, $\text{MSe} = 1.41$, $p < .005$, and $F(6, 276) = 5.74$, $\text{MSe} = .98$, $p < .0001$, respectively. As shown in Figure 5, although the apparent depth of P2 and I2 figures did not vary with their location in the visual field, the apparent depth of P4 and I4 figures did vary with location. Observers' judgments indicated that the I4 figures appeared to have more depth when they appeared in the LVF rather than the center or the RVF, $F(1, 46) = 14.34$, $\text{MSe} = .57$, $p < 0.001$, and $F(1, 46) = 8.63$, $\text{MSe} = .73$, $p < .01$, respectively, perhaps because the inconsistent corner was always one of the two corners farthest from fixation in the LVF. This finding suggests that observers were not reliably extracting the viewpoints of all of the corners of the figures in making their judgments about the depth of the depicted objects.

Insert Figure 5 about here

This LVF effect was obtained for I4 figures of all sizes—no significant three-way interaction among figure type, location and size was found—which suggests that the exclusion of far corners was not due simply to their retinal eccentricity (because far
corners of small figures were closer to fixation than far corners of large figures). Of course, the corners of the smaller figures were also smaller than the corners of the large figures, and consequently, may not have been more perceptible, even though they were closer to fixation. Were the far corners neglected because of their lowered perceptibility, however, one might expect to see variations in the I4 location effect with variations in the size of the attentional focus. That we did not implies that the far corners may have been neglected because depth judgments were not based on object-wide information.

P4 figures appeared to be deeper when they were presented in the RVF or the LVF as opposed to the center of the visual field, \( F(1, 46) = 17.15, MSe = .39, p < .01, \) and \( F(1, 46) = 10.86, MSe = 0.40, p < .002, \) respectively. This pattern is also consistent with the proposal that observers were not simply surveying the four corners of the figures in order to judge the depicted depth.

**Experiment 2**

In Experiment 2 we examined whether observers could distinguish between possible and impossible figures under the same conditions of brief exposure. Before the experimental trials, we showed observers examples of possible and impossible figures and pointed out that impossibility was signaled by corner viewpoint inconsistency. Hence, these viewers may have adopted a strategy of searching for corners that depicted inconsistent viewpoints. If observers can identify the viewpoint of only a
single corner in a brief glance, then they should not be able to
distinguish between possible and impossible figures when the
figures are exposed for only 150-ms. On the other hand, if
observers can integrate viewpoint information from more than a
single corner in a single glance, they might be able to
distinguish between briefly exposed possible and impossible
figures. In that case, a comparison of performance with I4 and I2
figures in the different presentation locations will give some
indication of how global the integration was.

In Experiment 2, we again employed the blocked and mixed
presentation conditions to allow us to examine whether observers'
possibility judgments were affected by the size of the area over
which their attention was distributed.

Judgments regarding possibility will be inspected to see
whether they display the same patterns as judgments regarding
depicted depth. Similar patterns will be taken to suggest that
perceived depth and perceived possibility are based on
overlapping variables, of an equivalent local or global nature;
dissimilar patterns would imply that the two perceptual
attributes are not based on completely overlapping variables.

Method

Subjects. Another 48 college students from the State
University of New York at Stony Brook participated in the
experiment to satisfy a psychology course requirement. All had
vision that was normal or corrected to normal. As in Experiment
1, half of the subjects were randomly assigned to the blocked presentation group, and the other half, to the mixed presentation group.

Procedure. As in Experiment 1, subjects participated in the experiment individually. Prior to the experimental trials, subjects were instructed about figural impossibility, while they viewed a drawing of a Penrose and Penrose (1958) impossible triangle. They were told that since it is only possible to view an object from a single viewpoint at any given time, the triangle was considered an "impossible figure," because the corners were depicted from different points of view. Subjects were then shown a drawing of a possible triangle, in which the three corners were depicted from the same point of view. Next, the experimenter showed subjects two more figures, one possible and one impossible, in succession, and asked them to identify whether the figure was possible or impossible (the order was counterbalanced across subjects). All subjects made correct identifications.

Subjects were instructed to use a ten-point rating scale to express their confidence that the figure they had seen was possible or impossible. They were to use the number "1" to indicate that they were certain that the figure was possible, and the number "10" to indicate that they were certain that the figure was impossible. They were to use the numbers between 1 and 10 to indicate varying degrees of certainty between these two extremes.
In other respects, the procedure of Experiment 2 was the same as that of Experiment 1.

**Results and Discussion**

As in Experiment 1, the main effect of figure type was significant, $F(3, 138) = 34.43$, $MSE = 26.8$, $p < .0001$. As can be seen in Figure 6, observers were generally more confident that the possible figures ($Ms = 3.78$ for P4 and 4.70 for P2) rather than the impossible figures ($Ms = 5.87$ for I4 and 7.09 for I2) depicted possible objects. Within these categories, observers were more confident that the P4 figures depicted possible objects than the P2 figures and were less confident that the I2 figures depicted possible figures than the I4 figures. (All pairwise comparisons were significant at the .05 level.) The pattern of possibility judgments across figure-type differs from the pattern of depth judgments, where I4 and I2 figures were judged to depict objects of equal depth and P2 figures appeared to depict deeper objects than P4 figures (the latter only in the blocked presentation condition). This dissimilarity in the patterns of depth and possibility ratings implies that observers' possibility judgments in Experiment 2 were not based simply on the apparent depth of the depicted object.

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Insert Figure 6 about here
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As also shown in Figure 6, the three-way interaction among
figure type, size, and presentation condition was significant, $F(6, 276) = 2.09$, $MSE = 3.24$, $p = .05$. Possibility judgments made by observers in the blocked presentation condition did not vary with the size of the figures, $F < 1$, whereas possibility judgments made by observers in the mixed presentation condition did vary with figure size, $F(6, 138) = 4.86$, $MSE = .86$, $p < .001$.

In particular, observers' confidence ratings did not distinguish between small versions of I2 and I4 figures nor between small versions of P2 and P4 figures (both $p$’s > .1), although ratings of small impossible figures ($M = 6.38$) were still higher than ratings of small possible figures ($M = 4.78$). These findings indicate that the analysis of structural details in a picture requires attention. These results also can rule out either the
t account that subjects maintained an intermediate sized
tentional focus in the mixed presentation, which would predict
superior performance in judging the medium figures, or the
account that they adopted the strategy of maintaining and moving
a narrow attentional spotlight, which would predict superior
performance in judging small figures. (See also the discussion of
Experiment 1.)

Hence, in the mixed presentation condition, when the
processing resources were spread over a large area, possibility
judgments suggest that observers' ability to distinguish between
different figures was reduced. Recall that in the mixed
condition of Experiment 1 the medium and small figures looked
flatter than the large figures (see Figure 4). Note, however, that the possibility judgments made by observers in the mixed presentation condition were compressed for small figures only (see Figure 6), whereas depicted depth appeared to decrease progressively from large to medium to small figures.

As in Experiment 1, the main effect of location and its interaction with figure type were found significant, $F(2, 92) = 5.14, MSe = 4.33, p < .01$, and $F(6, 276) = 3.93, MSe = 2.83, p < 0.001$, respectively. Possibility judgments about possible figures were unaffected by presentation location, but possibility judgments about impossible figures were affected by presentation location. As can be seen in Figure 7, the difference in possibility judgments between I4 and P2 figures was smaller when presented in the LVF than when presented in the center or the RVF: With LVF presentation, the inconsistent corner of I4 figures was one of the two corners farthest from fixation; however, observers seemed better able to distinguish between the I4 and the P2 figures when they were presented in the center or the RVF. This location effect was found for I4 figures of all sizes in both blocked and mixed presentation conditions. This finding implies that observers' possibility judgments were based on a less than object-wide analysis, as their tridimensionality judgments had been.

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Insert Figure 7 about here

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The apparent possibility of I2 figures was affected by both size and location, as shown in Figure 7. Observers were more certain that large I2 figures depicted impossible objects when they were presented in the center of the visual field rather than the LVF or the RVF, $F(1, 46) = 10.32$, $MSe = 2.37$, $p < .01$, and $F(1, 46) = 8.09$, $MSe = 3.22$, $p < .01$, respectively. The opposite pattern was obtained with small I2 figures: observers were less certain that small I2 figures depicted impossible objects when they were presented in the center of the visual field rather than the LVF or the RVF, $F(1, 46) = 4.41$, $MSe = 3.46$, $p < .05$, and $F(1, 46) = 8.45$, $MSe = 4.15$, $p < .01$. This latter finding is surprising since the corners of the I2 figures were closer to the fovea with central presentation. One might have thought that their inconsistency would have been more apparent, regardless of their size, producing a pattern like that obtained with the large figures for all figure sizes. The lowered confidence that small centrally-presented I2 figures depicted impossible figures cannot be a consequence of increased apparent depth in those figures, as the apparent depth of the I2 figures was unaffected by these variables in Experiment 1 (see Figure 4).

General Discussion

These experiments demonstrate that the depth perceived in impossible figures is not as great as the depth perceived in possible figures. In addition, these experiments show that, for the most part, observers can distinguish between briefly exposed
possible and impossible figures. Therefore, we conclude that observers can integrate information over areas larger than a single corner within one glance at a figure. Information integration is by no means object-wide, however: The hemifield effects obtained with I4 figures for both judgments suggest that the two corners farthest from fixation were not analyzed in detail within a single glance.

Furthermore, the experiments revealed that both depth and possibility judgments were influenced by the size of the attentional focus: When the attentional focus was wide, and processing power within the attentional focus was consequently low, as in the mixed presentation condition, the effects of figure-type on the apparent possibility of small figures were diminished. On the other hand, when the size of the attentional focus could be tailored for figure size, as in the blocked condition, observers' ability to distinguish between different figures was not reduced for the small figures. Attentional effects were obtained for depth judgments as well: Here, the objects depicted by both medium and small figures appeared to flatter than those depicted by the large figures.

These experiments demonstrate that perceived organization can vary with the density of the processing resources within an attentional focus, thereby extending the conditions in which such attentional effects have been obtained to the realm of object perception. Moreover, these experiments extend the conditions
under which the perceived object and the physical object have been shown to be non-isomorphic: In this case, the mismatch between the percept and the stimulus occurred when the entire object fell within the focus of attention (or could have fallen within the attentional focus), but the processing power within that focus of attention was insufficient to extract the necessary structural details. The widest condition of attentional focus that would have sufficed to include all corners of the largest figures (less than 4.5 x 5.8 deg) was relatively small compared to the size of the unrestricted visual field. Hence, the results suggest that the processing of pictorial details specifying the tridimensionality of a depicted object and the viewpoint of its corners requires some minimum amount of processing resources. An interesting question for future research is whether the same is true for real 3D objects. Note that these experiments demonstrate that the width of the attentional focus can affect the pick-up of structurally-relevant details, and not simply of details of surface decoration.

What message do these results carry for local and global theories of perceptual organization? Our results are consistent with neither theory as stated in the extreme. Perceived organization was neither that induced by a single corner, nor was it the simplest organization that could be fitted to object-wide information. Both perceived depth and possibility varied with figure type and size, presentation location, and width of
attentional focus. Questions regarding local versus global organization will not be answered until roles for these variables are included in theories of perceptual organization.

These experiments demonstrate that apparent tridimensionality and apparent possibility are not based on completely overlapping variables. The dissimilarities in the patterns of depth and possibility ratings suggest one of the following. First, different cues may be integrated for the different judgments. A second possibility is that the different judgments rely on the same cues (e.g., the viewpoints of individual corners), but those cues are assigned different weights depending on the observers' task. Future research will have to identify the relevant cues and their importance for each task.

A related line of research examining local versus global processing should be mentioned here, if briefly. That research has used compound stimuli in which large (global) shapes (typically two-dimensional letters) are given by the arrangement of smaller unconnected local elements (typically other 2D letters). The placement of the local elements in compound stimuli determines the identity of the global shape, but the identity of the local elements is irrelevant to the identity of the global shape (Navon, 1977; Pomerantz, 1983). Research using these stimuli has tended to support the notion that global information is processed faster than local information (i.e., the
analysis of global information "precedes" the analysis of local information), at least for global stimuli that are smaller than about 6 to 9 deg of visual angle and which appear in peripheral retinal locations (Kinchla & Wolfe, 1979). Moreover, Lamb and Robertson (1988) have shown that local processing benefits more than global processing from a decrease in the size of the attentional focus.

The issues in the global versus local precedence literature are really quite different from those in the debate about globally-induced versus locally-induced organization. Indeed, Pomerantz (1983) has argued that conclusions based on tasks using compound stimuli will not necessarily generalize to tasks using stimuli (such as ours) in which changing either the identity or the location of the local elements would change the global shape. The latter type of stimuli must be used in experiments designed to examine whether perceived organization is locally- or globally-determined. Compound stimuli are artificial stimuli in that they are constructed from two levels only. Hence, using these figures to examine questions of perceptual organization could only serve to prolong the irresolution between local and global theories.
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Hochberg, J. (1981). Levels of perceptual organization. In M.


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Author Notes

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Figure Captions

Figure 1. (a) An impossible figure adapted from Hochberg (1968); (b) a Necker cube adapted from Peterson and Hochberg (1983), which includes occlusion cues at the top intersection (1) which specifies that the cube is facing downward and to the left. Orientation is unspecified at the bottom intersection (2); (c) the drawing of an open box used to instruct subjects how to rate the apparent depth of presented figures in Experiment 1.

Figure 2. The stimulus figures used in Experiments 1 and 2: a & b are possible figures for which all four corners were depicted from the same point of view, (P4); c & d are possible figures viewed from an eye-level perspective (P2); e & f are impossible figures for which one corner was depicted from a viewpoint inconsistent with that of the other three corners (I4); g & h are impossible figures for which the top and bottom corners were depicted from different points of view (I2).

Figure 3. Apparent depth ratings in Experiment 1 as a function of size and presentation condition (N = 48).

Figure 4. Apparent depth ratings in Experiment 1 as a function of figure type and presentation condition (N = 48).

Figure 5. Apparent depth ratings in Experiment 1 as a function of figure type, size, and location (N = 48). LVF = left visual field; CTR = center; RVF = right visual field.

Figure 6. Confidence concerning possibility in Experiment 2 as a function of figure type, size, and presentation condition (N =
Figure 7. Confidence concerning possibility in Experiment 2 as a function of figure type, size, and location (N = 48). LVF = left visual field; CTR = center; RVF = right visual field.
<table>
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<tr>
<th>Figure Type</th>
<th>Stimulus Figures</th>
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<td><strong>P2</strong></td>
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Confidence concerning Possibility

Size

Blocked

Mixed

Large

Medium

Small

P4  P2  14  12