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Asymmetrical contrast effects induced by luminance and color configurations

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In the two experiments, the use of a psychophysical procedure of brightness/darkness cancellation shed light on interactions between spatial arrangement and figure–ground contrast in the perceptual filling in of achromatic and colored surfaces. Achromatic and chromatic Kanizsa squares with varying contrast, contrast polarity, and inducer spacing were used to test how these factors interact in the perceptual filling in of surface brightness or darkness. The results suggest that the neuronal processing of surfaces with apparent contrast, leading to figure–ground segregation (i.e., perceptual organization), is governed by mechanisms that integrate both luminance contrast and spatial information carried by the inducing stimuli, while discarding information on contrast polarity or color. The findings are discussed in relation to earlier observations on brightness assimilation and contrast. They support theories of nonantagonistic neural mechanisms suppressing local contrast or color signs in brightness-based figure–ground percepts. Such mechanisms might be necessary to cancel potentially conflicting polarities in geometrically complex visual stimuli so that perceptual filling in resulting in the most plausible representation of figure and ground can be achieved.

The geometric properties of visual configurations inducing spatial brightness effects, particularly of so-called illusory figures (see Spillmann & Dresp, 1995, for review), have been the subject of extensive psychophysical investigation (e.g., Brigner & Gallagher, 1974; Dresp, 1992; Dresp, Lorenceau, & Bonnet, 1990; Lesher & Mingolla, 1993; Shipley & Kellman, 1992; Spillmann, Fuld, & Gerrits, 1976). For example, the influence of size, spacing, and luminance of stimuli that produce perceptual filling in (Gerrits & Vendrik, 1970) of bright or dark surfaces via some kind of inwardly directed contrast mechanism (Grossberg & Mingolla, 1985) was demonstrated in a study on the Kanizsa square (Kanizsa, 1955). A brightness matching/cancellation procedure (Heinemann, 1955, 1972) was used in which observers had to adjust the luminance of the central region of the configuration, the so-called illusory square, until it matched the darkness of the general background (Dresp, 1992). This is equivalent to a cancellation of the phenomenal difference in brightness or darkness between figure and ground. Black Kanizsa squares (for an illustration, see Figure 1) with white inducing elements were presented on a black background, with the square-shaped region in the center appearing darker than the dark background. The experiments showed that such configurations produce the expected darkness filling in consistent with classic simultaneous contrast (e.g., Frisby & Clatworthy, 1975): A dark area in the stimulus appears darker when it is surrounded by a white inducing area. To cancel this darkness enhancement, the test area has to be adjusted to a luminance level that is higher than that of the background, and the relative strength of darkness enhancement is measured by the difference in luminance between the background and the test field after adjustment. In Dresp's study, darkness enhancement of the illusory square was found to increase consistently with the size, the proximity, and the luminance intensity of the inducing stimuli, showing that this kind of simultaneous contrast filling in is highly sensitive to the spatial properties, or geometry, of the surrounding configuration. Psychophysical studies by Shipley and Kellmann (1992), and Lesher and Mingolla (1993) likewise demonstrated the importance of stimulus geometry on the phenomenal strength of brightness effects in a large variety of perceptually filled in figures. Their rating experiments investigated in particular the effect of the size of the gap between parts of the inducing stimulus or the ratio between gap size and total stimulus width/length, referred to as *support ratio*, on the strength of illusory contour brightness and clarity.

De Weert and Spillmann (1995) studied the effect of surround luminance on local reference fields in configurations in which the inducing elements were full disks made of alternating black and white rings presented on gray backgrounds. These disks, surrounding a gray, pincushion-shaped central area, do not generate illusory contours. The authors pointed out that their stimuli produced filling-in effects in the opposite direction of classic simultaneous contrast in the sense that the gray cen-

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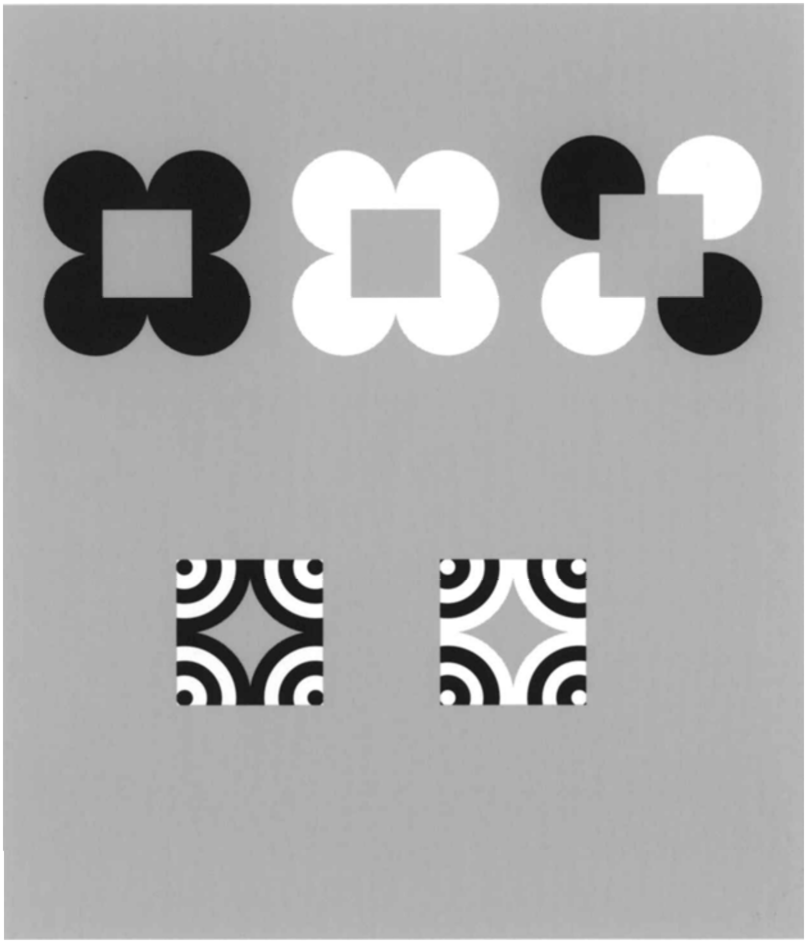

Figure 1. Some of the stimuli used in the present experiments. Apparent brightness (top left) or darkness contrast (top middle) is generated via filling in of the square-shaped surface in the center of the configurations, which was used as a test field in our experiments. When the inducing configuration possesses opposite contrast polarities with equal contrast intensity, filling in takes place (top right), but remains phenomenally ambiguous (i.e., subjects find it hard to say whether the square appears lighter or darker than the background). Whether the configurations are physically closed (top left and middle) or are perceptually closed by so-called illusory contours (top right) does not influence the direction of the contrast effects. Ring configurations with opposite contrast polarities of equal contrast intensity may also generate darkness (bottom left) or brightness filling in (bottom right), as illustrated by the "pincushion" shaped surfaces, which are similar to those used by de Weert and Spillmann (1995).

tral area of the configurations was found to be lightened by white rings bounding the pincushion (Figure 1, bottom right) and to be darkened by black rings (Figure 1, bottom left). This observation is identical to phenomena referred to as brightness or darkness assimilation. De Weert and Spillmann's matching experiments showed that in these cases of assimilation, both the perceptual darkening and the perceptual lightening of the test surfaces increased with increasing luminance of the white or black surrounds. However, quite unexpectedly, observers always had to make a gray test field darker in order to match it to the perceived brightness of the gray induced area, or reference field (the pincushion surface). This result was unexpected insofar as phenomenally *brighter* pincushions were matched by *decrements* of the test field. Earlier studies with stimuli of positive and negative contrasts (Beck, 1966; Festinger, Coren, & Rivers, 1970; Hamada, 1985, 1987) produced similar observations. With the use of a subjective scaling procedure, Beck found that the phenomenal brightness of reference fields, whether induced by white or by black stripes on a gray background, was systematically rated *darker* than that of a uniformly gray comparison field. At high contrast, darkness induced by white stripes was rated stronger than darkness induced by dark stripes. Festinger et al. (1970), using a *test-to-reference field matching* procedure similar to that of de Weert and Spillmann, found that a gray reference area with white stripes was matched by a *stronger decrement* of the test field, in comparison with a gray reference area with black stripes despite the fact that the area with the white stripes looked phenomenally *lighter.* Subsequently, asymmetries of brightness and darkness adjustments were reported in the Craik–O'Brien illusion (Hamada, 1985) and in the Ehrenstein illusion (Hamada, 1987). In both cases, phenomenally *lighter* illusory areas (reference fields) were matched by decrements of the test fields. These observations are sometimes referred to as *Hamada's paradox* (e.g., Grossberg & Mingolla, 1985).

With colored pincushion inducers on colored backgrounds, de Weert and Spillmann (1995) observed that neither assimilation nor simultaneous contrast was generated. The absence of both illusory contours and filling in in isoluminant color configurations had been reported in an earlier study by de Weert (1984), and was discussed for the first time by Gregory (1977) within the framework of his cognitive theory of perceptual illusions. The fact that the colored pincushion stimuli produced no difference in hue between reference and test fields led Spillmann and de Weert to the conclusion that the filling in phenomena they found had to be explained on the basis of a luminance factor in which the difference in luminance between the inducing configuration and its background play the predominant role. Other studies concerned with perceptual filling in and apparent brightness have shown that changes in the spatial properties of the stimuli, such as the size of individual figure elements or their configuration, produce complex interactions with local changes in figure–ground contrast, or in the polarity of that contrast, in achromatic stimuli. Such interactions might change or even reverse the relative brightness or darkness of a reference field, and might explain matching or rating asymmetries observed in a variety of cases (e.g., Beck, 1966; Heinemann, 1972; Reid & Shapley, 1988; Shapley & Reid, 1985). Reid and Shapley proposed a theoretical account for interactions between local luminance contrast at edges, separating test fields from reference fields, and the global spatial configuration by a two-stage processing model. The model suggests an early neural mechanism that is sensitive to local edge contrast and a higher cortical mechanism mediating brightness responses that take into account only the weighted sum of the contrasts generated at the first stage of processing. This approach is conceptually similar to Hamada's (1984, 1985, 1987, 1991) theory of a neural, *nonantagonistic* barrier mechanism that suppresses the sign of local contrast responses generated at an earlier stage. Hamada' s theory has been of relevance to Grossberg and Mingolla's (1985) macro-model approach to brightness-based form perception. Shevell, Holliday, and Whittle (1992) proposed a two-stage model of brightness induction in which the first-stage responses are generated independently in the monocular pathways, depending solely on adjacent signal inputs, and a cortical (binocular) second-stage process that is driven by first-stage signals aggregated from throughout the visual field in a nonlinear manner. Thus, Shevell et al.'s approach accounts for brightness asymmetries in complex visual percepts in which the phenomenal appearance of the reference field is not only determined by light signals from the immediate surround field but also by light signals from all over the visual field.

Although each of the theories briefly introduced here attempt to explain a limited set of psychophysical observations, they all converge toward the idea that, at some stage in the processing of brightness-based figure–ground percepts, the direction, or sign, of local contrast has to be discarded. The present study, in which brightness/darkness cancellation procedures equivalent to the one described earlier by Dresp (1992) were used, was designed to shed more light on the possible functional significance of interactions between figure–ground organization (spatial factor) and figure–ground contrast (luminance factor) in achromatic and colored configurations of the Kanizsa type. Different combinations of contrast intensity, contrast polarity, and color were used to determine how they might influence the filling in of brightness in figures with varying spatial properties.

EXPERIMENT 1
Figure–Ground, Luminance Contrast, and Polarity

In the first experiment, we varied figure–ground geometry (spatial factor) by varying the spacing of the four inducing elements of Kanizsa squares. With the closest spacing, the inducers completely surround the square-shaped figure in the center, and the configuration gives rise to classic simultaneous contrast. With larger spacings, the square is not completely surrounded by the inducers, but appears perceptually closed by so-called illusory contours that are perceived at the four open sides (Figure 1, top right). The intensity and direction of figure–ground contrast (luminance factor) was varied by presenting different combinations of contrast polarities at different luminance levels on a gray background of constant luminance. Configurations with a single contrast polarity give rise to a perceptual darkening effect that fills in the square-shaped surface in the center when the inducers are bright (Figure 1, top middle) and to a perceptual lightening effect when the inducers are dark (Figure 1, top left). When combinations of light and dark inducers are in a given configuration, the filling in effect remains phenomenally ambiguous and may shift from perceptual darkening to perceptual lightening (Figure 1, top right).

Method

Subjects

Eight observers with normal or corrected-to-normal vision participated in the experiment. They were all naive as to the purpose of the study, but were accustomed to performing in psychophysical experiments.

Stimuli

The stimuli consisted of Kanizsa squares with four inducing elements of constant size (about 50 arcmin diameter). The spacing, contrast polarity, and strength of contrast of the inducing elements varied. The gaps separating their borders were 0, 50, and 200 arcmin. The contrast polarity within a given configuration was either positive (white inducers on gray background), negative (black inducers on gray background), or combined (black and white inducers on gray background as in Figure 1). Michelson contrasts (Lmax−Lmin/Lmax+Lmin) similar to those used by de Weert and Spillmann (1995) were chosen: 0.20, 0.51, and 0.80. These corresponded to luminance values of 13.7, 9.1, and 2 cd/m^2 for dark inducers (Lmin), and 22, 26.6, and 34.5 cd/m^2 for bright inducers (Lmax). The luminance of the background was constant at 17.8 cd/m^2. The configurations were presented in separate blocks of trials (two blocks per figure). They were flashed on the screen of a high-resolution color monitor (TAXAN) with a 60-Hz frame rate, connected to an IBM-compatible computer equipped with a VGA graphics card. Presentation duration of each trial was about 480 msec (30 frames), and the subjects had to cancel the illusory brightness/darkness enhancement of the square in the center of the configuration. This could be achieved by changing the luminance of the square via two keys on the computer keyboard, one for luminance increments and one for decrements. One of the keys had to be struck as soon as the configuration had disappeared from the screen, and a response via the keyboard initiated the following presentation of the configuration 800 msec later.

Procedure

The subjects were asked to fixate the center of the screen, and their task was to adjust the luminance of the centrally displayed square in a given configuration until it matched the brightness of the general background, which was equivalent to a cancellation of the phenomenal brightness/darkness enhancement of the square. One adjustment took an average of 22 trials for a given figure, and the value of the last luminance adjustment was then substracted from the background luminance level in the case of decrements and was added to background luminance in the case of increments. The resulting values were taken as a measure of the strength of brightness/darkness enhancement. The starting luminance was set at an intensity below or above the background luminance, in random order. In a first session, the figures were presented in random order in separate blocks of trials, according to a method of constant stimuli. Presentation of each figure was then repeated, again in random order, in a second session with each subject. A given trial block was terminated when the subject hit the third response key, which indicated that the brightness of the adjusted field in a given figure appeared identical to that of the general background.

Results

Mean results from Experiment 1 are represented in Figure 2. Differences between the adjusted luminance of the test figure (the illusory square) at the last trial and the background luminance, measuring the subjective equality in brightness of figure and ground, are plotted as a function of the spacing between inducing elements, their polarity, and their contrast. Comparison between individual data showed no noticeable interindividual variability, and results were therefore averaged over sessions and subjects.

The curves in Figure 2 show that the subjective brightness enhancement measured in Experiment 1 was always expressed in increments. This means that the luminance that was required to cancel the brightness effect was systematically higher than the background luminance. This holds for configurations with black inducers only, configurations with white inducers only, and for configurations with inducers of both contrast polarities. The total amount of adjusted figure–ground difference decreases as the spacing between inducers increases in a given configuration. This decrease is fairly steep between separations of 0 and 50 arcmin between inducers, then tends to level off. The effect of spatial separation was statistically significant [$F(2,8) = 42.82, p < .01$].

Figure–ground differences significantly increased with increasing contrast of the inducers [$F(2,8) = 15.59$, $p < .01$]. Furthermore, the results shown in Figure 2 show strongest figure–ground differences in configurations with inducers of both polarities and weaker differences in figures with only black inducers. The effect of contrast polarity on figure–ground segregation is, however, not statistically significant.

EXPERIMENT 2
Figure–Ground, Luminance Contrast, and Color

In the second experiment, we varied figure–ground geometry (spatial factor) by varying the spacing of the inducing elements of the figures in the same way as was done in Experiment 1. Figure–ground contrast (luminance factor) was varied by presenting colored (red) inducers at different luminance levels on a green background of constant luminance while keeping the color contrast, or chromaticity, of the configurations constant. De Weert and Spillmann (1995) reported the absence of assimilation effects when isoluminant red–green pincushion-type stimuli on a gray background were used. Their data imply that luminance contrast rather than spatial configuration determines the filling in phenomena. We wanted to test whether this would be confirmed for the case of illusory surface brightness.

Method

Subjects

Five of the 8 subjects from Experiment 1 and 3 new subjects participated in the second experiment.

Stimuli

The stimuli consisted of Kanizsa squares with four inducing elements of constant size (about 50 arcmin diameter). The spacing and luminance of the inducing elements varied. The gaps separating their borders were 0, 50, and 200 arcmin. The chromaticity of a given configuration was constant, and Michelson contrasts were similar to those in Experiment 1. These corresponded to luminance values of 22, 27, and 33 cd/m^2 for the red ($x = .5756$ CIE, $y = .3679$ CIE) inducers, which all appeared phenomenally brighter than the background and appeared to differ in brightness when presented at the contrasts chosen here. The luminance of the green ($x = .2863$ CIE, $y = .3669$ CIE) background was constant at 17 cd/m^2. Red inducers darker than the background were not tested, since they looked phenomenally identical ("black" on green), which means they did not appear to differ in brightness when presented at the contrasts chosen here.

Like de Weert and Spillmann (1995), we also used isoluminance of figure and ground in one of the conditions. Psychophysical iso-

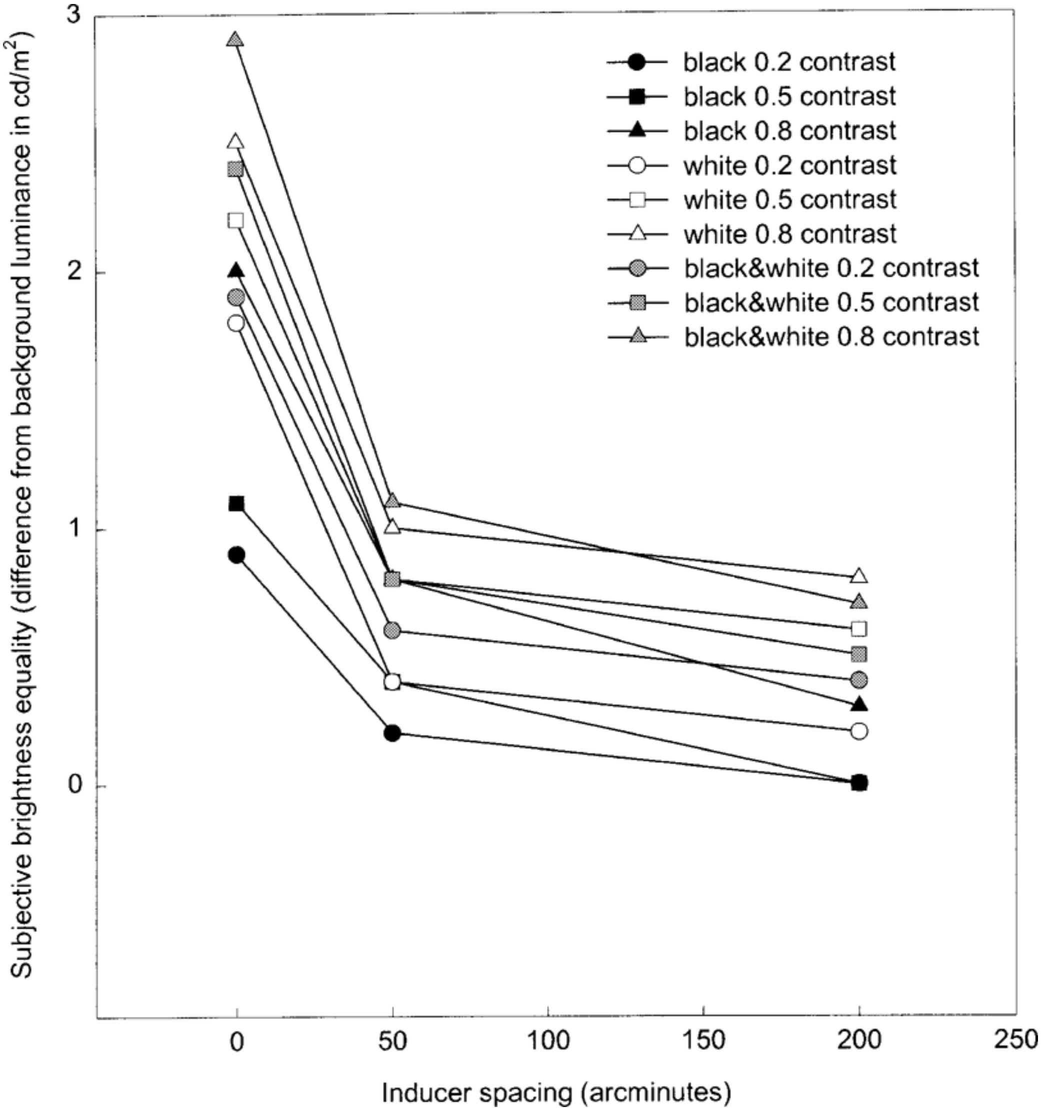

Figure 2. Luminance changes required to cancel brightness/darkness enhancement of the illusory square expressed in differences between the final luminance of the test figure (the illusory square) and the background luminance. The luminance differences are plotted as a function of the spacing between inducing elements, contrast polarity, and contrast intensity (Experiment 1). The data revealed little interindividual variability. Results were averaged over sessions and subjects. The curves show that brightness/darkness cancellation is always expressed in increments. This holds for configurations with black inducers only, configurations with white inducers only, and configurations with inducers of both contrast polarities.

luminance was assessed by means of a classic *flicker test* in which the subjects indicated when they perceived minimal flicker of two superimposed, rapidly alternating, surfaces with randomly arranged textures of the two colors under investigation. The experimental display and general conditions of presentation were identical to those described in Experiment 1.

Procedure

The subjects were asked to fixate the center of the screen, and their task was to adjust the luminance of the centrally displayed square of a given configuration until it matched the brightness of the general background. The experimental procedure was the same as that in Experiment 1.

Results

Mean results from Experiment 2 are given in Figures 3 and 4. Figure 3 shows the differences between the adjusted luminance of the test figure at the last trial and the background luminance, measuring the subjective equality in brightness of figure and ground, plotted as a function of the spacing between red inducing elements and their contrast. Subjective brightness cancellation was systematically expressed in increments (i.e., the luminance required for cancellation was higher than the background luminance). As explained earlier, we did not use red inducers that looked darker than the background. Preexperiments with some of the subjects suggested, however, that a reversal of the effect was not to be expected. The total amount of subjective figure–ground contrast decreased as the spacing between red inducers that looked brighter than the background increased. This effect was statistically significant [$F(2,8) = 53.78, p < .01$].

Figure 3 shows that the luminance added to the test square to cancel brightness enhancement was minimal or zero in configurations with colored inducers that were isoluminant with the background. Figure–ground differences as measured here became noticeable only when luminance contrast was added to the color contrast of the inducers. However, this effect of luminance contrast was not statistically significant.

Figure 4 shows mean results comparing adjusted figure–ground differences with achromatic and chromatic configurations as a function of the luminance contrast of the inducing elements, called figure–ground contrast here. The condition with isoluminant inducers and background was not included here. Although induced brightness, as measured in our experiments, systematically increased with figure–ground contrast in all the achromatic configurations, this was not the case with chromatic configurations. The global difference in effects between achromatic and chromatic configurations was statistically significant [$F(1,12) = 13.25, p < .01$].

GENERAL DISCUSSION

The results presented here suggest that the effects of brightness enhancement in illusory figures are governed by mechanisms that rely on interactions between luminance contrast and spatial information in the surrounding configuration. This conclusion is based on the decrease in the strength of *surface* brightness, as measured by the luminance increment needed to cancel the illusory percept, with increasing spatial separation of the inducing elements and decreasing figure–ground contrast. Similar effects of spatial separation have been reported previously by Shipley and Kellman (1992) and by Lesher and Mingolla (1993) in regard to the strength or clarity of illusory *contours*.

The perceptual filling in of surface brightness, which is a prerequisite for figure–ground segregation and the perceptual grouping of illusory figures (e.g., Grossberg & Mingolla, 1985), appears to discard local information relative to the sign of contrast. In fact, configurations with inducers of opposite contrast polarity were found to produce the strongest figure–ground effects here. This might indicate that, at some critical stage in the neural processing of brightness-based figure–ground percepts, a barrier mechanism is activated that blocks potentially conflicting information of direction, or polarity, of contrast. Such an interpretation is supported further by the asymmetry observed in the cancellation of both darker and lighter Kanizsa squares, which was unexpectedly reflected by increments.

Similar asymmetries have been observed before in various brightness enhancement phenomena by Beck (1966), Festinger et al. (1970), and Hamada (1985, 1987). The principal evidence in favor of a *polarity barrier* in our study is characterized by a remarkable consistency of luminance adjustments made by different subjects in the phenomenally ambiguous illusory figures with inducers of opposite contrast polarity. These adjustments are, again, reflected by systematic increments.

A comparison between studies investigating phenomena of apparent contrast or assimilation with different procedures is presented in Table 1. The table summarizes converging evidence from at least five different phenomena that illustrate that psychophysical judgments may go in an unexpected direction when subjects attempt to match, cancel, or rate the apparent brightness of a field induced by a surrounding configuration. Whether the phenomenon is described as assimilation or as contrast, it appears that unexpected decrements are produced when subjects are required to match a test field to a reference field that appears phenomenally *lighter* than the test field. Festinger et al. (1970) suggested that the direction of the psychophysical response (adjustment toward lighter or darker) in the matching task is not deter-

Table 1
Comparison of Studies Investigating Phenomena of Apparent Contrast or Assimilation With Different Procedures

Author	Configuration Method	Phenomenal Appearance of Reference Field	Direction of Subjective Rating or Test-Field Luminance Adjustment
Beck (1966)	Periodic grating	darker than background	rated “darker”
	Subjective rating	lighter than background	rated “darker”
Festinger et al. (1970)	Periodic grating	darker than background	test decrement
	Test-to-reference field matching	lighter than background	test decrement
Hamada (1985)	Craik O’Brien illusion	darker than background	test decrement
	Test-to-reference field matching	lighter than background	test decrement
Hamada (1987)	Ehrenstein illusion	darker than background	test decrement
	Test-to-reference field matching	lighter than background	test decrement
de Weert & Spillmann (1995)	Induced pincushion	darker than background	test decrement
	Test-to-reference field matching	lighter than background	test decrement
Dresp & Fischer (present study)	Kanizsa square	darker than background	reference increment
	Reference field cancellation	lighter than background	reference increment

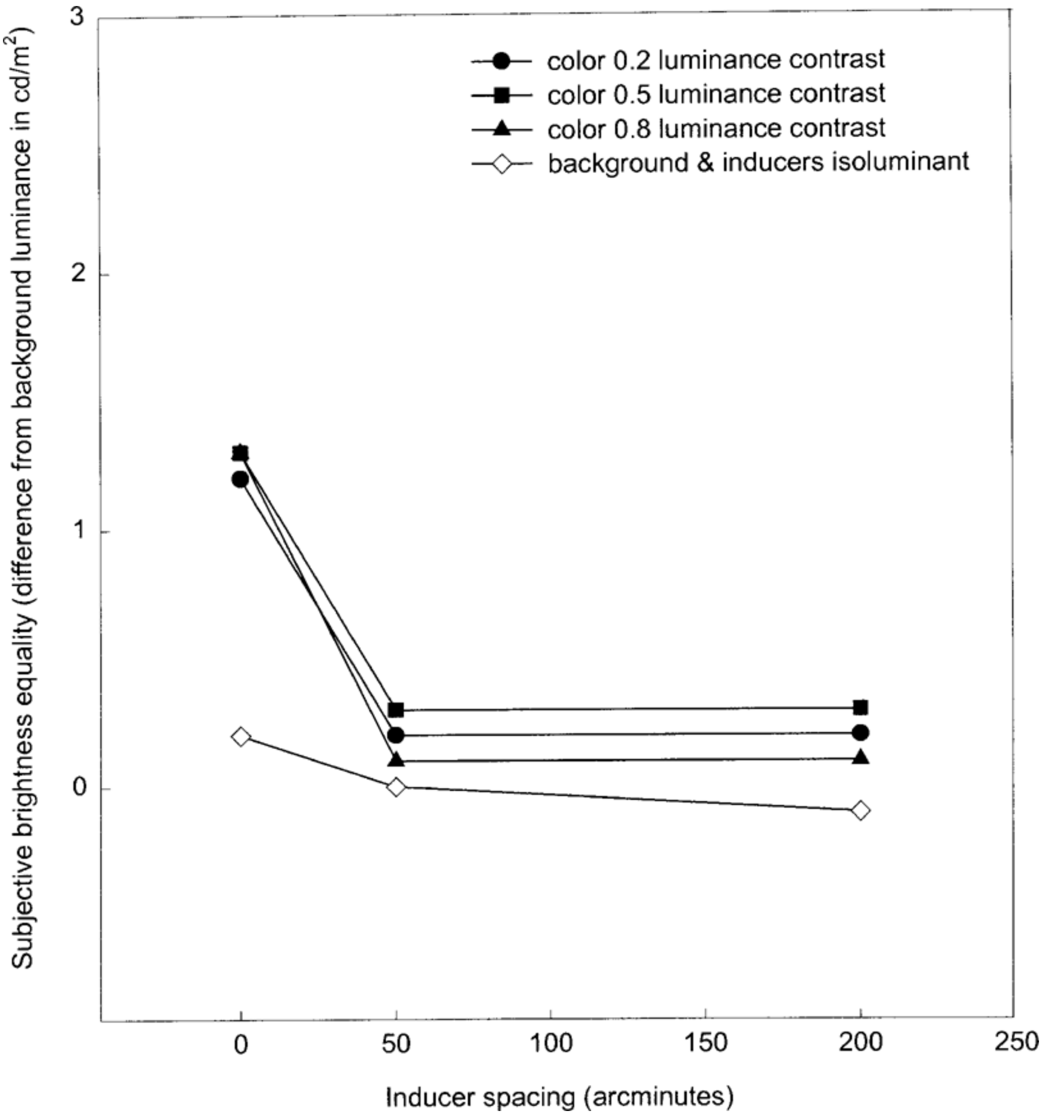

Figure 3. Luminance changes required to cancel brightness/darkness enhancement of the illusory square expressed in differences between the final luminance of the test figure (the illusory square) and the background luminance. The data are plotted as a function of the spacing between colored inducing elements and their contrast. As in Experiment 1, brightness/darkness cancellation was systematically expressed in increments. There was little or no effect (i.e., no perceptual filling in) when inducers and background were isoluminant.

mined by the phenomenal appearance, but rather by whether the field to be adjusted is the background or the figure. Some of the data reviewed in Table 1 are consistent with such a conclusion. For example, when the task consists of *test-to-reference field matching*, the test field generally corresponds to either a field within the background region, or to a separate stimulus (sometimes called *comparison field*) with background luminance. In this case, reference fields *lighter* than the test field always yield background decrements, whether the phenomenon is apparent contrast (e.g., Hamada's, 1985; Craik–O'Brien illusion, referred to in Table 1) or assimilation (e.g., de Weert & Spillmann, 1995, induced pincushion, referred to in Table 1).

Attempts to provide a theoretical account for psychophysically observed brightness or darkness asymmetries generally suggest two-stage processing models, with a first stage that is sensitive to local contrast and its sign, and a second stage in which contrast intensity only, not its sign, is preserved (e.g., Hamada, 1991; Shapley & Reid, 1985; Shevell et al., 1992). The extent to which such models can make general predictions regarding the direction of a psychophysical brightness/darkness match is another question. Shevell et al. tried to model the effect of surround brightness on local brightness matches quantitatively in haploscopic viewing, demonstrating empirically and mathematically that a surrounding surface influences a brightness match only when the area

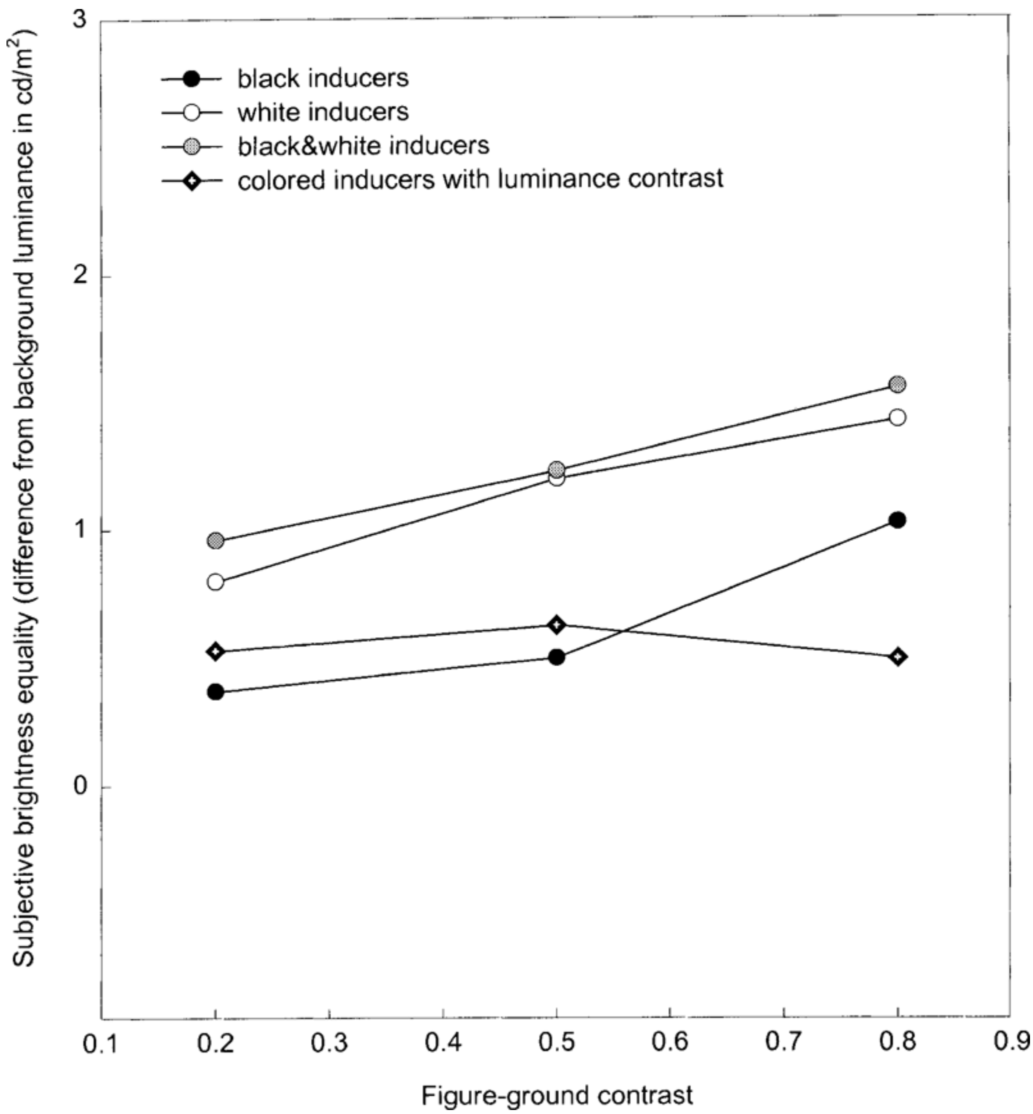

Figure 4. Luminance changes required to cancel brightness/darkness enhancement of the illusory square expressed in differences between the final luminance of the test figure (the illusory square) and the background luminance. Data are plotted for achromatic and chromatic configurations as a function of the contrast of the inducing elements. Here, this contrast is called *figure–ground contrast*. The condition with isoluminant inducers and background was not taken into account. Although effects systematically increased with figure–ground contrast in all the achromatic configurations (Experiment 1), this was not the case with the chromatic configurations (Experiment 2).

immediately surrounding one of two test fields differs from the area immediately surrounding the other test field. The consequence of such relative contrast differences in the surround configurations would be that the neural representations of the test areas at the fused binocular level become more strongly influenced by the global than by a strictly local luminance context. Shevell et al.'s model implies further that psychophysical brightness matches are more likely to be affected by variations in contrast, or gray levels, around the test field than by a unique contrast. Whether Shevell et al.'s predictions would account for findings other than their own remains to be seen. There is, however, little doubt that the mechanisms underlying brightness filling in of complex configurations constrain the perceptual system to eliminate local signs of contrast at some stage of processing, as suggested by Hamada's, Shapley and Reid's, and Shevell et al.'s experiments and models. The idea that disregarding contrast polarities in brightness effects represents a truly perceptual constraint rather than being the result of some postperceptual strategy factor is empirically supported by the data from our study, given the consistency of psychophysical responses as a function of inducer luminance on the one hand, and of spatial separation, a factor not tested in most of the earlier studies, on the other.

When colored elements are presented on a colored background, filling in is significantly weaker compared with the effects induced by achromatic elements on a gray background. Induction effects are totally absent when colored inducers and background are isoluminant. This observation is similar to those reported by de Weert (1984) regarding the formation of illusory contours, by de Weert and Spillmann (1995) regarding assimilation, and by Wachtler, Teufel, and Wehrhahn (1995) regarding the Craik–Cornsweet illusion, a particular case of apparent contrast. The absence of perceptual filling in with isoluminant color configurations of the Kanizsa type has also been reported in studies by Dresp and Wehrhahn (1996), which indicated that mechanisms of figure–ground segregation, or perceptual grouping, did not seem to respond well to isoluminance. Only when luminance contrast was added, was the brightness of the colored squares different than that of the background, and it was found to depend on the spatial separation of the colored inducers.

The effects found in our experiments generally suggest that the perceptual filling in of brightness is sensitive to luminance contrast and spatial configuration, but exhibits little or no sensitivity to contrast polarity and color. As proposed in the form vision model by Grossberg and Mingolla (1985), filling in always appears to result in the perceptual emergence of the most plausible solution for figure–ground organization (see also Pessoa, Thompson, & Noe, 1998, for a review on filling in phenomena). The visual system may use sign-invariant neural mechanisms to deal with potentially conflicting information of contrast polarity or color in complex visual stimuli. In such cases of conflict, sign-invariance would enable consistent brightness or darkness filling in leading to coherently structured percepts. We speculate that such filling in may involve the "colorblind" magnocellular (M) pathways of the visual system.

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