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CHAPTER 13

The visual phantom illusion: a perceptual product of surface completion depending on brightness and contrast

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Abstract: The visual phantom illusion was first discovered by Rosenbach in 1902 and named 'moving phantoms' by Tynan and Sekuler in 1975 because of its strong dependence on motion. It was later revealed that phantoms can be generated by flickering the grating (flickering phantoms) or by low-luminance stationary gratings under dark adaptation (stationary phantoms). Although phantoms are much more visible at scotopic or mesopic adaptation levels (scotopic phantoms) than at photopic levels, we proposed a new phantom illusion which is fully visible in photopic vision (photopic phantoms). In 2001, we revealed that the visual phantom illusion is a higher-order perceptual construct or a Gestalt, which depends on the mechanism of perceptual transparency. Perceptual transparency is known as a perceptual product based upon brightness and contrast. We furthermore manifested the shared mechanisms between visual phantoms and neon color spreading or between visual phantoms and the Petter effect. In our recent study, the visual phantom illusion can also be seen with a stimulus of contrast-modulated gratings. We assume that this effect also depends on perceptual transparency induced by contrast modulation. Moreover, we found that the Craik–O'Brien–Cornsweet effect and other brightness illusions can generate the visual phantom illusion. In any case, we explain the visual phantom illusion in terms of surface completion, which is given by perceptual transparency.

Keywords: visual phantoms; perceptual transparency; surface completion; illusion; neon color spreading; grating induction

What is the visual phantom illusion?

The visual phantom illusion refers to the completion phenomenon in which something like mist appears to lie over a physically homogenous surface (Tynan and Sekuler, 1975). Specifically, when part of a sinusoidally modulated luminance grating is transversely occluded by another surface, the two separate gratings appear to be continual *in front of* the occluder (Weisstein et al., 1982; Brown and Weisstein, 1988, 1991). If the luminance of the occluder is the same as the darkest one of the grating, the darker parts of the gratings appear to be continual (dark phantoms: Fig. 1a), while if the luminance of the occluder is the same as the brightest one of the grating, the brighter parts of the gratings appear to be continual (Sakurai and Gyoba, 1985) (light phantoms: Fig. 1b).

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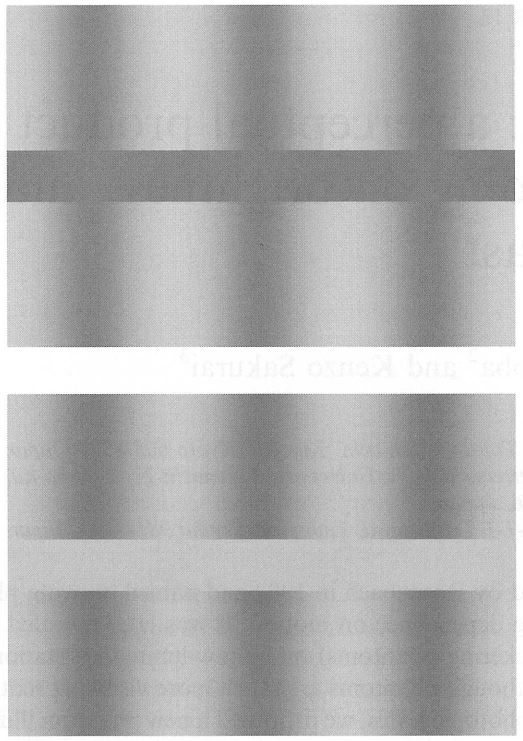
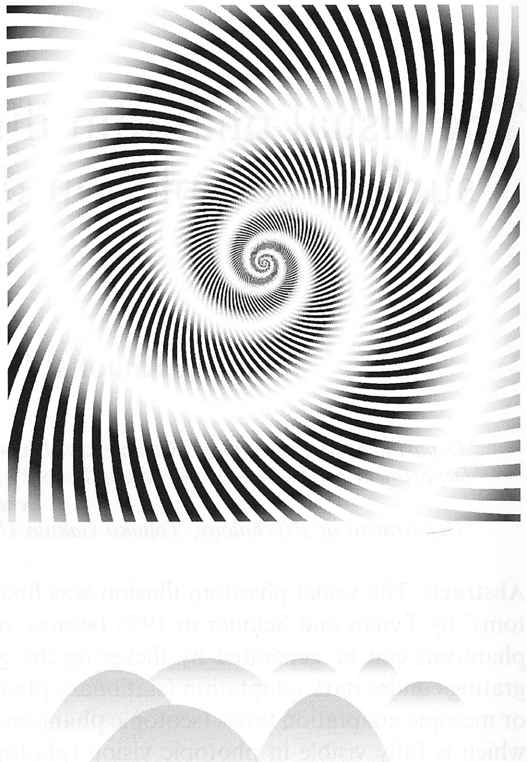


(a)

(b)

Fig. 1. Visual phantoms, which appear to be continual in front of the physically homogeneous occluder. (a) The dark parts of the upper grating appear to be continual with those of the lower grating in front of the occluder, when the occluder is dark. We hereafter call them 'dark phantoms'. (b) The light parts of the upper grating appear to be continual with those of the lower grating in front of the occluder, when the occluder is bright. We hereafter call them 'light phantoms'. Note that the inducing gratings are identical while only the occluder luminance is different between the two images.



(a)

(b)

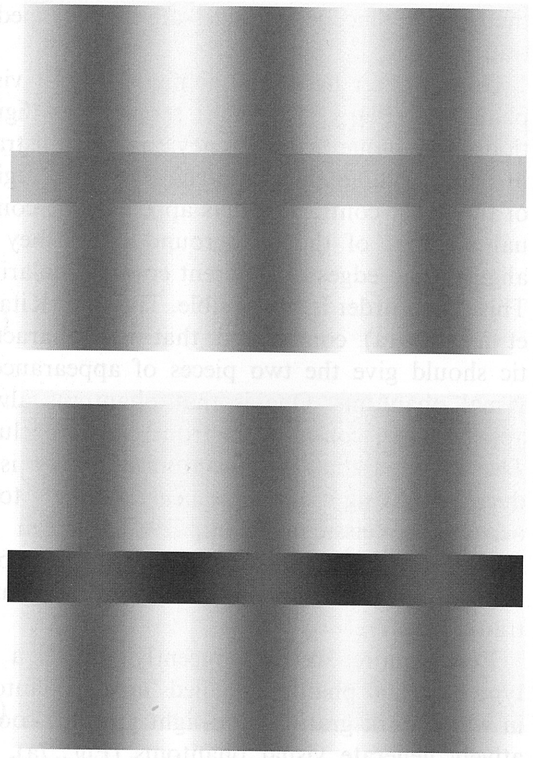
Fig. 2. Misty appearance of visual phantoms. (a) It appears as if there were two spirals of white mist floating in front of a black-and-white spiral stripes, though the white stripes are physically homogenous. (b) There appears a sea of clouds with tops of mountains protruding. This 'sea' is visual phantoms.

This illusion was first discovered by Rosenbach (1902) and developed by Tynan and Sekuler (1975) as 'moving phantoms' because of its strong dependence on motion. It was later revealed that phantoms can be generated by flickering the grating (flickering phantoms) (Genter and Weisstein, 1981) as well as by low-luminance stationary gratings under dark adaptation (stationary phantoms) (Gyoba, 1983). Moreover, we found that dark adaptation is not necessary for stationary phantoms, because many people see stationary phantoms in photopic vision when inducing gratings are of low spatial frequency and of low contrast (Fig. 1). Actually, stationary phantoms are ubiquitous, e.g. the perception of mist (Fig. 2).

The visual phantom illusion is a phenomenon of brightness induction

It had been believed that the brightness induction in visual phantoms is *in phase* with the inducing grating (Mulvanny et al., 1982; Weisstein et al., 1982), as exaggerated in Fig. 3a, because the induced phantom grating appears to be continual with the inducing grating. This belief was questioned by McCourt (1994) who pointed out that the induced brightness in the occluder is *counterphase* with the inducing grating, as exaggerated in Fig. 3b. This finding was confirmed in subsequent research (May et al., 1999).

According to McCourt (1994), this counterphase induction is a kind of grating induction



(a)

(b)

Fig. 3. (a) Exaggeration of 'in-phase' visual phantoms. In this figure, luminance modulation is given to the occluder in phase with the flanking gratings. (b) Exaggeration of 'counterphase' visual phantoms. In this figure, luminance modulation is given to the occluder out of phase with the flanking gratings. In both cases, three dark columns appear to be continual in front of the occluder.

(McCourt, 1982), which is one of the strongest brightness illusions (Fig. 4). He proposed an explanation of dark phantoms in which the dark phase of the inducing grating is combined with the light phase of induced brightness on the black occluder because of brightness similarity between them. Then, he thought that counterphase brightness induction sponsors this perceptual continuation.[1]

[1]We have recently found that in brief presentation (e.g. 50 ms) visual phantoms are in phase with the inducing gratings. This leaves the possibility that moving or flickering phantoms are in-phase brightness induction (Mulvanny et al., 1982); this point has not been argued by McCourt (1994).

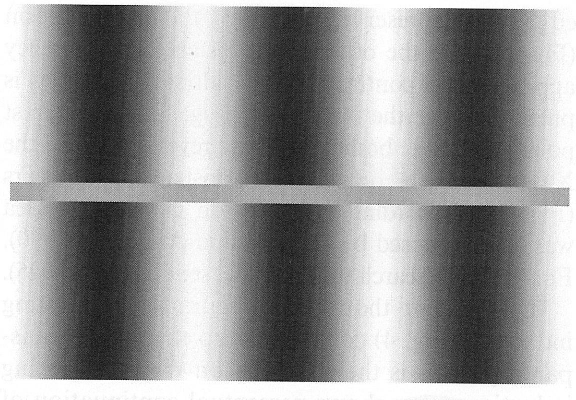


Fig. 4. Grating induction. The homogenously gray occluder appears to be modulated in brightness, counterphase with the inducing gratings. In grating induction, inducing gratings do not appear to be continual in front of the occluder.

The visual phantom illusion is a phenomenon of perceptual transparency

Grating induction, however, is quite different from visual phantoms in its appearance since the standard grating induction pattern never gives perceptual continuation of the gratings in front of the occluder. What is responsible for this difference?

We directed our attention to a phenomenon in perceptual transparency (Kitaoka et al., 2001a), in which adjacent areas that are similar in luminance tend to appear in front (Fuchs, 1923; Oyama and Nakahara, 1960; Metelli, 1974). We considered the mechanism of perceptual continuation of visual phantoms in terms of different types of transparency classified by Anderson (1997). Our idea is that visual phantoms reflect 'unique' transparency whereas McCourt's grating induction is characterized by 'no' transparency.

Anderson (1997) phenomenologically classified perceptual transparency into two types: unique and bistable transparency. In the former, a transparent surface is always perceived in front of the other surface, while in the latter, the perceived depth of two surfaces alternates and the surface in front appears to be transparent. These two types of perceptual transparency depend on the type of X-junctions. Unique transparency appears when contrast polarity along one edge is reversed over the X-junction, while contrast polarity along the other edge is preserved over the X-junction (Fig. 5a). On the other hand, bistable transparency appears when contrast polarity along both edges is preserved over the X-junction (Fig. 5b). If contrast polarity along both edges is reversed over the X-junction, no or invalid transparency appears (Fig. 5c). According to Anderson (1997), this idea was first proposed by Adelson and Anandan (1990). For further research on this issue, see Kitaoka (2005).

It is evident that the configuration of grating induction (Fig. 4) corresponds to that of no transparency. This is the main reason why the grating induction never shows perceptual continuation of

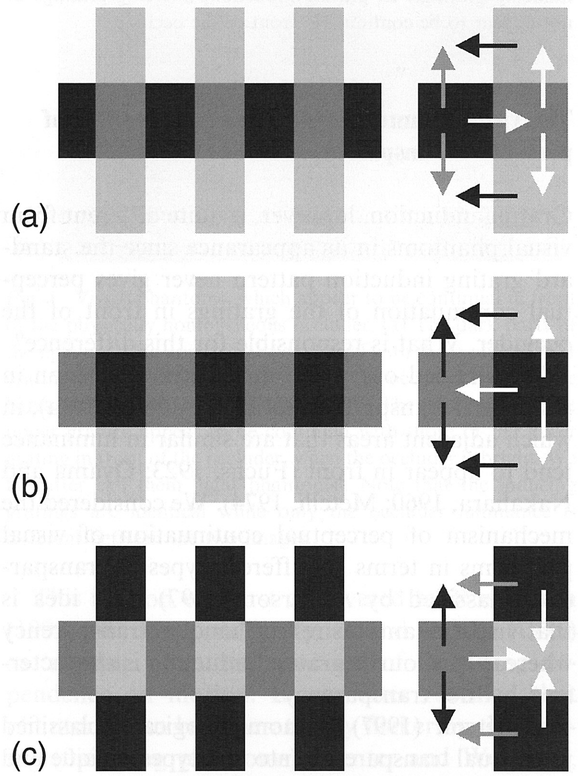


Fig. 5. The phenomenological classification of perceptual transparency depending on contrast polarity along edges over X-junctions. (a) Unique transparency, in which vertical gray rectangles appear to be transparent or translucent in front of the horizontal black rectangle. (b) Bistable transparency, in which vertical gray rectangles appear to be transparent in front of the horizontal gray rectangle, or the latter appears to be transparent in front of the former. (c) No transparency, in which transparency is not perceived. Arrows indicate which region is brighter between two adjacent regions.

the grating, since those edges are not grouped by transparency.

On the other hand, the configuration of visual phantoms (Fig. 1) renders a series of configurations of unique transparency, as demonstrated in Fig. 6. In unique transparency, adjacent regions of the lower contrast always appear to be continual in front of the background when they are aligned with edges of different contrast polarities. This depth order is irreversible. Thus we (Kitaoka et al., 2001a) conjectured that this characteris tic should give the two pieces of appearance of visual phantoms. One is that phantoms always appear to be continual in front of the occluder. The other is that the phantom visibility is reduced by giving crossed (= near) disparity to the occluder (Weisstein et al., 1982; Brown and Weisstein, 1991) because this binocular cue comes into conflict with the monocular cue (= unique transparency).

Furthermore, we have recently devised a new type of visual phantoms called 'mixed phantoms' in which dark gratings and light gratings cooperatively generate visual phantoms (Fig. 7a). The phases of these inducing gratings are opposite.

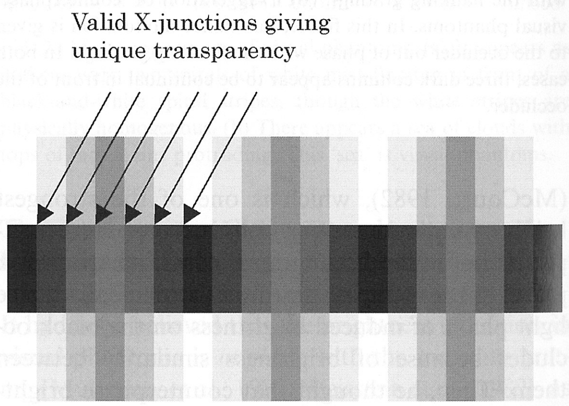


Fig. 6. A schematic explanation (Kitaoka et al., 2001a) of perceptual continuation of visual phantoms in terms of unique transparency. In this figure, every series of vertical edges changes contrast polarity when crossing horizontal edges while every series of the horizontal edges keeps contrast polarity. Thus the appearance is stratiform, i.e. the dark-gray, narrowest rectangle is in front of the middle-gray, middle-size rectangle, which in turn is in front of the light-gray, widest rectangle. These layers appear to be transparent and the order in apparent depth is fixed. This figure corresponds to Fig. 3b.

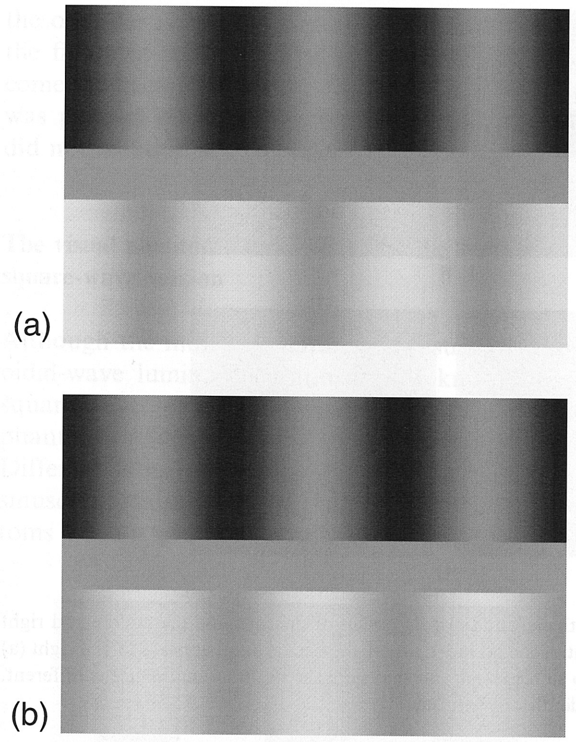


Fig. 7. 'Mixed' phantoms. The upper half gives the visual phantoms with the 'bright' occluder, i.e. light phantoms (Fig. 1b), while the lower half renders those with 'dark' occluder, i.e. dark phantoms (Fig. 1a). In this image, light phantoms and dark ones share the same gray occluder. (a) Three gray vertical columns or phantoms appear to be continual in front of the occluder when the luminance phases between the upper and lower gratings are shifted for half a cycle. (b) Phantoms disappear or bridge obliquely when the luminance phases are aligned.

This variant cannot be explained simply with brightness illusion but is quite consistent with the idea that the visual phantom illusion is characterized by perceptual transparency. If the phases of the inducers are aligned, grating induction becomes obvious but phantoms disappear or bridge obliquely (Fig. 7b).

Finally, we have recently devised an image that simultaneously shows visual phantoms and grating induction, as shown in Fig. 8. These findings, combined, indicate that the visual phantom illusion is different from grating induction though they share the same characteristics in brightness induction in the early stage.

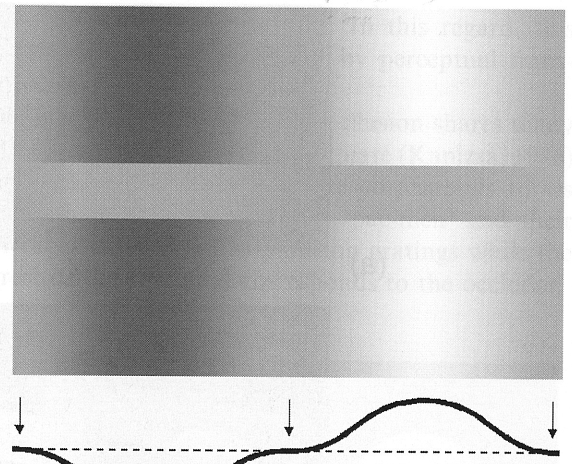


Fig. 8. An image where visual phantoms and grating induction are simultaneously observed. The luminance modulation of the inducing gratings is 'double-sinusoidal' as shown in the lower, where the broken line shows the luminance of the occluder. Visual phantoms are seen around the intersection between the luminance of the inducing gratings and that of the occluder, as pointed by arrows. For grating induction, the left half of the occluder appears to be brighter than the right half.

The visual phantom illusion is a phenomenon of figure–ground segregation

When the luminance of the occluder is low, the dark gratings appear to form phantoms or the *figure* (dark phantoms: Fig. 1a). This indicates that the lighter parts of the gratings become the *ground*. Inversely, when the luminance of the occluder is high, the light gratings appear to be phantoms or the figure (light phantoms: Fig. 1b) and the darker parts of the gratings become the ground. This appearance is enhanced by adding binocular disparity between the inducing gratings and the occluder (Brown and Weisstein, 1991) (Fig. 9).

Although visual phantoms are characterized by visual interpolation between two gratings, visual extrapolation from one grating shares the properties with visual phantoms (Gyoba, 1996). Figure 10 shows this stereogram. When the occluder or the surround is dark, dark gratings appear to be the figure in front while the rest bright parts become the background (Fig. 10a). Inversely, when

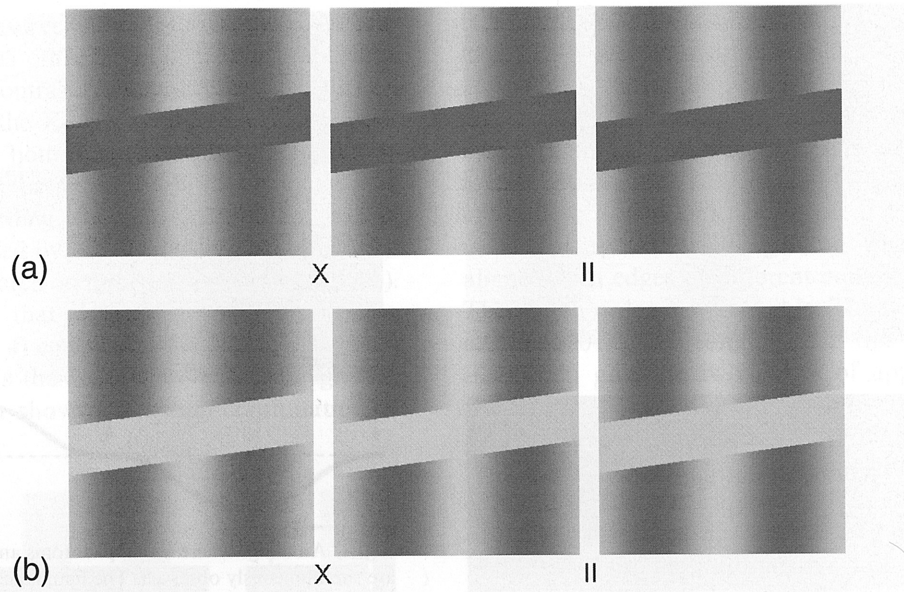


Fig. 9. A stereogram of visual phantoms. When observers cross-fuse the left and middle panels or uncross-fuse the middle and right panels, dark phantoms (a) or light phantoms (b) appear to float in front of the occluder, where the background appears to be bright (a) or dark (b). Note that inducing gratings are identical between the two stereograms and that only the occluder luminance is different. Oblique occluders are depicted to avoid their 'stereo capture' to the depth of phantoms.

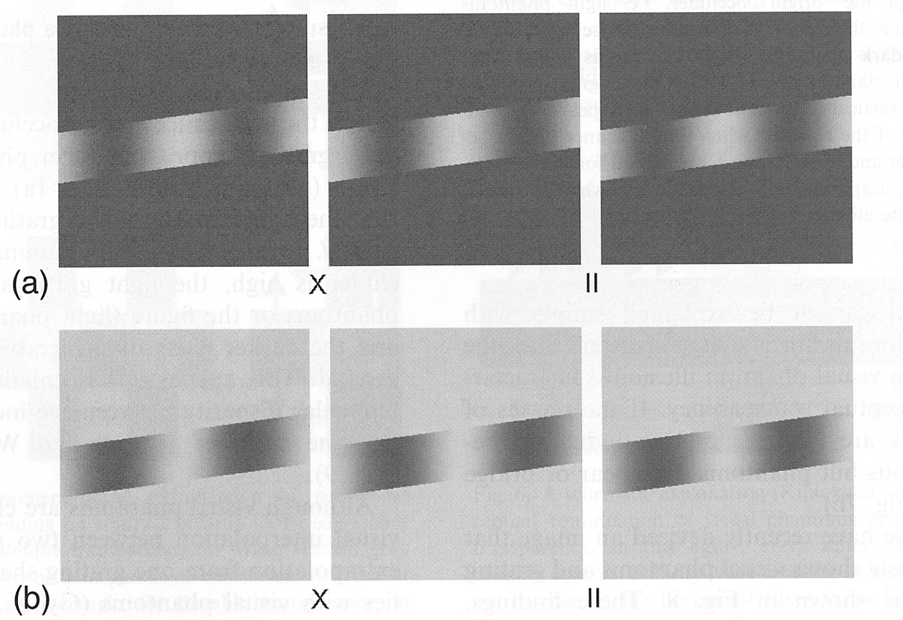


Fig. 10. A stereogram of visual extrapolation. When observers cross-fuse the left and middle panels or uncross-fuse the middle and right panels, (a) dark columns appear to float in front of the bright background or (b) light columns appear to float in front of the dark background. Note that inducing gratings are identical between the two stereograms and that only the occluder (= surround) luminance is different.

the occluder is bright, light gratings appear to be the figure in front, while the rest dark parts become the background (Fig. 10b). This reversibility was pointed out by Anderson (1999, 2003), who did not mention visual phantoms, however.

The visual phantom illusion includes the square-wave version

Although the inducing gratings are usually sinusoidal-wave luminance gratings, it is known that square-wave luminance gratings also give visual phantoms (Gyoba, 1983), as shown in Fig. 11. Different from the visual phantoms induced by sinusoidal-wave gratings, the square-wave phantoms do not give misty or hazy appearance but look like 'opaque' columns. In this regard, this version is not characterized by perceptual transparency.

The square-wave phantom illusion shares many properties with the Kanizsa square (Kanizsa, 1976) (Fig. 12). The illusory square corresponds to visual phantoms, and the four 'pac-men' and their wedges correspond to inducing gratings while the rest or the surround corresponds to the occluder.

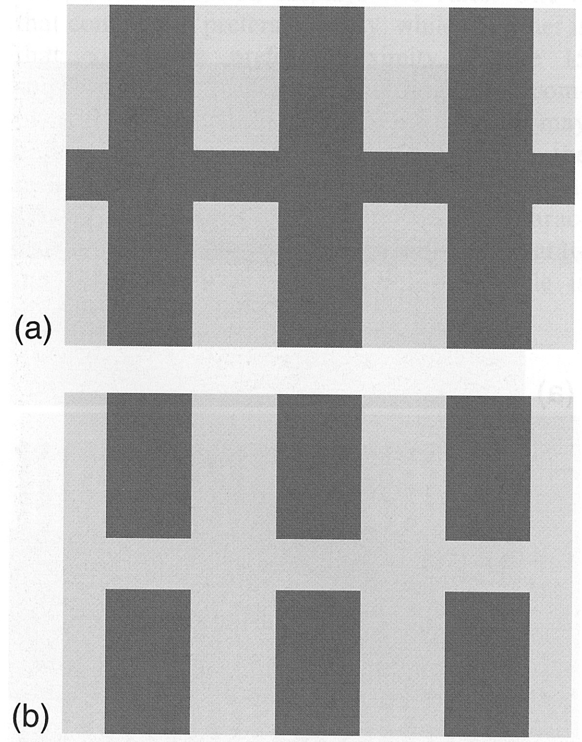


Fig. 11. The square-wave version of visual phantoms. (a) Dark columns appear to be continual in front of the occluder, where the background appears to be bright. (b) Light columns appear to be continual in front of the occluder, where the background appears to be dark. Note that inducing gratings are identical between the two images and that only the occluder luminance is different.

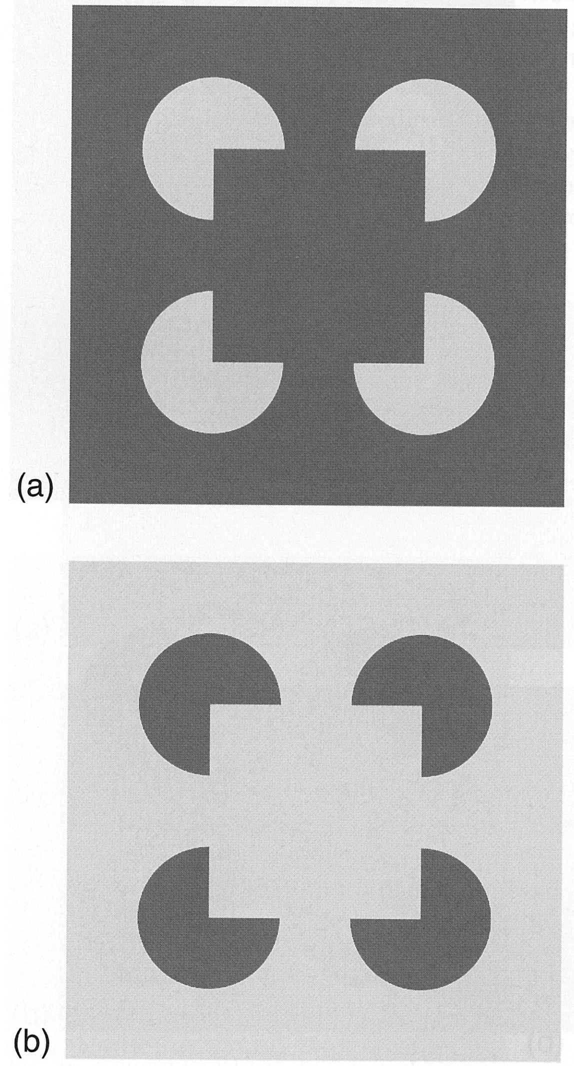
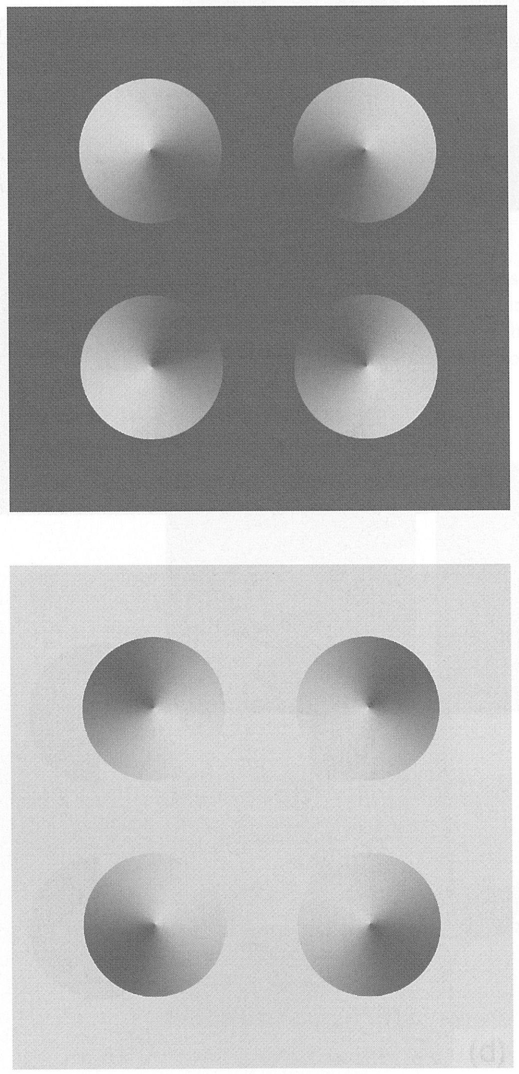


Fig. 12. The Kanizsa square. (a) A dark square appears to be in front of four light circles and the dark background. (b) A light square appears to be in front of four dark circles and the bright background.

Inversely, the Kanizsa square can be changed to the sinusoidal-wave or misty version, as shown in Fig. 13. The inducers are circles with sinusoidally modulated luminance radials. Dark 'mist' appears when the surround (i.e. corresponding to the occluder) is dark whereas light 'mist' appears when the surround is bright. This 'mist' corresponds to visual phantoms.



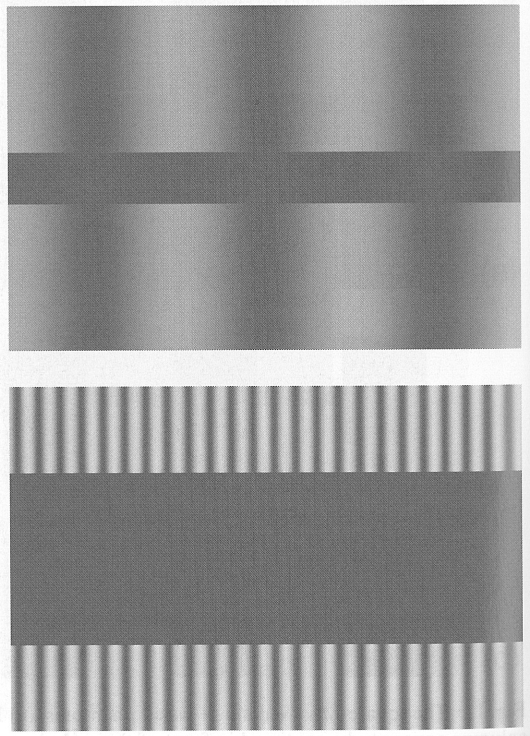
(a) (b)

Fig. 13. The 'sinusoidal-wave' or misty version of the Kanizsa square. (a) Dark mist appears to be in front of four light circles and the dark background. (b) Light mist appears to be in front of four dark circles and the light background.

The visual phantom illusion depends on spatial frequency

Visual phantoms can be seen clearly when the inducing gratings are of low spatial frequency (Tynan and Sekuler, 1975; Genter and Weisstein, 1981; Gyoba, 1983). The higher the spatial frequency, the lower the visibility of phantoms. Moreover, the taller the occluder height, the lower the visibility of phantoms (Fig. 14).

This characteristic quite resembles Petter's effect (Kitaoka et al., 2001c). When two objects of the same brightness and of different sizes overlap, the perceived period of the thicker region that appears in front of the thinner region is longer than that of the thinner region that appears in front of the thicker region (Petter, 1956; Kanizsa, 1979; Shipley and Kellman, 1992; Masin, 1999; Singh



(a) (b)

Fig. 14. Dependence of the visual phantom illusion on spatial frequency. (a) Phantoms are visible when the spatial frequency of the inducing gratings is low or the occluder height is short. (b) Phantoms are invisible when the spatial frequency of the inducing gratings is high or the occluder height is tall.

et al., 1999). The preferred explanation of Petter's effect is that an object completed by a shorter interpolating contour tends to be perceived in front of an object completed by a longer one, since modal completion requires more 'energy' than amodal completion and the larger object in front is usually accompanied by shorter interpolating contours than does the smaller one (Petter, 1956; Tommasi et al., 1995; Takeichi et al., 1995; Forkman and Vallortigara, 1999).

This explanation agrees with the dependence on spatial frequency in visual phantoms.

Aligned phantoms versus misaligned phantoms

As one of visual completion phenomena, the visual phantom illusion displays two rules. One is that completion prefers linearity, while the other is that completion prefers proximity. Figure 15 shows that oblique gratings may be linearly completed (aligned phantoms) while instead they may appear to be connected vertically between the nearest neighbors (misaligned phantoms) (Gyoba, 1994a; Brown et al., 2001). This bistable characteristic of visual phantoms is not observed in grating induction, in which the proximity rule is dominant.

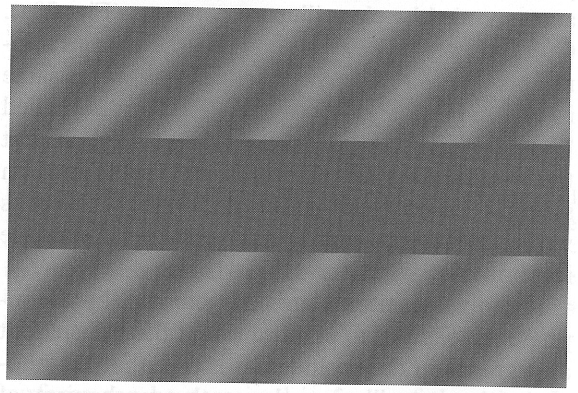


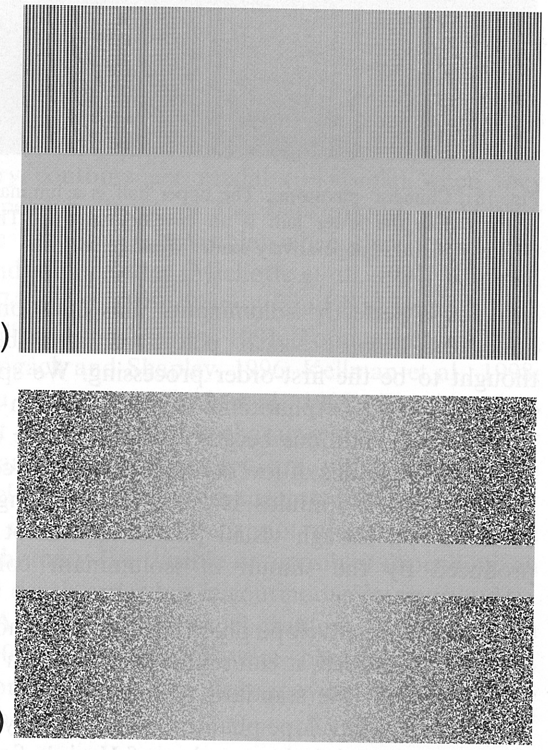
Fig. 15. Two pieces of appearance of visual phantoms. One is that phantoms are obliquely aligned with the inducing gratings (aligned phantoms). The other is that phantoms vertically connect the nearest neighbors of the gratings (misaligned phantoms).

New types of the visual phantom illusion

Envelope phantoms

Regions of low contrast can generate visual phantoms (Sakurai et al., 2000), as shown in Fig. 16. This phenomenon is explained as follows. First, regions of low contrast appear to include transparent layers or surfaces in front of carriers (Langley et al., 1998). Then, the perceived surfaces are completed over the occluder, thus displaying visual phantoms. This appearance is enhanced by adding crossed disparity to the envelope, as shown in Fig. 17.

In psychophysics, contrast modulation is often applied to examine the second-order processing. Here is an open question: Does this envelope phantom illusion disappear when the contrast-modulated



(a) (b)

Fig. 16. Contrast-modulation-dependent phantoms or envelope phantoms. The envelope grating renders the phantom grating. In particular, regions of the lower contrast form phantoms. (a) The carriers are luminance gratings of high spatial frequency. (b) These are random dots.

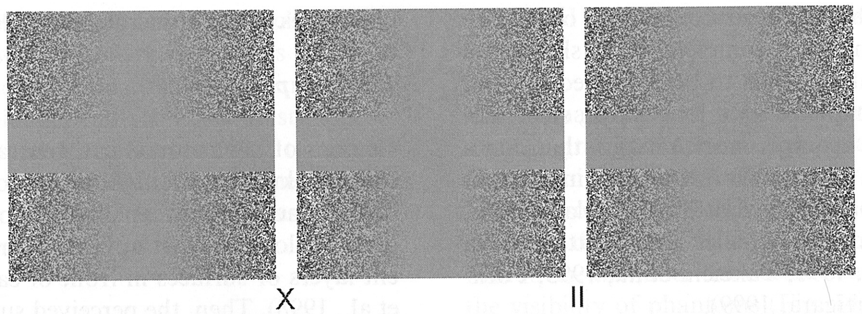


Fig. 17. A stereogram of envelope phantoms. When observers cross-fuse the left and middle panels or uncross-fuse the middle and right panels, regions of the lower contrast appear to be continual in front of the occluder.

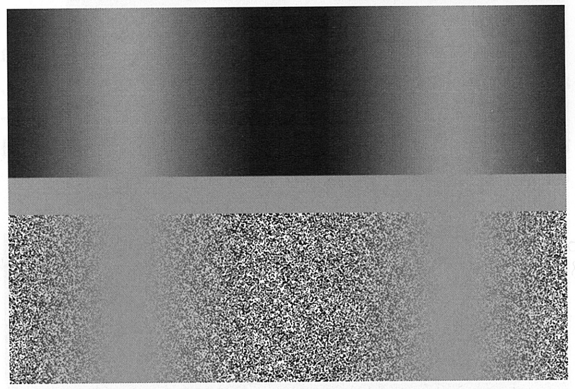


Fig. 18. 'Chimera' phantoms. The upper half is a luminance grating while the lower half is an envelope grating. These different gratings cooperatively render visual phantoms.

stimulus is perfectly isoluminant? This question is important because visual phantoms have been thought to be the first-order processing. We speculate that envelope phantoms would remain in the isoluminant conditions because surface can be obtained from regions of low contrast even if the contrast-modulated stimulus is isoluminant (Langley et al., 1999), though visual phantoms cannot be produced by the stimuli of isoluminant colors (Gyoba, 1994b)[2].

Anyway, the envelope phantom illusion is not a special one. Indeed, it can render phantoms in cooperation with the standard phantoms (Fig. 18). Moreover, the envelope phantom illusion can yield the contrast-modulation version of Varin's figure (Fig. 19). This relationship is parallel to the close relationship between standard phantoms and the Kanizsa Square.

Photopic phantoms

The standard configuration of visual phantoms is that the luminance of the occluder is the same as the darkest or brightest luminance of the inducing gratings (Fig. 1). When the occluder luminance is placed between them, grating induction appears (Fig. 4). What happens if the occluder luminance is higher or lower than the range of the gratings? Then, another type of visual phantoms appears (Kitaoka et al., 1999).

When the grating of high luminance is occluded by a dark occluder, the occluder appears to be transparent through which an illusory grating in phase with the surrounding gratings is observed, accompanied by clear illusory contours (Fig. 20a). On the other hand, when the grating of dark luminance is occluded by a bright occluder, the same illusion occurs (Fig. 20b). These illusions are called 'photopic' phantoms because we had thought that the standard visual phantoms are visible only in scotopic vision (Kitaoka et al., 1999), which was wrong because standard phantoms are fully visible in photopic vision, too (Fig. 1).

Photopic phantoms are characterized by the in-phase appearance in phantoms and the transparent appearance in the occluder. It is true that the photopic phantom illusion shares the mechanism of perceptual transparency with the standard phantom illusion, but it depends on bistable transparency (Anderson, 1997) (Fig. 5b). This type of transparency allows that any of the intersected

[2]According to Brown (2000), isoluminant color can generate visual phantoms in the moving condition.

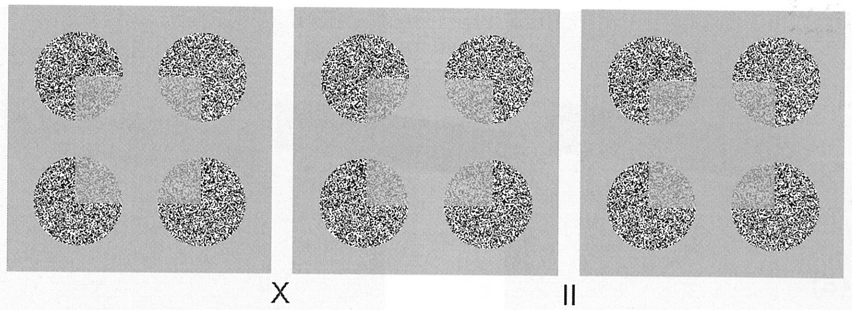


Fig. 19. A stereogram of the contrast-modulation version of Varin's figure. When observers cross-fuse the left and middle panels or uncross-fuse the middle and right panels, they can see a translucent square in front of the background. For Varin's figure, see Fig. 22.

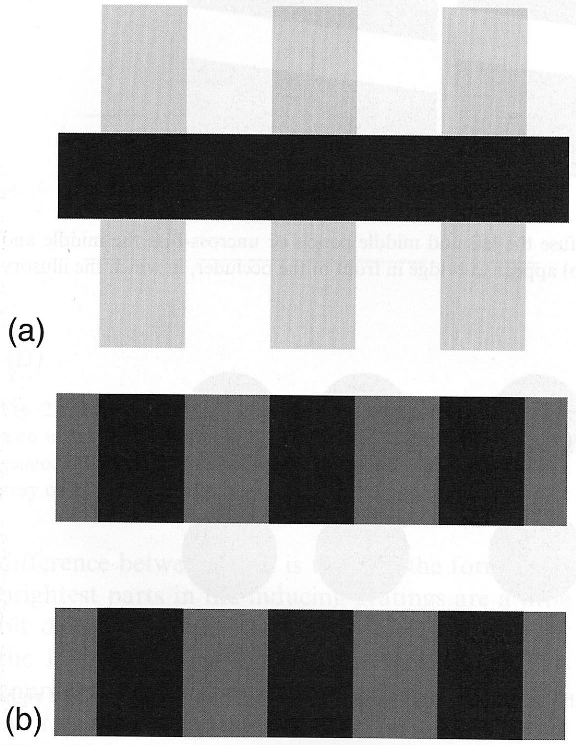


Fig. 20. Photopic phantoms. In-phase phantoms accompanied by clear illusory contours are observed behind the occluder. The occluder thus appears to be transparent. (a) The inducing gratings are of high luminances while the occluder is dark. (b) The inducing gratings are of low luminances while the occluder is bright. Some observers have difficulty seeing photopic phantoms.

surfaces can be perceived in front of the other. In the monocular condition, phantoms are faintly seen behind the occluder that appears to be transparent. However, phantoms appear to be much more vivid when crossed disparity is added to the inducing gratings and phantoms are perceived in front of the occluder (Kitaoka et al., 1999) (Fig. 21).

This enhancement is called 'stereoscopic enhancement' (Harris and Gregory, 1973; Gregory and Harris, 1974; Lawson et al., 1974; Whitmore et al., 1976; Fujita, 1993). Stereoscopic enhancement is much more frequently mentioned in Varin's figure (Varin, 1971; Nakayama et al., 1990) (Fig. 22), which we think can be a variant of the photopic phantom illusion.

In relation to stereoscopic enhancement, there is an accepted idea on contour completion that illusory contours are modal (= visible) when they appear in front of the background while they are amodal (= invisible) when they appear behind the occluder (Michotte et al., 1991; Kanizsa, 1974, 1976, 1979; Shimojo and Nakayama, 1990; Kellman and Shipley, 1991; Tommasi et al., 1995; Ringach and Shapley, 1996; Kellman et al., 1998; Liu et al., 1999; Singh et al., 1999). This idea does not agree with the characteristics of photopic phantoms because they are visible behind the occluder. It is therefore suggested that the visibility of illusory contours is not characterized by a dichotomy (i.e. visible or invisible) depending on the depth order but is continuous in magnitude.

Actually, the first visual phantoms that Rosenbach (1902) demonstrated were photopic phantoms. More precisely, they were moving photopic phantoms.

Neon phantoms

Neon color spreading is a striking visual illusion which produces apparent completion of color or

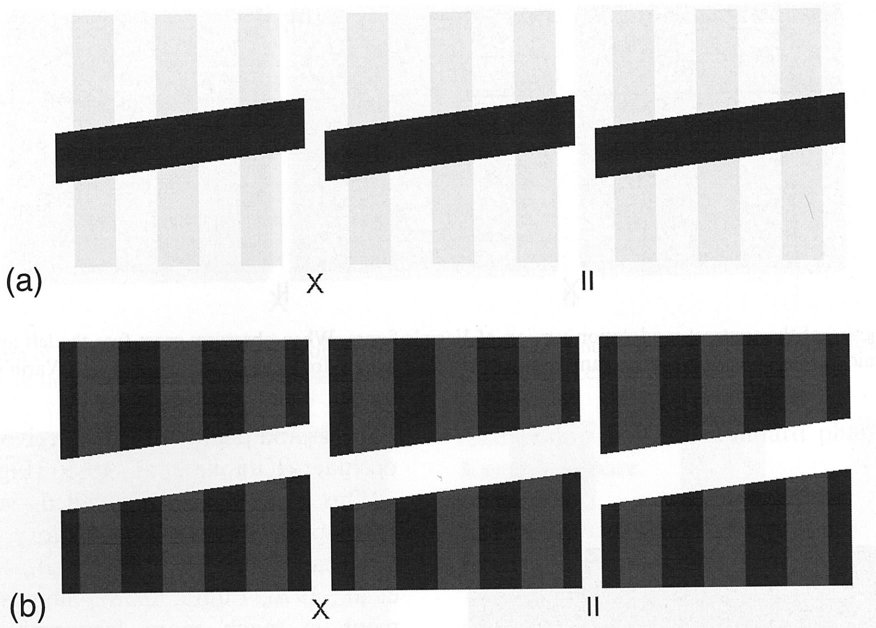


Fig. 21. A stereogram of photopic phantoms. When observers cross-fuse the left and middle panels or uncross-fuse the middle and right panels, three light-gray columns (a) or three dark-gray columns (b) appear to bridge in front of the occluder, in which the illusory contours appear to be clearer than observed monocularly.

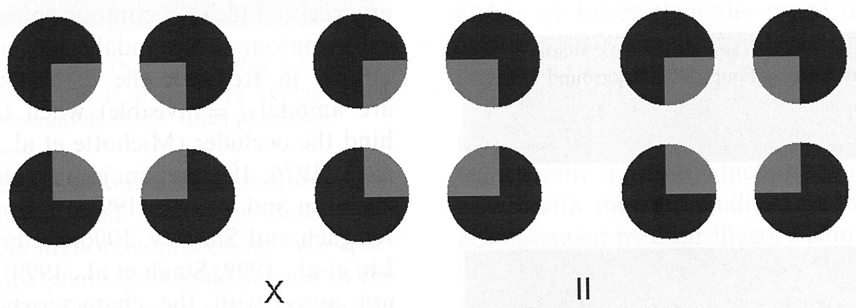


Fig. 22. A stereogram of Varin's figure. When observers cross-fuse the left and middle panels or uncross-fuse the middle and right panels, they can see a translucent square in front of the background.

lightness (Varin, 1971; Van Tuijl, 1975; Van Tuijl and de Weert, 1979; Redies and Spillmann, 1981; Redies et al., 1984; Bressan et al., 1997) (Fig. 23). The brightness induction is in phase with the inducer. This character is the same as that of photopic phantoms. The only difference in stimulus configurations is the difference in the height of the inducing grating. That is short in neon color spreading while that is tall in photopic phantoms. What happens if the latter is shortened? A new in-phase phantom illusion appears (Fig. 24). This new type or the neon phantom illusion shares the same characteristic in spatial frequency as those of the other phantoms (Kitaoka et al., 2001b).

Counterphase photopic phantoms

Photopic and neon phantoms are characterized by in-phase brightness induction, but there is a counterphase version, as shown in Fig. 25a. This version looks like standard stationary phantom illusion, giving a misty appearance (Fig. 1b). The

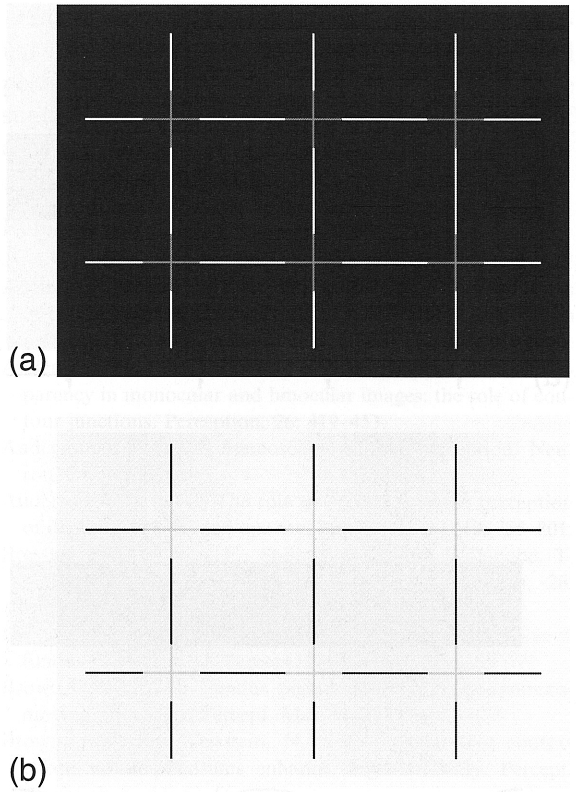


Fig. 23. Neon color spreading. (a) Illusory, dark 'diamonds' are seen in front of gray crosses though the background is homogeneously dark. (b) Illusory, light 'diamonds' are seen in front of gray crosses though the background is homogeneously bright.

difference between them is that for the former the brightest parts in the inducing gratings are a little bit darker than the bright occluder, whereas for the latter they are the same in luminance. This counterphase photopic phantom illusion is different from the 'in-phase' photopic phantom illusion (Fig. 20) at the point that counterphase phantoms are always seen in front of the occluder, which is based upon unique transparency (Figs. 5b and 6) like the standard stationary phantoms.

This counterphase photopic phantom illusion is closely related to the glare effect as proposed by Zavagno (1999) or Zavagno and Caputo (2001). When the gratings are separated at the brightest parts, the glare effect is manifest (Fig. 25b). It should be noted that the glare is brighter at a glance than the nonglare white parts, but the glare actually appears to be darker when analytically

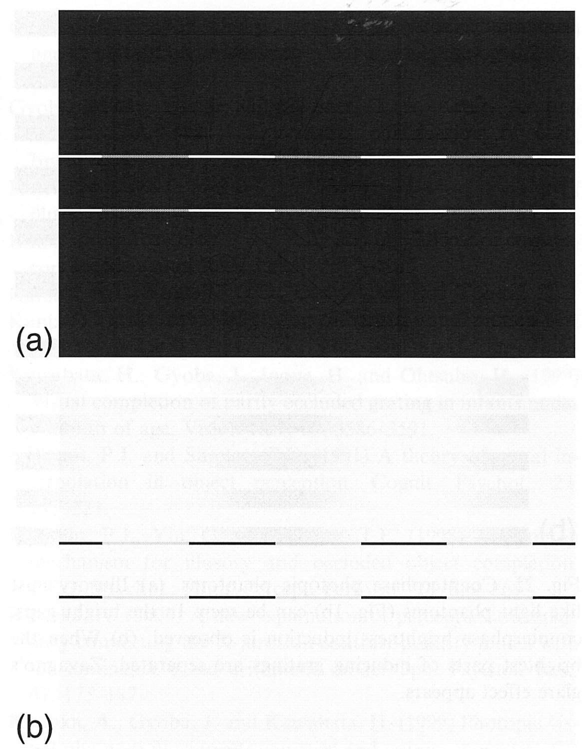


Fig. 24. Neon phantoms. In-phase phantoms accompanied by clear illusory contours are observed in front of, behind, or flush with the gap. (a) The inducing gratings are of high luminances while the gap or background is dark. (b) The inducing gratings are of low luminances while the gap or background is bright.

observed. This inconsistency reminds us of the interaction between high-order mechanisms and low-order ones in brightness perception and might bring some fruitful hints to its study in the future.

Craik– O'Brien– Cornsweet phantoms

Our latest finding is that the stimulus of the Craik–O'Brien–Cornsweet effect (O'Brien, 1958; Craik, 1966; Cornsweet, 1970) can yield in-phase phantoms like photopic phantoms or neon phantoms, where apparent lightness gratings induce phantoms (Fig. 26a). In the Craik–O'Brien–Cornsweet image, there are no luminance gratings physically. This means that the Craik–O'Brien–Cornsweet phantoms do not depend on luminance but *lightness*. Figure 26b shows a variant, in which the apparent lightness induces in-phase phantoms in the occluder though the whole luminance profiles are

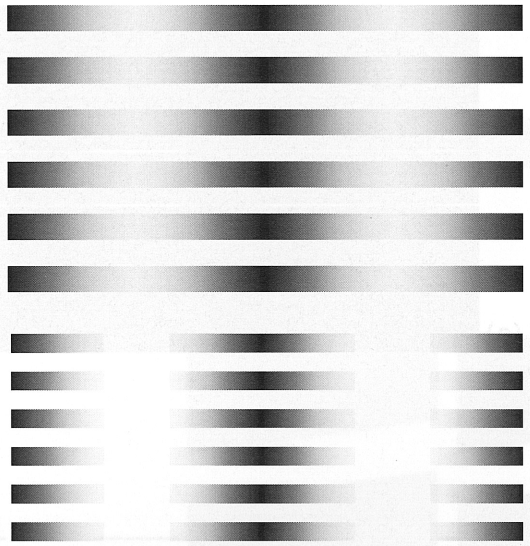


Fig. 25. Counterphase photopic phantoms. (a) Illusory mist like light phantoms (Fig. 1b) can be seen. In the bright gaps, counterphase brightness induction is observed. (b) When the brightest parts of inducing gratings are separated, Zavagno's glare effect appears.

counterphase sinusoidal waves. These new types also support our idea that the visual phantom illusion is based upon some high-order visual processing.

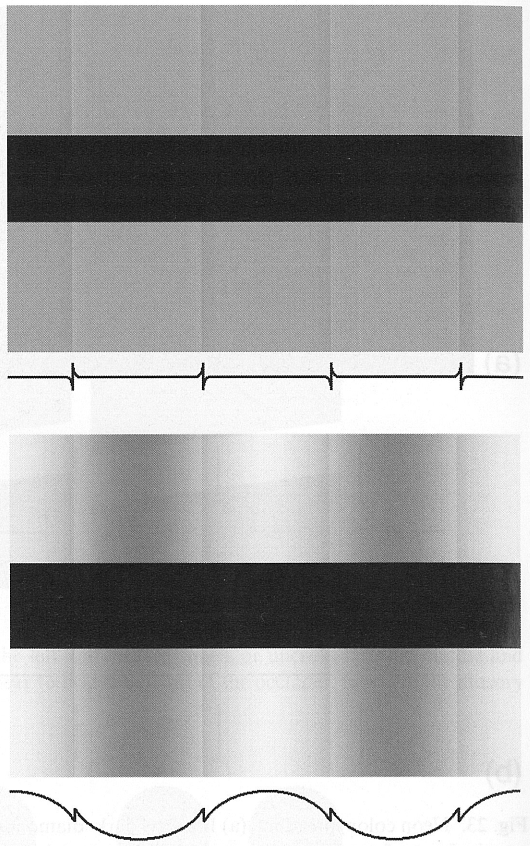


Fig. 26. (a) Craik–O'Brien–Cornsweet phantoms. (b) Sine-to-square phantoms. For both panels, phantoms are in phase with apparent lightness gratings, not luminance gratings. That is, the occluder appears to be dark, light, dark, light and dark from the left to the right. The luminance profile of the inducers is shown below in each panel, where the luminance modulation given at the edges is similar to each other.

Possible neural mechanisms underlying the visual phantom illusion

It had been discussed that visual phantoms might depend on transient channels (Kulikowski and Tolhurst, 1973; Tolhurst, 1973) because phantoms had been visible in motion or flicker before Gyoba (1983) who first demonstrated stationary phantoms. Gyoba (1994b) suggested the involvement of the magnocellular pathway (Livingstone and Hubel, 1987) because phantoms are vivid in low luminance and disappear with isoluminant colors.

Brown (1993, 2000) reported the involvement of fundus pigmentation, in which lightly pigmented observers saw phantoms more clearly than did darkly pigmented ones (e.g. African-Americans). We speculate that the pigmentation might affect the perception of brightness or contrast, which plays a critical role in the visual phantom illusion.

Recent evidence supports the idea that the visual phantom illusion originates from high-order visual areas because it involves the figure-ground processing (Weisstein et al., 1982; Brown and Weisstein, 1991), illusory contours (Kitaoka et al., 1999, 2001b), or perceptual transparency (Kitaoka et al., 1999, 2001a,b). Physiology has started to support this idea, in which visual phantoms activated the extrastriate cortex as well as V1 (Sasaki and Watanabe, 2004; Meng and Tong, 2004; Meng et al., 2005). However, there remains an open question why moving or flickering phantoms are much more vivid than stationary phantoms.

Finally, it should be stressed again that the visual phantom illusion is ubiquitous, not a special percept. For example, Kawabata et al. (1999) have suggested that infants younger than one month of age can see visual phantoms.

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SECTION V

Form, Object and Shape Perception

Introduction

Although seeing 3D shapes seems effortless, a tremendous amount of computation underlies form perception. The following chapters explore various aspects of these computations at various levels of analysis. A fundamental unsolved problem in visual neuroscience is how the human visual system recovers the 3D form of objects and scenes from inherently ambiguous 2D retinal images. The core computational problem is one of correctly and rapidly interpreting inherently ambiguous patterns of retinal activation. The following chapter by Mamassian most explicitly explores the nature of the inferences underlying perception, but inference is a recurring theme in all the chapters.

The processing of form information begins in the retina with center–surround and color-opponent receptive fields that confer upon ganglion cells a sensitivity to edges. The information the retina transmits to the brain for further processing is a compressed version of the image that emphasizes border information at multiple spatial scales. Ganglion cells with similar tuning characteristics are distributed throughout the retina, and can be thought of as bandpass channels that accomplish a decomposition of the image using something analogous to Fourier analysis or in more recent conceptualizations, a wavelet decomposition. The fact that retinal processing emphasizes edge information suggests that contours play a crucial role in generating later representations of 3D form.

A keystone in thinking about the neural mechanisms of visual perception is the concept of hierarchical processing of the details of the visual image. A widely held view is that this processing occurs in a number of stages, the first of which performs an analysis or filtering of the retinal image by extracting different, elementary features (primitives) or classes of image "energy". Early cortical processing appears to consist of a neural description of various image primitives and their locations within the scene. This description is a simplified version of the original retinal image, but is still far from explicit identification of the 3D structure of the visible world. One basic form of feature energy is motion energy. How form information constrains the interpretation of this energy so that correct 3D trajectories can be computed is considered in the following chapter by Tse and Caplovitz.

It is commonly held that "higher" stages of visual processing combine aggregates of primitive features into progressively more complex representations. Two generally dichotomous characterizations of these elements should be mentioned. One is that contours are primitives, which are used to define surfaces and object boundaries. The other is that receptive fields operate as localized, spatial frequency filters. It is not known which of these two general formulations (edge detection or spatial frequency analysis) is more accurate. Both types of detectors appear to exist and may constitute the extremes of a spectrum of processing types.

It is widely believed that early visual cortical areas are involved in grouping local information across the image into aggregate wholes. Because grouping involves decisions about what belongs with what in an image, it is tantamount to an inference about the state of the world. As such, grouping procedures do not merely extract information from the image; they create or construct new information. Thus, detected types of orientation, motion and other types of energy are used to construct an experience of a 3D world.