Conflicting figure–ground and depth information reduces moving phantom visibility

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Abstract. Moving phantom visibility was measured in two experiments where the global figure – ground and depth relations within phantom-inducing patterns were manipulated. The local inducing environment where the illusion occurred was identical for all patterns. Phantom visibility was significantly reduced when occlusion cues specified the phantom-inducing parts of a pattern as ground. These results suggest conflicting figure – ground and depth information interferes with the representation and perception of phantoms as figure regions.

1 Introduction

The visual system is rarely required to resolve an ambiguity about what is figure and what is ground. The various objects and surfaces in the environment are segregated and perceived in depth easily and automatically. Whether it is a drawing of a figure on a piece of paper or the piece of paper as figure against the table, figure and ground are segregated without conscious awareness. The automaticity of this ability to organize the visual world in depth is a major difficulty in trying to understand the process of figure – ground segregation. Visual phantoms (Tynan and Sekuler 1975) are an illusion that might provide a window into the hidden, automatic process of figure – ground segregation.

A common phantom-inducing pattern consists of a black horizontal strip occluding the middle of a black-and-white, vertical, square-wave grating that is continuously moving from left to right. When phantoms are visible, the previously interrupted black grating stripes now phenomenally appear to complete in front of the opaque horizontal strip. The occluder undergoes a unique figure – ground reversal, first appearing in front of the grating, then appearing as ground behind the drifting phantom stripes. A phantom stimulus is unstable in the sense that, over time, the occluder alternates between being in front of the grating stripes (when no phantoms are visible) and being behind the phantom stripes.

The fluctuating nature of phantoms indicates an active process whereby a three-dimensional interpretation is being sought for an ambiguous two-dimensional stimulus. This makes a phantom stimulus more similar to figure – ground reversible stimuli like Rubin's faces/vase than to illusory contours and surfaces.(1) The three-dimensional

(1) The stimulus conditions, phenomenal appearance, and fluctuating nature of phantoms also separate this effect from the grating-induction effect (McCourt 1982). The typical grating-induction stimulus is a vertical sine-wave grating with a blank horizontal region across the middle, the blank region having a contrast equal to the mean contrast of the inducing grating. The induced grating appears within the blank region 180° out-of-phase with the surrounding grating and does not fluctuate over time. For phantoms to appear, the horizontal blank region must be the same or nearly the same brightness as some part of the inducing pattern (eg white inducing regions would not complete across a black or gray occluder due to low level brightness information segregating them from the occluder) (Brown 1985; Brown and Weisstein 1985; Maguire and Blattberg 1986). Thus the stimulus conditions that produce phantoms and their phenomenal appearance suggest that the phantom illusion is a very different phenomenon from the grating-induction effect.

organization of an illusory contour pattern (eg the Kanizsa triangle) is usually unambiguous resulting in a very stable illusory percept (although see Bradley 1987). However, the three-dimensional organization of a figure–ground reversible stimulus fluctuates over time. Thus, phantoms are a unique type of figure–ground reversible stimulus. When one of the possible figure–ground organizations is perceived (ie a phantom is interpreted), the contours and surfaces appropriate for that organization are supplied by the visual system.

Phantom visibility is affected by many variables (for a review see Maguire and Brown 1987). However, the ambiguous depth relation between the occluder and the phantom-inducing regions appears to be a critical characteristic of a phantom display with the particular three-dimensional interpretation of this relation determining whether or not phantoms are perceived. When the occluder is grouped as a separate surface in front, it is interpreted as being homogeneous and phantoms are not visible. However, when a grouping is adopted that includes phantoms, the phantom parts of the occluder appear closer in depth and seem different in lightness(2) even though they are physically identical to the nonphantom parts. The figural status of the phantom regions may be related to their phenomenal appearance for two reasons. First, a region seen as figure often appears "richer", "more impressive" (Rubin 1921) than when it is seen as ground. Second, the perceived lightness of a region has been found to be influenced by its perceived position in three dimensions (Beck 1965; Gilchrist 1977, 1979, 1980; Gilchrist et al 1983). For example, a region reflecting a fixed amount of energy to the retina can appear as two quite different lightnesses depending on where it is organized in depth relative to the viewer. The perceived differences in spatial layout and lightness between phantom and nonphantom portions of the occluder are consistent with these findings.

In addition to their phenomenal appearance, recent evidence suggests that phantoms are associated with processes and mechanisms involved in figure–ground processing (Brown 1985; Brown and Weisstein 1988a). For example, a figure–ground context effect (Wong and Weisstein 1982) can be produced using a phantom display as the figure–ground context (Brown and Weisstein 1988a). In the figure–ground context effect the visibility of briefly flashed lines was better in a region when it was perceived as figure than when the same region was perceived as ground (Wong and Weisstein 1982). Brown and Weisstein (1988a) found an analogous effect; target visibility was better in the perceived phantom compared to nonphantom portions of a homogeneous occluder. This phantom context effect was contingent on the perception of phantoms. When phantoms were not visible, there was no context effect. The effect on target visibility was related to the representation of a region as figure or ground.

The following experiments are also concerned with the segregation and representation of figure and ground. One of the most common attributes of a figure–ground distinction is the implicit depth relations associated with it. Figure is commonly perceived in front, while ground is typically perceived as continuing behind the figure (Rubin 1921). Therefore, interposition can be a strong cue to depth (Chapanis and McCleary 1953) and figure–ground segregation (Rubin 1921). Interposition was used in the following experiments to create different figure–ground and depth relations within phantom-inducing patterns. The experiments evalute the influence of these different relations on moving phantom visibility.

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(2) The perceived lightness may be more of a qualitative than a quantitative distinction as indicated by the results of Mulvanny et al (1982) which show that a phantom grating is cancelled by a 180° out-of-phase real grating in the occluder at detection threshold.

2 Experiment 1

If the parts of an inducing pattern that appear to complete as phantoms are represented as figure regions when phantoms are perceived, would additional information designating them as figure regions enhance phantom visibility? Conversely, would contrary information designating them as ground regions interfere with or degrade phantom visibility? The first experiment addressed these questions with the use of the patterns shown in figure 1.

Each pattern consisted of gray and white regions on a black background. When the patterns were drifted from left to right with a gray horizontal strip occluding the middle, the gray vertical regions were perceived to complete as phantoms across the occluder. For demonstration purposes, the occluder has been removed from the patterns in figure 1 so the entire patterns can be seen. Figure 2 illustrates one of the patterns with the occluder present.

During the experiment the occluder always blocked the middle of each pattern. In pattern a in figure 1, interposition cues indicated the gray inducing regions as figure in front of the white regions. Likewise, interposition cues indicated the gray inducing regions as ground behind the white regions in pattern c. Patterns b and d were control patterns for a and c, respectively. The gray vertical inducing regions were identical but the horizontal gray regions were removed, eliminating any interposition cues. If phantom visibility is enhanced by additional depth information cueing the gray regions as figure, then pattern a would be expected to produce greater phantom visibility than patterns b, c, and d. In addition, phantom visibility should be less for pattern c compared to a, b, and d if information contrary to interpreting the phantom-inducing regions as figure hinders phantom visibility.

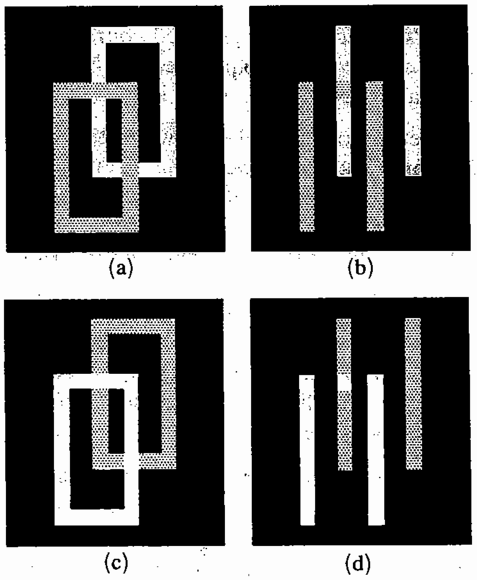

Figure 1. Four phantom-inducing patterns used in experiment 1. The textured areas represent solid gray. Observers always saw the patterns with a gray horizontal occluder present. Pattern a cues the gray regions as figure, in front of the white regions. Pattern c cues the gray regions as ground, behind the white regions. Patterns b and d are figure-ground neutral control patterns.

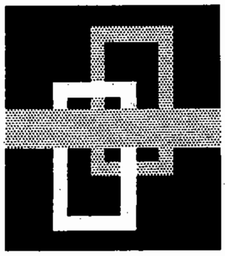

Figure 2. An example of pattern c in figure 1 with the occluder present. When phantoms are seen, the vertical gray regions are perceived to complete themselves in front of the horizontal occluder.

It is important to note that the designation of the depth and figure-ground relations in all of these patterns is relative, especially when the pattern is drifting with an occluder present. Numerous descriptions of the figure-ground and depth relations are possible even for the control patterns. For example, consider three different descriptions of pattern b in figure 1 as it is drifted with an occluder present.

(i) There is a black background on which some white and gray vertical strips are moving which have their middle occluded by a stationary gray horizontal strip.

(ii) There is a black background on which some white vertical strips are moving which have their middle occluded by a stationary horizontal gray region which has some gray vertical strips moving in front of it.

(iii) There is a black background on which some white vertical strips are moving above and below a moving gray horizontal region with gray vertical pieces attached above and below it.

The result of (i) is that phantoms are not visible, but the gray and white vertical strips are perceived to complete amodally (Kanizsa 1979) behind the occluder. The result of (ii) is a phantom interpretation where the white strips still complete amodally, but now the gray strips are perceived to complete modally in front of the occluder. Description (iii) illustrates that other interpretations are possible, even though the most common occurrence is for the perception to alternate between the first two descriptions as phantoms disappear and appear over time. The question asked in this experiment was whether the likelihood of a phantom interpretation would be affected by additional figure-ground and depth information about the inducing regions.

2.1 *General method*

Subjects, stimuli and apparatus, and the procedure are described in general here for both experiments. Any specific differences will be noted as needed.

2.1.1 *Subjects.* Students from an Introductory Psychology class received course credit for participation in the experiments (experiment 1, $N = 6$; experiment 2, $N = 13$). All had normal or corrected-to-normal vision. Each observer was tested individually.

2.1.2 *Stimuli and apparatus.* Stimuli were presented on a black-and-white television monitor (Setchell-Carlson) using an image processor (Grinnell Image Processor) controlled by a computer (LSI-11/23). The monitor screen subtended a visual angle of 6.8 deg (height) by 7.27 deg (width). Viewing was monocular and performed using a chinrest in a darkened room. All stimuli were suprathreshold and clearly visible from the viewing distance of 2.56 m.

All patterns were composed of gray ($0.83\ \mathrm{cd\ m^{-2}}$) and white ($8.46\ \mathrm{cd\ m^{-2}}$) lines, 0.57 deg thick on a black ($0.012\ \mathrm{cd\ m^{-2}}$) background. A horizontal gray ($0.83\ \mathrm{cd\ m^{-2}}$) strip 2.0 deg × 7.27 deg (shown in figure 2 and shown cutaway in figure 4c) occluded the middle of the screen. Observers only saw the stimuli with the occluder present. A dim fixation point was always visible at center of the screen.

2.1.3 *Procedure.* During the first five minutes of an experimental session an observer viewed a 0.9 cycles $\mathrm{deg^{-1}}$, black-and-white, square-wave grating drifting from left to right at $0.58\ \mathrm{deg\ s^{-1}}$ with a black occluder (2.0 deg × 7.27 deg) across the middle. While observers fixated a dim fixation point at the center of the screen, they were asked to describe the appearance of the display. In particular, they were asked to describe which portions of the display appeared to move, which appeared stationary, and which regions, if any, appeared connected. At some point during this period all observers spontaneously described phantoms. They were then informed of the illusory nature of their perception and that the illusion was called phantoms.

Observers were next instructed on the use of a timer button for reporting when they saw phantoms. They then practiced for three minutes, pressing the button when phantoms were visible and releasing it when they were not. Finally, observers were instructed that they were going to view other phantom patterns that were more complex than simple repetitive stripes and that they should continue to use the button to report any phantoms as in the practice.

During the remainder of the experiment each pattern was presented five times in random order. A pattern drifted continuously from left to right at 0.58 deg s^{-1} for one minute in each trial. Two measures were made on each trial: (i) the percentage of time for which the phantoms were visible out of the total viewing time (henceforth called phantom strength), and (ii) the amount of time that elapsed in each trial before phantoms were first reported (henceforth called incubation time).

2.2 *Results and discussion*

Phantoms were visible with all of the patterns tested. When phantoms were visible, the vertical gray inducing regions of the patterns were perceived to complete themselves as figure in front of the occluder. Repeated measures ANOVAs for phantom strength ($F_{3,15} = 3.95$, $p < 0.05$) and for incubation time ($F_{3,15} = 7.13$, $p < 0.01$) were both significant. Post hoc analysis (Newman-Keuls) found pattern c significantly different from the other three patterns for both phantom strength ($p < 0.01$) and incubation time ($p < 0.01$). As is evident from figure 3, phantom strength was nearly half and incubation time nearly double for pattern c compared to a, b, and d.

Additional information cueing the phantom-inducing regions as figure in pattern a did not facilitate phantom visibility. However, phantom visibility was attenuated when the figure-ground and depth relations specified the inducing regions as ground in pattern c. Because the vertical gray inducing regions were perceived as figure when they completed as phantoms, cueing them as ground within the pattern conflicted with their interpretation as phantom figures. While pattern c did produce phantoms, the longer incubation time suggests that this conflicting information had to be resolved before the phantoms became visible.

A closer examination of the patterns, however, suggested a possible alternative explanation. Consider figure 2 again. When phantoms are seen with this pattern, the left vertical gray bar is perceived to weave in depth behind the white region and then in front of the occluder. The left vertical gray bar in its control pattern (pattern d in figure 1) is exactly the same, but the organization needed for it to complete as a phantom is simpler (ie no weaving in depth is required). Even if it were interpreted as an interrupted vertical bar (ie the white square is a piece missing from it), it still produced phantoms as effectively as patterns a and b which were not interrupted. Only in pattern c were the gray regions cued as ground. Thus, c was also the only pattern requiring a gray inducing region to weave in depth behind the white regions and then in front of the gray occluder in order to be perceived as continuous from

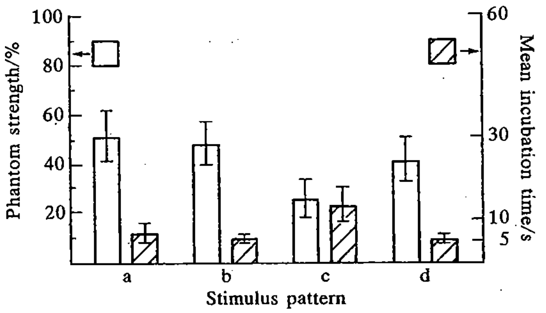

Figure 3. Phantom strength and incubation times for the four patterns of experiment 1. Pattern c was significantly different from the rest.

top to bottom when completing as a phantom. In other words, a phantom interpretation may have been more difficult in pattern c, not because of the global specification of the gray inducing regions as ground, but due to the changes specific to the classification of the left gray vertical inducing-region as figure and ground along its extent. The second experiment addressed this issue.

3 Experiment 2

In this experiment the patterns shown in figure 4 (a, b, and c) were used as phantom-inducing stimuli. Interposition was again used to cue the gray regions of the patterns as either figure (pattern a), ground (pattern b), or neutral (pattern c) in the global organization of the pattern. However, none of the vertical gray regions had to weave in these patterns because the occlusion cue designating the gray regions as figure or ground was located at the top and bottom, between the horizontal gray and vertical white regions. Therefore, the vertical gray inducing regions were exactly the same in each pattern. If local changes in the depth cue designating the left gray vertical inducing-region as figure or ground along its extent was the factor attenuating phantom visibility in experiment 1 (pattern c) then phantom visibility should be the same for these patterns.

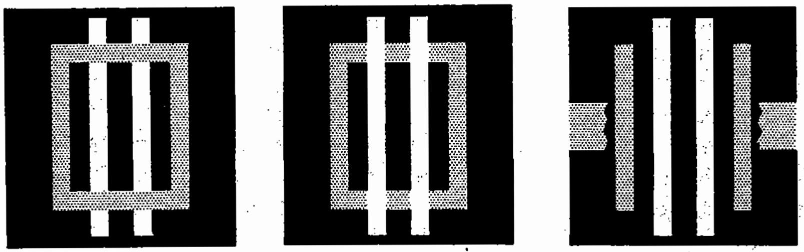
(a) (b) (c)

Figure 4. Three patterns used in experiment 2. Note the occlusion cues have been moved to the top and bottom of the inducing patterns making the vertical gray regions exactly the same for all patterns.

3.1 *Results and discussion*

Repeated measures ANOVAs for phantom strength ($F_{2,24} = 4.17$, $p < 0.05$) and for incubation time ($F_{2,24} = 6.27$, $p < 0.01$) were again both significant. Post hoc analysis (Newman-Keuls) revealed that phantom strength was significantly reduced ($p < 0.05$) and incubation time significantly greater ($p < 0.05$) for pattern b than for patterns a and c. These results, (shown in figure 5) along with those from experiment 1, provide strong evidence that phantom visibility is attenuated when figure-ground

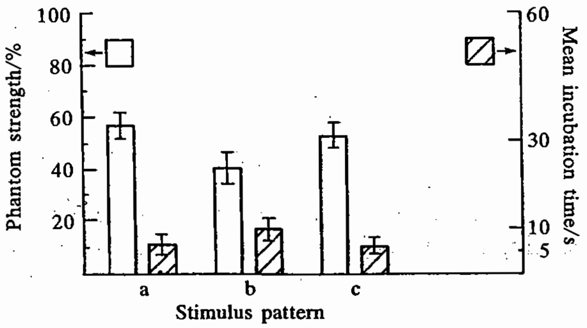

Figure 5. Phantom strength and incubation times for the three patterns of experiment 2. Pattern b was significantly different from the rest.

and depth relations specify the phantom-inducing regions as ground in the overall organisation of a pattern.

4 General discussion

The experiments reported here show that phantom visibility is affected by the overall organization of the figure–ground and depth relations within a phantom-producing pattern. There were no differences in phantom strength or incubation time for figure–ground neutral patterns and patterns where the inducing regions were specified as figure in the global organization. However, phantom strength was reduced and incubation time increased for patterns with interposition cues designating the phantom-inducing regions as ground in their overall organization. Something specific to this latter pattern type made a phantom interpretation less likely and/or more difficult. We suggest that it is the conflicting figure–ground and depth information about the inducing regions in these patterns. As mentioned above, while phantoms phenomenally appear as figure regions, recent evidence also indicates that phantoms are represented as figure regions (Brown 1985; Brown and Weisstein 1988a). The patterns specifying the inducing regions as ground create a conflict with the typical representation of phantoms as figure.

The differences in phantom strength across patterns may be related to what Koffka (1935) called the "degree of figuredness" of a region. "How much the fact that a figure is ground for another figure affects the degree of its figuredness we cannot tell. Possibly no such effect exists; possibly, and I should say probably, such an effect will sometime be proved and measured". If we except that phantoms are figure when perceived, then phantom strength might be considered as a measure of the degree of figuredness of the phantom-inducing parts of our patterns (ie their ability to suggest/indicate phantom figures). Phantom visibility was only attenuated for patterns where the gray inducing-parts of the pattern were unambiguously designated as ground relative to another figure (the white parts). Thus, the figuredness of the inducing parts of these patterns was less, as indicated by a decrease in phantom strength.

It is important to remember that phantoms were reported with all of our patterns, thus reducing any likelihood that the differences in phantom visibility across patterns were due to low-level sensory factors. For example, the local brightness relationship along the border between the occluder and the phantom-inducing regions was equally ambiguous (in fact identical) for all patterns, which should have led to equal phantom visibility (Brown 1985; Brown and Weisstein 1985; Maguire and Blattberg 1986). Similarly, there should have been an equal tendency to group the inducing regions together, because in each pattern the inducing regions moved together at the same speed in the same direction (common fate) and were aligned above and below the stationary occluder (good continuity). The influence of these factors might be explained by interactions between local contour-processing mechanisms and cooperative long-range contour-processing mechanisms operating on the low-level sensory information of the image (Grossberg and Mingolla 1985; Grossberg 1987). Information from local processing would segregate the image into light/dark and moving/nonmoving regions. This information would be used by long-range cooperative processes, sensitive to the alignment and common motion characteristics of the image, to signal potential groupings of the occluder and inducing regions. While these sensory factors may explain why phantoms were possible with each pattern, and why there was a tendency to group the inducing regions together, they can not account for the differences in phantom visibility we found across patterns because these factors were held constant.

Processes operating on three kinds of information must be involved in the differences in phantom visibility that we found, and in phantom visibility in general. These processes are (i) the specification of edges/boundaries between regions of an image, (ii) the specification of occlusion relations and the relations between partially occluded regions and, (iii) the specification of the depth relations between regions involving boundaries and occlusion relations. Obviously these are interrelated and still unresolved issues common to any investigation into the segregation of regions (real or illusory) in space (2-D or 3-D). A review of theories addressing these issues is not the purpose here. However, two recent approaches appear closely related to our results and are discussed next.

First, consider the effects of the perceived figure–ground and depth relations on phantom visibility from a depth-based edge-classification viewpoint (Nakayama et al 1989; Shimojo et al 1989). When one object occludes another, a contour is produced on the retina at the edge where they overlap in depth. It has been proposed that such contours are classified as intrinsic to the occluding object and extrinsic to the occluded object based on relative depth information alone (binocular and/or monocular). An intrinsic contour is part of the bounding contour of an occluding object, contributing to its shape identification and recognition, while an extrinsic contour is an extraneous edge with no inherent relation to an object's shape or recognition (Nakayama et al 1989; Shimojo et al 1989). This hypothesis is consistent with the observation that the contour separating figure and ground 'belongs to' the figure, with the ground continuing behind the closer figure region (Rubin 1921). The figure–ground reversible nature of phantoms and the influences of perceived depth on their visibility suggests that the edge-classification hypothesis would be particularly relevant to the perception of phantoms.

Discussing the perception of phantoms in terms of the edge-classification hypothesis, however, requires two modifications to the hypothesis. First, edge classifications must be able to occur where no edges are physically present. For example, when the occluder is perceived in front, its upper and lower edges would be intrinsic to it while being extrinsic to the interrupted inducing pattern. However, where these edges are modally perceived to interrupt the phantom-inducing parts of the pattern, their perception and classification involves extrapolating across physically uniform parts of the image. When phantoms are visible these previously modally completed portions of the occluder are now perceived as extending amodally behind the completed phantom figures. Therefore, these illusory edges alternate between being classified as intrinsic to the occluder when phantoms are not visible, and being neither extrinsic nor intrinsic according to the edge-classification hypothesis when phantoms appear. Similarly, the illusory edges demarcating the boundary between the phantom and nonphantom parts of the occluder would be classified as intrinsic to the phantom figures and extrinsic to the interrupted occluder. The results reported here suggest a second modification to the edge-classification hypothesis. Edge classifications in one part of an image should be able to affect, and/or be affected by, edge classifications occurring in other parts of the image. The decreased phantom strength and increased incubation time for patterns with interposition cues designating the gray phantom-inducing regions as ground support this modification. Within these inducing patterns, the edges between the white and gray regions would have been classified as intrinsic to the occluding white regions and extrinsic to the occluded gray regions. This may have interfered with the classification of the illusory edge between the occluder and the phantom-inducing regions discussed above. Normally the amount of depth information available for classifying the edges in an image would be redundant, considering static and kinematic monocular and binocular depth cues. It is important therefore, to consider those situations where the depth information is ambiguous.

A second approach to image segmentation, closely related to our phantom results and concerned with ambiguous depth situations in general, is the hypothesis that the same unit-formation process mediates the perception of partially occluded objects as unified objects and the perception of illusory figures (Kellman and Shipley 1987; Kellman and Shipley 1991; Shipley and Kellman 1990). This theory is especially concerned with the formation of object boundaries across uniform regions of an image and the specification of relations between spatially separated (ie partially occluded) regions. Whether a region is seen as modally or amodally complete is not determined by the processes forming the units that are perceptually completed, but by the specification of the relative depth of the units based on the available depth information in the image (Kellman and Shipley 1991). When the depth information is unambiguous, (eg in our normally depth-information-rich environment) the relative depth specification of regions may precede and determine the classification of boundaries between regions (Kellman and Shipley 1991), a view consistent with the edge-classification hypothesis. However, unit formation may precede depth placement when there is inadequate or ambiguous depth information (Kellman and Shipley 1991). Spontaneously splitting figures (SSFs) are an example of this differentiation between unit-formation and depth-specification processes (Kellman and Shipley 1991). Consider the vertical gray inducing-strip on the right in figure 2 in isolation with the horizontal gray occluder by covering the rest of the figure with your finger. This is a simplified example of a SSF. Despite the uniformity of the gray (textured) regions, they are probably often seen as two units (a vertical and a horizontal region). At first the vertical region may be seen as modally complete, overlapping the horizontal region that amodally completes beneath it. After prolonged inspection, however, this depth relation reverses and may continue to alternate. This indicates that unit formation occurs separately, with depth placement determining what is perceived to complete modally and amodally (Kellman and Shipley 1990). In terms of the discontinuity theory, our results suggest that in order for the gray inducing-regions to modally complete as phantom figures the relative depth placement of all gray regions has to be determined. Resolution of the ambiguous depth relation between the gray inducing-regions and the occluder in pattern c in figure 1 and pattern b in figure 4 was probably hindered by the conflicting depth information indicating the inducing regions to be ground behind the white regions, while the white regions were simultaneously being signalled as ground behind the gray occluder. Thinking about phantom perception in terms of the discontinuity hypothesis and using phantom displays to explore the hypothesis may contribute to a better understanding of both.

Our automatic and immediate experience of the figure–ground and depth relations in the environment contributes to the difficulty in attempting to understand the processes underlying these abilities. One fruitful approach has been to explore the relationship between figure–ground and depth perception and the spatial and temporal frequency response of the visual system (Wong and Weisstein 1982, 1983, 1984, 1985, 1987; Klymenko and Weisstein 1986, 1989a, 1989b; Brown and Weisstein 1988b; Klymenko et al 1989). Another approach is to use visual phantoms as a tool for exploring the processes underlying figure–ground and depth perception (Brown 1985; Brown and Weisstein 1985). Relationships between spatial and temporal aspects of a phantom stimulus and phantom visibility (ie the perception of illusory figures) can be studied by restricting the information available. For example, any edge classifications or three-dimensional figure–ground interpretations made in our study had to be based exclusively on monocular depth information because of our two-dimensional stimuli and monocular viewing conditions. Global, organizational effects on phantom visibility can also be studied by keeping the local, sensory aspects of the phantom-inducing stimuli constant as was done in our experiments. Our results then, are another example of global aspects of a stimulus affecting the processing of local information (Weisstein and Harris 1974; Baron 1981; Biederman 1981; Wong and Weisstein 1982). Insights gained from future phantom studies may provide a window into the processes involved in figure-ground and depth perception under normal circumstances.

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