Perception, 2001, volume 30, pages 959 – 968

DOI:10.1068/p3082

Perceptual continuation and depth in visual phantoms can be explained by perceptual transparency

Akiyoshi Kitaoka¶
Department of Behavioral Physiology, Tokyo Metropolitan Institute for Neuroscience, Musashidai, Fuchu, Tokyo 183-8526, Japan; e-mail: akitaoka@tmin.ac.jp

Jiro Gyoba
Department of Psychology, Tohoku University, Aoba-ku, Sendai 980-8576, Japan

Hideaki Kawabata
Department of Psychology, Kyushu University, Higashi-ku, Fukuoka 812-8581, Japan

Kenzo Sakurai
Department of Psychology, Tohoku Gakuin University, Izumi-ku, Sendai 981-3193, Japan
Received 16 May 2000, in revised form 7 March 2001

Abstract. We try to explain perceptual continuation and depth in the visual-phantom illusion in terms of perceptual transparency. Perceptual continuation of inducing gratings across the occluder in stationary phantoms could be explained with unique transparency, a notion proposed by Anderson (1997 *Perception* **26** 419 – 453). This view is consistent with a number of previous reports including that of McCourt (1994 *Vision Research* **34** 1609 – 1617) who criticized the stationary phantom illusion from the viewpoint of his counterphase lightness induction or grating induction, which might involve invalid transparency. Here we confirm that the photopic phantom illusion (Kitaoka et al, 1999 *Perception* **28** 825 – 834) really gives in-phase lightness induction and involves bistable transparency. It is thus suggested that perceptual continuation and depth in the visual-phantom illusion depend on perceptual transparency.

1 Introduction

The visual-phantom illusion is a kind of perceptual-completion phenomenon, which appears in a configuration like that shown in figure 1. The most important characteristic of this illusion is that the phantoms appear continuous with the inducing gratings across the occluder. Moreover, phantoms are always perceived in front of the occluder (Weisstein et al 1982; Brown and Weisstein 1988, 1991). 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 the phantoms can be generated by flickering the grating (flickering phantoms) (Genter and Weisstein 1981) as well as by using low-luminance stationary gratings under dark-adaptation conditions (stationary phantoms) (Gyoba 1983). We hereafter call the stationary-phantom illusion 'scotopic phantoms' since we recently found a different type of visual-phantom illusion called 'photopic' phantoms (Kitaoka et al 1999), which are fully visible in photopic levels and have an appearance quite different from that of scotopic phantoms (see figure 8).

Since scotopic phantoms appear continuous across the occluder, it had long been believed that induced lightness is 'in phase' with the inducing grating, as exaggerated in figure 2, which gives in-phase luminance modulation to the occluder. This belief was questioned by McCourt (1994) who pointed out that the induced lightness in the occluder is in 'counterphase' with the inducing grating. This finding was confirmed in subsequent research (May et al 1999; Kimura, personal communication).

According to McCourt (1994), this counterphase induction is a kind of grating induction (McCourt 1982), which is one of the strongest lightness illusions (figure 3).

¶ Present address: Department of Psychology, Ritsumeikan University, Toji-in Kitamachi, Kita-ku, Kyoto 603-8577, Japan; e-mail: akitaoka@lt.ritsumei.ac.jp

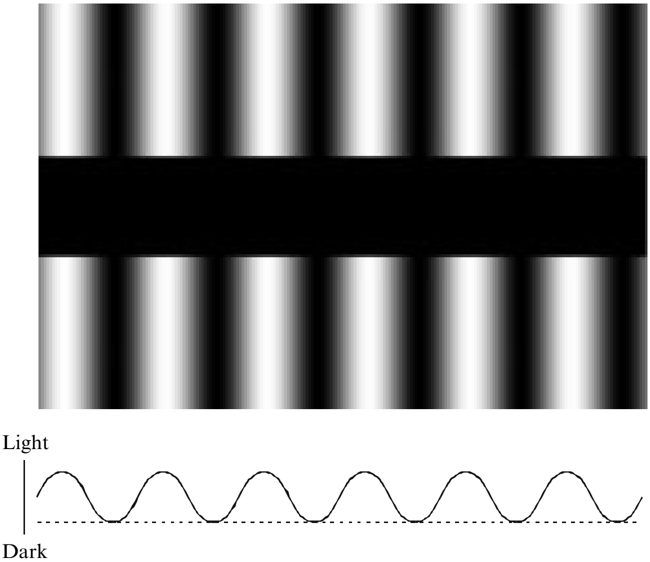


Figure 1. A stimulus that gives perceptual continuation of gratings across the occluder, which has been studied as the stationary visual-phantom illusion (hereafter 'scotopic phantoms'). Physically, a vertical sinusoidal grating with luminance modulation is occluded by a black horizontal occluder. The luminance of the occluder (broken line) is the same as the lowest luminance of the grating (sinusoidal solid curve). In this figure, under dark illumination or in motion, observers frequently see 'black phantoms' in front of the occluder that vertically connect the upper and lower dark parts of the grating (Gyoba 1983). It should be noted that McCourt (1994) attributed this phenomenon to the grating-induction effect.

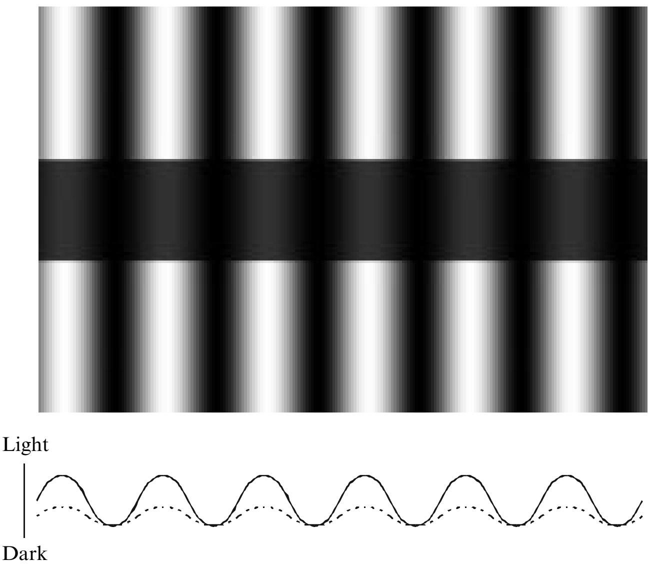


Figure 2. Exaggeration of the in-phase appearance that had long been believed as an adequate manifestation of scotopic phantoms, in which the lightness induction of the occluder (broken curve) is in phase with that of the inducing grating (solid curve). It should be stressed that in this figure the occluder is physically modulated in luminance.

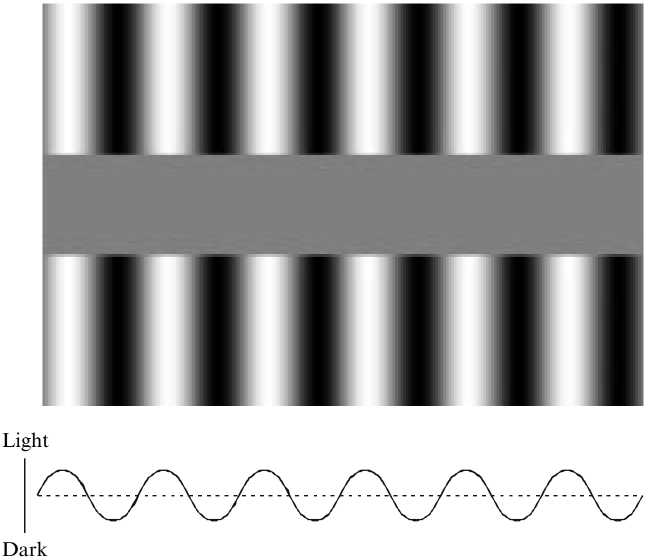


Figure 3. The grating induction discovered by McCourt (1982). Induced by the grating (solid curve), counterphase lightness changes are observed in the homogeneous gray occluder (broken line). This configuration never gives observers perceptual continuation of gratings.

The grating-induction effect, however, is quite different from scotopic phantoms in its appearance since grating induction never gives perceptual continuation of the grating. What is responsible for the difference if the lightness induction in scotopic phantoms is in counterphase?

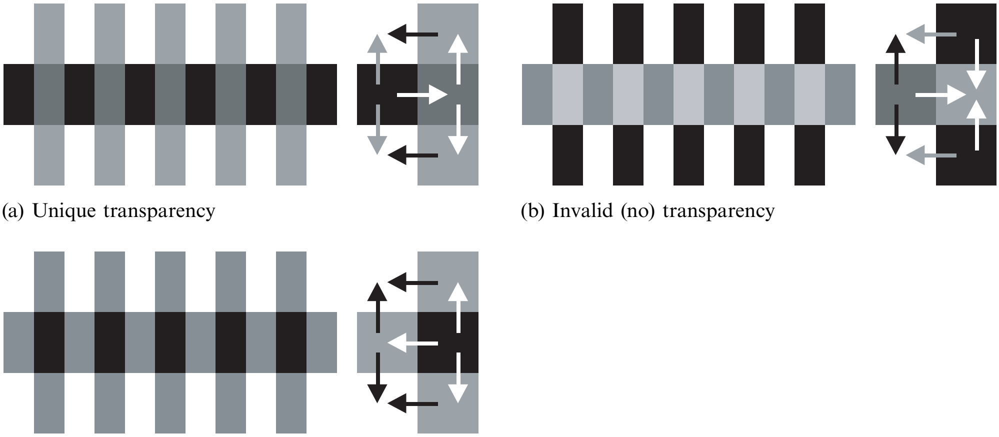
McCourt (1994) proposed an explanation in which the dark phase of the inducing grating is combined with the light phase of induced lightness on the black occluder because of brightness similarity between them. Then, he thought that counterphase lightness induction sponsors this perceptual continuation. His first assumption, however, does not explain the reason why phantoms appear in front of the occluder. His second assumption is inconsistent with the appearance of figure 2 in which perceptual continuation appears to be enhanced by in-phase luminance modulation on the occluder.

However, the enhanced perceptual continuation in figure 2 can be explained by his first assumption of brightness similarity. We think that the notion of brightness similarity is a significant suggestion. Actually, a close relationship between similarity in luminance and perceptual continuation has been pointed out in the literature of perceptual transparency (eg Oyama and Nakahara 1960; Metelli 1974; Anderson 1997); adjacent areas that are similar to each other in luminance tend to appear in front of other areas. We thus focus on the role of transparency in the perceptual continuation of visual phantoms.

2 The model

Here we consider the mechanism of perceptual continuation of visual phantoms in terms of the different types of transparency classified by Anderson (1997). Our idea is that visual phantoms reflect unique transparency whereas McCourt's grating induction involves invalid transparency.

According to Anderson, the significant factor determining these types of transparency is the arrangement of edge-contrast polarity across an X junction (figure 4). Unique transparency (figure 4a) occurs when the polarity of edge contrast is constant along one series of edges and alternates along the other series of edges where it crosses the former series at an X junction. In this case, every series of edges appears to be continuous, and a pair of adjacent areas that is flanked by edges of different contrast



(a) Unique transparency

(b) Invalid (no) transparency

(c) Bistable transparency

Figure 4. The classification of transparency according to Anderson (1997). (a) Unique transparency that follows Metelli's (1974) formula, in which the gray bars are seen as transparent and perceived as if they were located in front of the horizontal black occluder. Since the apparent depth order is unique, this type is called unique transparency. (b) The figure invalid for transparency. (c) Bistable transparency, in which the vertical grating can be seen either in front of or behind the occluder. Arrows indicate the contrast polarity (pointing to the lighter side). For details, see the text.

polarity, and shows closer brightness similarity than does the other pair of areas, always appears at the front.

On the other hand, invalid transparency (figure 4b) appears when the polarity of edge contrast alternates at X junctions along each series. In this case, observers do not see perceptual continuation.

Finally, bistable or reversible transparency (figure 4c) appears when the polarity of edge contrast is constant along each series of edges. In this case, every series of edges appears to be continuous and observers see one series in front of the other at one moment and see the reversal at the other moment. Although satisfactory theoretical bases have not been provided for Anderson's (1997) classification to date, it is known to work well in various kinds of transparency phenomena.

It is evident that the configuration of McCourt's grating induction (figure 3) gives invalid (no) transparency (figure 4b). We think this is the main reason why the grating induction never shows perceptual continuation of the grating, since those edges are not grouped by transparency.

On the other hand, the configuration of scotopic phantoms renders unique transparency (figure 4a), as demonstrated in figure 5. This figure, which includes a physically modulated occluder, gives the same impression as 'black phantoms', which vertically connect black regions of inducing gratings and appear in front of the occluder (Sakurai and Gyoba 1985). The critical condition is that the highest lightness in the occluder is the same as or lower than the lowest lightness in the inducing grating. In this case, the polarity of edge contrast is constant along the borders between the occluder and inducing gratings, and alternates along the orientation of inducing gratings where edges cross the borders (see figure 6). Moreover, the black regions of the inducing gratings and the corresponding occluder region are closer in luminance than the rest. According to the principle of unique transparency, they appear to be continuous in front. However, we should add a rule that for the sinusoidal version (figure 5) transparency occurs where lightness is similar between the inducing grating and the occluder. This rule is consistent with McCourt's (1994) brightness similarity,

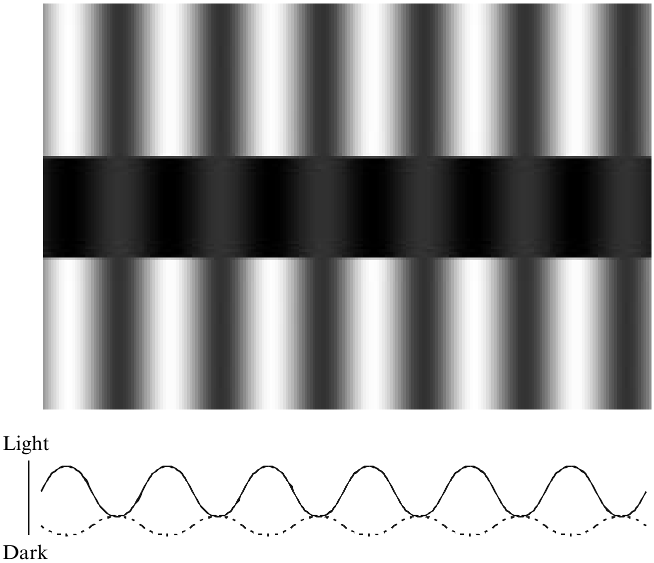


Figure 5. Exaggeration of the counterphase appearance of scotopic phantoms, involving unique transparency. This figure gives 'black phantoms' (Sakurai and Gyoba 1985). Although luminance changes in the occluder (broken curves) are in counterphase with the surrounding grating (solid curves), gray vertical phantoms can be seen in front of the occluder. It should be stressed that in this figure the occluder is physically modulated in luminance.

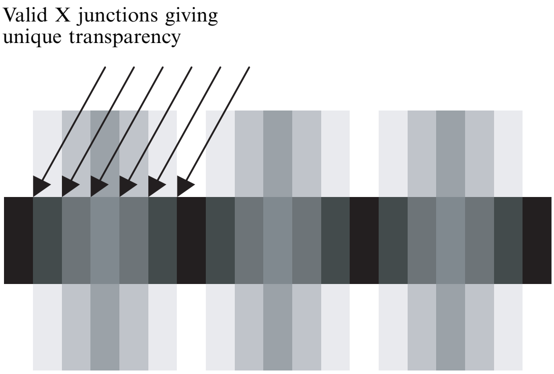


Figure 6. A schematic explanation of perceptual continuation of scotopic phantoms in terms of unique transparency. This figure is a reduced representation of figure 5. In this figure, every series of vertical edges changes contrast polarity when crossing horizontal edges while every series of the horizontal edges keeps contrast polarity. Thus the appearance is that the dark-gray, narrowest rectangle is in front of the middle-gray, middle-sized rectangle, which in turn is in front of the light-gray, widest rectangle. These layers appear transparent and the order in apparent depth is unique.

though McCourt does not explain the reason why phantoms appear at the front. In this sense, the notion of brightness similarity can be incorporated into the transparency model.

Finally, we recently claimed that photopic phantoms (see figure 8) depend on in-phase lightness induction and involve bistable transparency (figure 4c) (Kitaoka et al 1999). This claim is supported by the report that observers see photopic phantoms either in front of or behind the occluder (though the latter appearance seems to be predominant).

We propose a two-stage model (table 1) in order to explain the phenomenological differences among scotopic phantoms, grating induction, and photopic phantoms.

Table 1. The two-stage model to separate the scotopic visual-phantom illusion, the grating-induction effect, and the photopic visual-phantom illusion.

	Scotopic phantoms	Grating induction	Photopic phantoms
Lower stage (lightness induction)	counterphase	counterphase	in phase
Higher stage (transparency)	unique	invalid	bistable

Although we admit the claim of McCourt (1994) that scotopic phantoms depend on counterphase lightness induction, phantoms belong to a higher class than the class of lightness induction and are different from grating induction in respect of whether gratings appear to be continuous or not. This difference is critical in visual cognition since perceptual continuation is a significant source of figure – ground segregation as well as object recognition.

Our model incorporating transparency could explain other characteristics of visual phantoms. First, when the occluder is white in scotopic phantoms, 'white phantoms' appear, which vertically connect white regions of inducing gratings and appear in front of the occluder (Sakurai and Gyoba 1985). This can be demonstrated with physical modulation of occluder luminance (figure 7). Second, the finding that scotopic phantoms are visible under conditions of dark adaptation but less visible in photopic levels (Gyoba 1994) can be explained by the recent report that counterphase lightness induction on a black occluder is much greater in scotopic light levels than in photopic light levels (Kimura, personal communication). The increase in lightness induction might enhance the transparency effect. Third, the Zavagno effect, that a luminance-gradient figure gives illusory mist in front of a homogeneous background (Zavagno 1999), could be explained by unique transparency in the same manner as scotopic phantoms.

Here we should say that we do not always agree with McCourt's (1994) claim that visual phantoms are all based upon counterphase lightness induction. The photopic

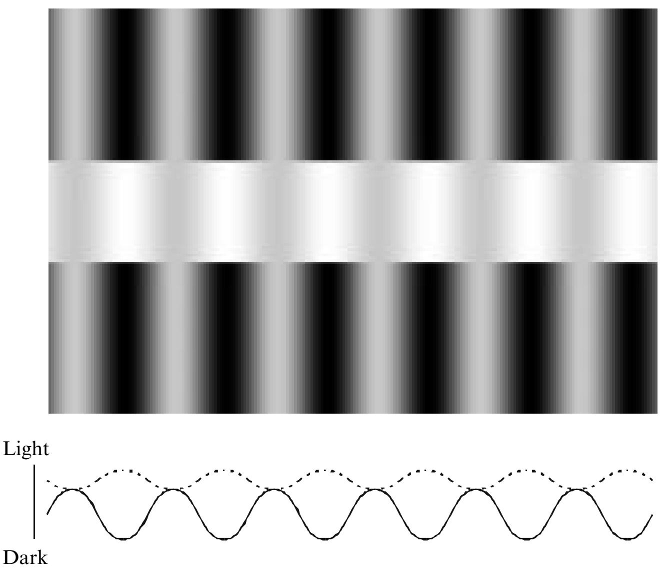


Figure 7. Exaggeration of the counterphase appearance of scotopic phantoms, giving 'white phantoms' (Sakurai and Gyoba 1985). Although luminance changes in the occluder (broken curves) are in counterphase with the surrounding grating (solid curves), gray vertical phantoms can be seen in front of the occluder. It should be stressed that in this figure the occluder is physically modulated in luminance.

phantom illusion proposed by us (Kitaoka et al 1999) (figure 8) might be an exception. We claimed that photopic phantoms depend on in-phase lightness induction and involve bistable transparency (figure 4c and table 1). If that claim is true, it is plausible that perceptual continuation of visual phantoms chiefly depends on the mechanisms of perceptual transparency since transparency groups edges or areas and forms surfaces.

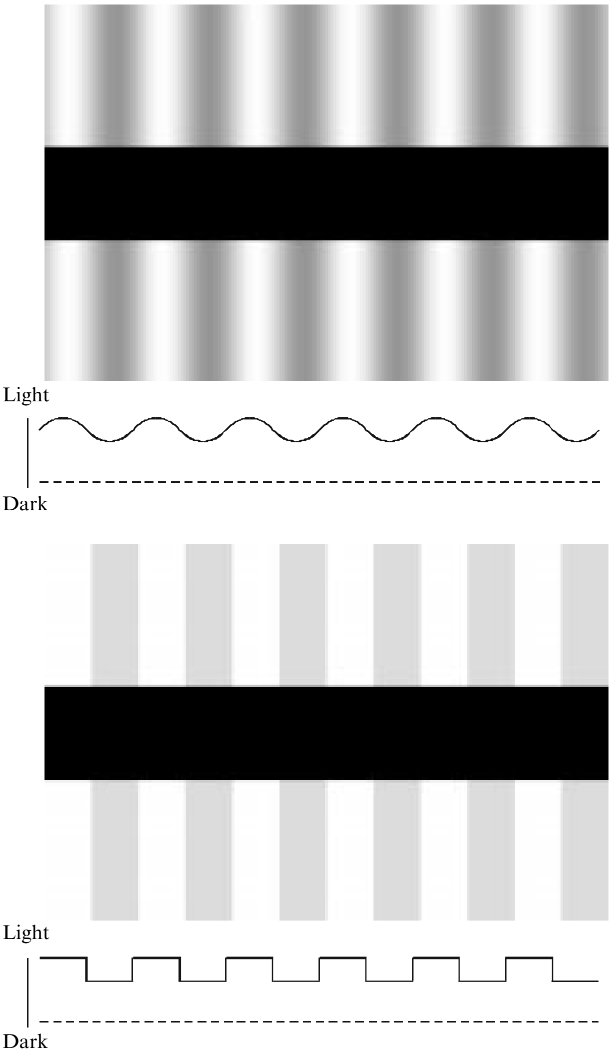


Figure 8. The photopic visual-phantom illusion (Kitaoka et al 1999). The name is based upon the characteristic that phantoms are visible under photopic vision as well as under scotopic vision. The critical figural feature is that the contrast of the inducing grating is low (solid curves) and its average luminance is distant from the luminance of the occluder (broken curves). For photopic phantoms, lightness induction is in phase with the inducing grating, phantoms are frequently seen behind the occluder when it is black, and square-wave phantoms (lower panel) give higher visibility than sine-wave phantoms (upper panel). These characteristics are the reverse of those for scotopic phantoms. Motion does not enhance the visibility of photopic phantoms so much. It should be noted that a few observers feel difficulty in perceiving photopic phantoms, especially in the sinusoidal version. This might be due to the possibility that sinusoidal-wave inducing gratings give stronger counterphase lightness induction than do square-wave ones and the visibility of in-phase photopic phantoms is lowered by cancellation.

3 An experiment
Since our claim [that photopic phantoms depend on in-phase lightness induction (Kitaoka et al 1999)] was only descriptive and there have been no experiments specifically designed to measure illusory gratings of photopic phantoms, in this experiment we measured the induced lightness of photopic phantoms and grating induction by means of a cancellation technique.

3.1 *Method*
3.1.1 *Subjects.* Five observers who were not aware of the purpose of this experiment and three trained authors (JG, HK, and KS) took part in the experiment. All subjects had normal or corrected-to-normal acuity.

3.1.2 *Stimuli.* The stimuli were generated by a Cambridge Research graphics card (VSG 2/3) mounted on a PC (Dell OptiPlex GX1) and were displayed upon a Sony monitor (IDEK MF8617) placed in a light room (115 lx on the display table). The monitor was gamma corrected. The stimuli were square-wave, vertical gratings (inducing gratings), which were partly occluded by a horizontal band (occluder). The size of the vertical gratings was 12.0 deg wide $\times$ 4.4 deg high while that of the occluders was 12.0 deg wide $\times$ 1.2 deg high. The spatial frequency of the grating was 0.625 cycle deg^{-1}. Light and dark gratings were used. For the light grating, the highest luminance was 52.18 cd m^{-2} while the lowest luminance was 34.04 cd m^{-2} (a contrast of 0.210). For the dark grating, the highest luminance was 24.98 cd m^{-2} while the lowest luminance was 6.84 cd m^{-2} (a contrast of 0.570). Thus, the light and dark gratings can also be regarded as low-contrast and high-contrast gratings, respectively. The luminance amplitude for both gratings was identical (18.14 cd m^{-2}). Four different luminances for the occluder were tested: 15.91, 24.98, 34.04, and 43.11 cd m^{-2}. This luminance step was constant (9.07 cd m^{-2}) and just half of the luminance amplitude of the gratings. In summary, there were eight conditions: 2 grating types (light versus dark) $\times$ 4 occluder luminances.

The occluder was modified with a cancellation stimulus, which consisted of a square-wave vertical grating, in phase or in counterphase with the surrounding gratings. The step of luminance changes for cancellation was about 0.007 cd m^{-2}. The average luminance of the cancellation grating was the same as that of the occluder to be tested.

3.1.3 *Procedure.* Subjects were individually tested. Head position was maintained with a chin rest and a head rest. Stimuli were observed through natural pupils, from a viewing distance of 138 cm. When subjects pressed upward or downward arrow keys, the contrast of the cancellation grating was changed. The task was to cancel the induced lightness by using the cancellation grating. The initial contrast of the cancellation grating, in phase or in counterphase, randomly chosen, was large enough to be perceived clearly. As described above, there were eight conditions. In each trial, occluder luminance was constant and each of light and dark inducing gratings was tested six times in random order for a subject. Four trials, corresponding to the four occluder luminances, were tested in random order.

For the obtained data, positive values mean counterphase cancellation, and indicate that the lightness induction was in phase. In contrast, negative values mean in-phase cancellation, and indicate that the lightness induction was counterphase. Data were converted to percent cancellation contrast (McCourt 1982), which is defined as: (contrast of the cancellation grating/contrast of the inducing grating) $\times$ 100.

3.2 *Results and discussion*
Figure 9 shows the results. Cancellation was counterphase when the luminance of the occluder was much lower or higher than the luminances of the inducing grating (conditions a and h in figure 9). Since these conditions give the photopic-phantom illusion (Kitaoka et al 1999), it was confirmed that the lightness induction of photopic phantoms is

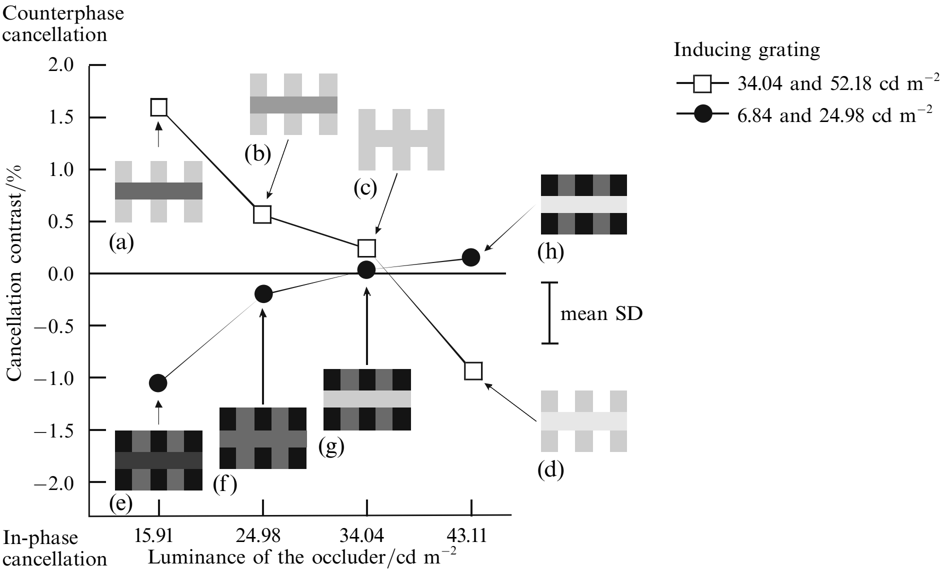


Figure 9. Results of the present experiment ($n = 8$): percent cancellation contrast as a function of luminances of the inducing grating and the occluder. In conditions a and h, cancellation was counterphase, indicating that the lightness induction was in phase (photopic phantoms), while, in conditions d and e, cancellation was in phase, which showed counterphase lightness induction (grating induction).

in phase. On the other hand, cancellation was in phase when the luminance of the occluder was between the high and low luminances of the inducing grating (conditions d and e). This confirmed the counterphase characteristic of McCourt's (1982) grating induction.

These findings were supported by the following nonparametric tests. In the condition for photopic phantoms, all observers (condition a in figure 9) or seven of the eight observers (condition h) gave counterphase cancellation values. These biases were statistically significant ($\chi_1^2 = 8.00$, $p < 0.01$; $\chi_1^2 = 4.50$, $p < 0.05$). On the other hand, in the condition for grating induction, seven of the eight observers (condition d) or all of the observers (condition e) gave in-phase cancellation values. These biases were also statistically significant ($\chi_1^2 = 4.50$, $p < 0.05$; $\chi_1^2 = 8.00$, $p < 0.01$). These findings were also supported by a two-way (within-subjects) ANOVA showing a significant interaction ($F_{3,21} = 11.37$, $p < 0.01$).

In an a posteriori test, condition a showed higher percent cancellation contrast than condition h ($t_7 = 3.22$, $p < 0.05$), though both gave in-phase photopic phantoms. This result is consistent with the finding that visibility of photopic phantoms is higher when inducing gratings are light and the occluder is dark (Kitaoka et al 1999). This result might indicate that a low-contrast inducing grating gives strong in-phase lightness induction since the light inducing grating is of low contrast as compared with the dark one. Of course, there is a possibility that counterphase lightness induction reduces visibility of in-phase photopic phantoms when the contrast of the inducing gratings is high.

Conditions c and f in figure 9 gave scotopic phantoms but the obtained values in these conditions were nearly zero. Although scotopic phantoms give counterphase lightness induction (McCourt 1994), this effect is strong only under dark adaptation (Gyoba 1983; Kimura, personal communication). Since our experiment was conducted under conditions of light adaptation, the observed lightness induction might be small. Conditions b and g gave weak photopic phantoms as compared with the phantoms in conditions a and h. This is consistent with the observation that photopic phantoms are most vivid when the luminance of the occluder is distant from the luminances of the inducing grating (Kitaoka et al 1999).

The values of percent cancellation contrast in grating induction were markedly low (at most 1%) as compared with those obtained by McCourt (1982) (the maximum value was 90%). This discrepancy is probably due to the use of relatively low-contrast inducing gratings, relatively large occluder heights, and square-wave inducing gratings in our experiment, since grating induction is strong with high-contrast inducing gratings (McCourt and Kingdom 1996), small occluder heights, and with a sinusoidal-wave grating (McCourt 1982).

4 Conclusion

The present experiment confirmed that photopic phantoms really depend on in-phase lightness induction and involve bistable transparency. Since scotopic phantoms depend on counterphase lightness induction and reflect unique transparency, as we have described, and the notion of transparency involves perceptual continuation (or grouping) of areas of different lightness, it is suggested that perceptual continuation of the visual-phantom illusion is based upon perceptual transparency (table 1).

Acknowledgements. The first author is greatly indebted to Dr Takayuki Sato for his encouragement. We thank Yuiko Sakuta for her support. We also thank Professor James G May and the anonymous referee for their helpful comments. This research was supported by Grant-in-Aid for Scientific Research, Ministry of Education, Science and Culture, No. 11410019 and No. 11710047.

References

Anderson B L, 1997 "A theory of illusory lightness and transparency in monocular and binocular images: the role of contour junctions" *Perception* **26** 419 – 453

Brown J M, Weisstein N, 1988 "A phantom context effect: Visual phantoms enhance target visibility" *Perception & Psychophysics* **43** 53 – 56

Brown J M, Weisstein N, 1991 "Conflicting figure – ground and depth information reduces moving phantom visibility" *Perception* **20** 155 – 165

Genter II C R, Weisstein N, 1981 "Flickering phantoms: A motion illusion without motion" *Vision Research* **21** 963 – 966

Gyoba J, 1983 "Stationary phantoms: A completion effect without motion and flicker" *Vision Research* **23** 205 – 211

Gyoba J, 1994 "Disappearance of stationary visual phantoms under high luminant or equiluminant inducing gratings" *Vision Research* **34** 1001 – 1005

Kitaoka A, Gyoba J, Kawabata H, 1999 "Photopic visual phantom illusion: Its common and unique characteristics as a completion effect" *Perception* **28** 825 – 834

McCourt M E, 1982 "A spatial frequency dependent grating-induction effect" *Vision Research* **22** 119 – 134

McCourt M, 1994 "Grating induction: A new explanation for stationary phantom gratings" *Vision Research* **34** 1609 – 1617

McCourt M E, Kingdom F A A, 1996 "Facilitation of luminance grating detection by induced gratings" *Vision Research* **36** 2563 – 2573

May J G, Brown J M, Roberts S, 1999 "Afterimages, grating induction and illusory phantoms" *Vision Research* **39** 3025 – 3031

Metelli F, 1974 "The perception of transparency" *Scientific American* **230** 90 – 98

Oyama T, Nakahara J, 1960 "The effect of lightness, hue and area upon the apparent transparency" *Japanese Journal of Psychology* **31** 35 – 48

Rosenbach O, 1902 "Zur Lehre von den Urtheilstäuschungen" *Zeitschrift für Psychologie* **29** 434 – 448

Sakurai K, Gyoba J, 1985 "Optimal occluder luminance for seeing stationary visual phantoms" *Vision Research* **25** 1735 – 1740

Tynan P, Sekuler R, 1975 "Moving visual phantoms: A new contour completion effect" *Science* **188** 951 – 952

Weisstein N, Maguire W, Williams M C, 1982 "The effect of perceived depth on phantoms and the phantom motion aftereffect", in *Organization and Representation in Perception* Ed. J Beck (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 235 – 249

Zavagno D, 1999 "Some new luminance-gradient effects" *Perception* **28** 835 – 838

© 2001 a Pion publication printed in Great Britain