Perception, 1990, volume 19, pages 483–489

Apparent brightness enhancement in the Kanizsa square with and without illusory contour formation

Birgitta Dresp, Jean Lorenceau, Claude Bonnet
Laboratoire de Psychologie Expérimentale, Université Paris V, EPHE, EHESS, Associé au CNRS, 28 rue Serpente, 75006 Paris, France
Received 19 June 1989, in revised form 15 December 1989

Abstract. The perceived strength of darkness enhancement in the centre of surfaces surrounded or not surrounded by illusory contours was investigated as a function of proximity of the constituent elements of the display and their angular size. Magnitude estimation was used to measure the perception of the darkness phenomenon in white-on-grey stimuli. Darkness enhancement was perceived in both types of the stimuli used, but more strongly in the presence of illusory contours. In both cases, perceived darkness enhancement increased with increasing proximity of the constituent parts of the display and with their angular size. These results suggest that the occurrence of darkness (or brightness) enhancement phenomena in the centre of the displays is not directly related to illusory contour formation.

1 Introduction

The Kanizsa figure (Kanizsa 1955) is one example of a large range of figures that have been known to the psychological community since 1900 when Schumann wrote for the first time about 'Scheinkanten'. It gives rise to the perception of a 'whiter than white' (or 'blacker than black') square (figure 1) surrounded by a more or less sharp contour at parts of the figure where no local discontinuity of colour, texture or contrast is visible, and has been the subject of various investigations in the psychological and neurophysiological domains as well as in artificial intelligence approaches (see Petry and Meyer 1987, for a review).

In trying to find an explanation for the contour phenomenon in the Kanizsa figure, most of the authors have stressed causal links that may exist between illusory contour formation and brightness (or darkness) enhancement of the surface surrounded by contours (Brigner and Gallagher 1974; Frisby and Clatworthy 1975; Kanizsa 1979; Bradley and Mates 1985; Watanabe and Oyama 1988). On the other hand, few investigators have discussed the possible independence of surface brightness and illusory contour genesis (Jory and Day 1979; Day and Jory 1980; Ware 1981).

Examining various situations of brightness enhancement, one can find, in fact, cases that raise doubt about the existence of a direct causal relation between illusory contours and the surface phenomenon. If we consider, for example, the Ehrenstein figure or the Koffka cross (Ehrenstein 1941; Koffka 1935; see figure 2), we observe

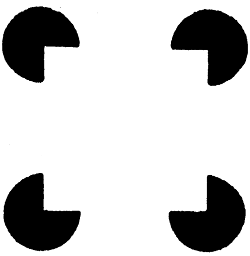

Figure 1. The Kanizsa square.

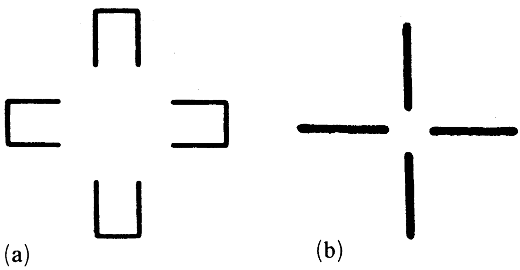

Figure 2. (a) The Ehrenstein figure; (b) the Koffka cros

strongly enhanced surface brightness in the absence of contour. The transition between the surface and the background appears to be rather progressive.

Interesting conclusions concerning brightness enhancement and illusory contour appearance have been drawn by Day and Jory (1980). Using the Koffka cross with an ill-defined region of enhanced brightness in the centre (just like the one described above), as well as variations of that figure obtained by adding different dot-configurations around the centre of the cross, they observed that the latter gave rise to the perception of shapes (diamond, square, or circle) with clearly defined illusory contours. This led the authors to assume that the formation of illusory contours may involve two stages. At the first stage, brightness enhancement is generated by local contrast, then a second step is necessary for illusory contours to occur. In fact, clearly defined illusory contours do not appear without regularly arranged elements which mark a boundary around the enhanced surface.

Our experiment provides further data which show that the coexistence of illusory contours and enhanced surface brightness does not necessarily indicate a direct causality between the two phenomena. The brightness (darkness in our experiment) enhancement exists in illusory-contour stimuli as well as in controls that do not give rise to contour formation. The results indicate that two highly interdependent factors have a strong influence on perceived surface darkness in the Kanizsa square as well as in the control figures: the proximity of the constitutive elements of the displays and their angular size. Using a magnitude estimation method (cf Bonnet 1986) different from the one we have been using in this experiment, Oyama and Watanabe (1988) produced results that show an influence of pacman proximity on perceived brightness enhancement in the Kanizsa square (the term 'pacmen' refers to the four elements at the corners of the Kanizsa figure).

The data reported here support Day and Jory's view concerning the genesis of illusory contours summarized above. The enhanced darkness perceived in the centre of the displays seems to be due in the first place to local contrast induced by the pacmen whether there is an illusory contour or not; this enhancement being stronger when the contours are present may suggest that they reinforce the brightness phenomenon by introducing a second type of process which is complementary to the local contrast mechanisms.

2 Method

2.1 *Subjects*

Twenty subjects ranging in age from 20 to 40 years served as observers. Most of them were students preparing for the 'Licence de Psychologie' at Paris V University.

2.2 *Materials*

The stimuli were presented binocularly on a high-resolution video monitor (Visionor Model M 51 CHR no. 1007, Lille, France). They were generated through a PC compatible computer (Olivetti M24) with the use of a special graphics adaptor (Galaxy SA-1019A, Evroz, Tel-Aviv) providing a display of 1024 pixels (horizontally) × 768 pixels (vertically) at 60 Hz frame rate (non-interlaced). The pixel size was 0.36 mm × 0.36 mm. Twelve of the stimuli were white-on-grey Kanizsa squares. Twelve other figures with pacmen turned upside-down served as controls (figure 3). Four inter-pacman distances were combined with three pacman sizes. The distances, d, were 20, 60, 100, and 140 pixels; pacman radii, r, were 10, 30, and 50 pixels. This combination led to distances between the centres of the displays and the closest white pixel that varied differently over the two figure conditions (see table 1 for the corresponding angular values). The luminance of the white pixels forming the pacmen was 280 cd m^{-2}, that of the grey pixels of the background 20 cd m^{-2}.

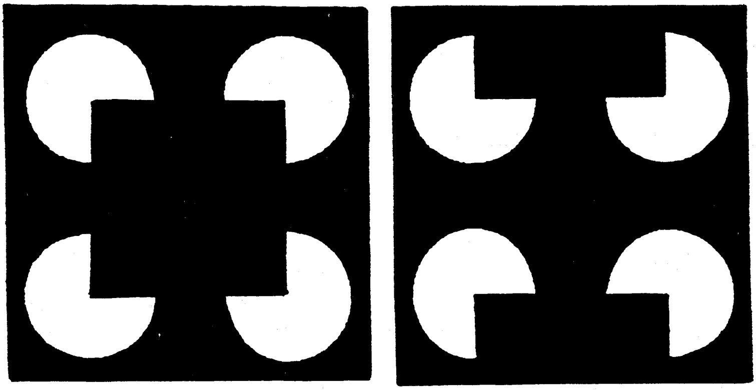

Figure 3. Stimuli used in the experiment.

Table 1. Angular distances between the fixation point and nearest white pixel as a function of inter-pacman distance, d, and radius, r, of the pacmen (all values given in deg).

r	d (Kanizsa squares)				d (controls)			
	0.54	1.61	2.69	3.76	0.54	1.61	2.69	3.76
0.27	1.52	3.04	4.56	6.09	0.98	2.50	4.03	5.55
0.81	3.04	4.56	6.09	7.61	1.43	2.95	4.47	5.99
1.34	4.56	6.09	7.61	9.13	1.87	3.40	4.92	6.44

2.3 *Procedure*

Presentation time of the figures was about 400 ms (25 frames) and the presentation order was randomized. The subject's head position was stabilized by means of a head-and-chin rest. The subject had to look at the centre of the screen where a white pixel indicated the fixation point during the presentation intervals which were held constant at 8 s. A 400 ms sound signal announced the stimulus that was flashed on the centre of the screen. The observers had to evaluate the apparent difference in darkness between the centre of the displays and the background. They were asked to draw a line on a response sheet where two directions were marked: one ranging from 0 to +, the other one from 0 to −. The 0 to + scale had to be used when the subject perceived the centre of the display darker than the background, the 0 to − scale when he judged it to be lighter; 0 had to be marked when no difference was perceived between the centre of the figure and the background. The length of the line drawn by the observers was to be proportional to the perceived brightness difference. For every stimulus a new response sheet was used. Each of the twenty-four displays was presented twice and only the second estimate was taken into account for data analysis. The lines drawn by the observers were measured and the corresponding millimetre values served as indices of perceived brightness differences.

3 Results

None of the subjects used the 0 to − part of the response scale. The responses ranged from 0 to 121 mm. Pacman proximity had a statistically significant effect on apparent darkness enhancement in the Kanizsa squares ($F_{3,57} = 61.968$, $p < 0.01$) as well as in the control displays ($F_{3,57} = 29.289$, $p < 0.01$). The data show an increase of perceived brightness differences with increasing pacman proximity. Furthermore, perceived darkness enhancement increases with increasing angular size of the pacmen.

This effect is statistically significant in the Kanizsa squares ($F_{2,38} = 97.937$, $p < 0.01$) as well as in the control figures ($F_{2,38} = 15.566$, $p < 0.01$). Interactions between proximity and angular size of the pacmen were significant in the Kanizsa squares ($F_{6,114} = 9.118$, $p < 0.01$).

The linear regressions between perceived brightness difference and inter-pacman distance were calculated for each subject. Slopes and intercepts were submitted to analyses of variance. A posteriori comparisons show that the slopes decrease between the 10 pixel radius and the 30 pixel radius in the Kanizsa squares ($F_{1,19} = 9.76$, $p < 0.01$); no difference is observed between the 30 and 50 pixel radii. In the control displays, the slopes do not differ over pacman size conditions. They are significantly higher in the Kanizsa squares for the 10 pixel radius ($F_{1,19} = 29.29$, $p < 0.01$); no difference between figure conditions is observed between the 30 and 50 pixel radii. These results suggest that illusory contours may play more of a role in the brightness phenomenon for the small pacman sizes than for the bigger ones.

The intercept values increase with increasing pacman size in both figure conditions ($F_{2,38} = 10.631$, $p < 0.01$ in the Kanizsa squares and $F_{2,38} = 11.992$, $p < 0.01$ in the controls). They are significantly higher in the Kanizsa squares ($F_{1,19} = 64.02$, $p < 0.01$). In table 2 mean slope and intercept values are given as a function of figure type and pacman size.

Illusory contours seem to have an effect on the brightness phenomenon. The results show that the perceived darkness enhancement is stronger in the Kanizsa squares than in the control figures ($F_{1,19} = 53.421$, $p < 0.01$). The differences between illusory contour and control conditions increase with increasing pacman proximity and size. Both interactions are statistically significant ($F_{3,57} = 14.224$, $p < 0.01$, and $F_{2,38} = 45.319$, $p < 0.01$, respectively). The highest differences between the two figure conditions are observed with a pacman radius of 10 pixels. Figure 4 shows perceived darkness enhancement as a function of the distance between fixation point and the closest white pixel, pacman size, and figure type.

Table 2. Mean intercept, l, and slope, θ, of the linear functions of perceived brightness difference decrease as a function of figure type and pacman size.

Pacman size	Kanizsa squares		Controls	
	l/mm	θ	l/mm	θ
0.27	62.261	−10.171	18.509	−2.912
0.81	81.187	−5.586	31.747	−4.207
1.34	93.877	−4.029	44.060	−4.374

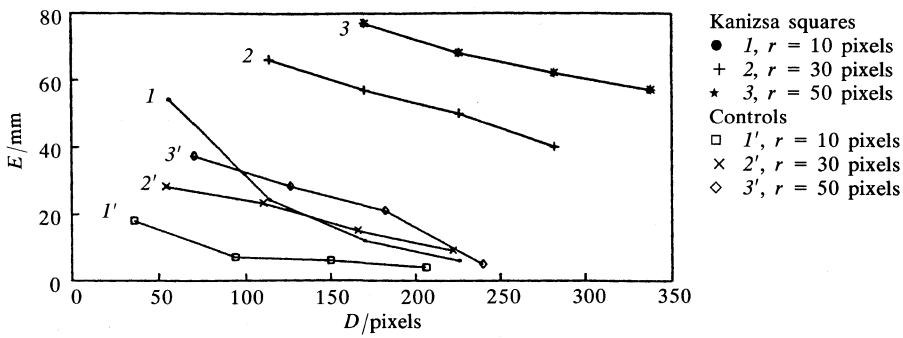

Figure 4. Perceived darkness enhancement, E, as a function of distance between fixation point and closest white pixel, D, pacman radius, r, and figure type.

For further analysis, variation coefficients were calculated. Figure 5 shows the variation coefficients for the two types of displays as a function of inter-pacman distance, *d*, and pacman diameter, *r*. For pacmen of 30 and 50 pixel radii in the Kanizsa square, the variation coefficient is stable over proximity conditions. For pacmen of 10 pixel radius it increased with increasing pacman separation. In the control figures, a linear increase with increasing pacman separation is observed for radii of 30 and 50 pixels. The smallest pacman size (10 pixel radius) shows the strongest increase. Generally, for a given pacman size, variation coefficients are higher in the control condition. This result suggests that darkness enhancement estimates generally seem to be more reliable in the Kanizsa figures which is probably due to the type of response scale used in our experiment. Some subjects chose the 0 category for response in the control conditions; on the contrary, 0 was never used for the Kanizsa squares. These differences observed in the response patterns can explain the differences in variation coefficients over the two figure conditions.

4 Discussion

Our data show in the first place that perceived darkness enhancement increases with increasing proximity and size of the pacmen. The fact that this result is statistically significant in the Kanizsa squares as well as in the control figures leads to the conclusion that the presence of illusory contours in Kanizsa displays alone cannot explain the brightness phenomenon observed in the centre of the surface of the figure. The four pacmen of the displays, whether they form a delineated square or not, activate local contrast mechanisms. The observed contrast effect may be similar to those described with luminance steps and generally referred to as Mach band phenomena (see Fiorentini 1972, for a review). One may suppose that the amount of local contrast increases with increasing pacman size. The influence of total amount of contrast on lateral inhibition spread has been recently discussed by Grossberg and Mingolla (1985). Their theory predicts increasing lateral inhibition spread with increasing amount of local contrast.

Further, our results show a strong difference in perceived darkness enhancement over the two figure conditions. Apparent brightness differences being considerably stronger in illusory contour displays, one may suppose contour formation to have a reinforcing influence on the brightness phenomenon.

Referring to Grossberg and Mingolla (1985) or to Zucker and Davis (1988), contour genesis is explained by line detector activation in the cortex. These line detectors are orientation-selective and, according to findings reported by von der Heydt et al (1984) and Redies et al (1986) with single-cell recordings in area 18

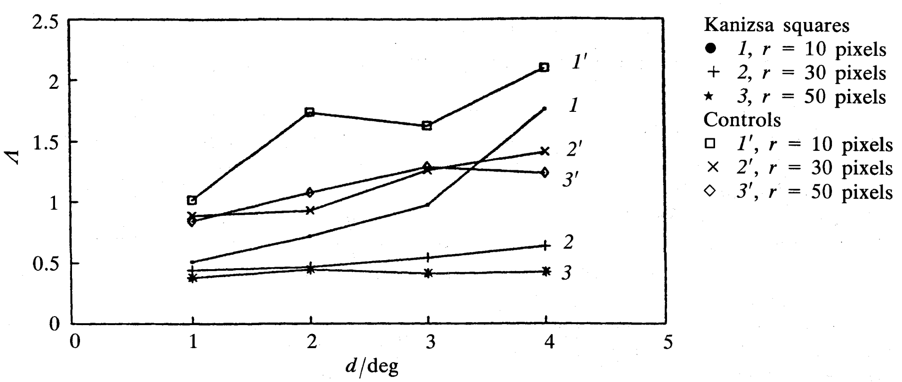

Figure 5. Variation coefficients, Λ, as a function of inter-pacman distance, *d*, pacman radius, *r*, and figure type.

of the prestriate cortex of the monkey and area 17 of the cat, they respond to continuous lines as well as to collinear line ends. The collinear borders of the pacmen in the Kanizsa square lead to the formation of a closed surface. This closure phenomenon seems to have a strong influence on perceived brightness/darkness enhancement in the centre of the surface and has already been considered as a most important factor by Kanizsa in his first paper on illusory contours and surfaces (1955). Day and Jory (1980) suggested that the boundary-marking effect of collinearly arranged elements around an enhanced surface may lead to an even spread of brightness filling in a precise and clearly defined surface. The fact that brightness enhancement is perceived more strongly in that type of surface may be due to a higher amount of structural information contained in the stimulus.

Furthermore, it seems reasonable to assume that the convolution product of line detector responses diminishes with decreasing pacman proximity. This has been stated, for example, by Zucker and Davis (1988) concerning size/spacing constraint analysis for dot grouping. Dumais and Bradley (1976) as well as Watanabe and Oyama (1988) have reported decreasing illusory contour strength with increasing distance between pacmen. With weakening contour strength the closure phenomenon weakens and this could explain the significant decrease in differences between results for the Kanizsa square and results obtained with the control figures when pacman spacing increases.

Analyses of linear regression slopes suggest that the contribution of illusory contours to the brightness phenomenon may be particularly important when pacman sizes are small.

Summarizing the data, illusory contours are not directly related to apparent surface brightness/darkness enhancement in the Kanizsa squares. The brightness phenomenon appears and varies systematically in control displays where no contours occur as well as in Kanizsa squares. This result is consistent with earlier findings of Day and Jory (1980) obtained with the Koffka cross (see introduction). Proximity and size of the constituent elements of the stimuli have a highly significant influence on perceived brightness enhancement in the centre of the figures. Illusory contour formation can be considered as a reinforcing factor introducing effects which appear to be complementary to the local contrast phenomena generated by the white (or, usually, black) elements of the displays.

References

Bonnet C, 1986 "Manuel Pratique de Psychophysique" (Paris, Armand Colin)

Bradley D R, Mates S M, 1985 "Perceptual organization and apparent brightness in subjective contour figures" *Perception* **13** 155 - 164

Brigner W L, Gallagher M B, 1974 "Subjective contour: Apparent depth or simultaneous brightness contrast?" *Perception and Motor Skills* **38** 1047 - 1053

Day R H, Jory M K, 1980 "A note on a second stage in the formation of illusory contours" *Perception & Psychophysics* **27** 89 - 91

Dumais S T, Bradley D R, 1976 "The effects of illumination level and retinal size on the apparent strength of subjective contours" *Perception & Psychophysics* **19** 339 - 345

Ehrenstein W, 1941 "Über Abwandlungen der L. Hermannschen Helligkeitserscheinung" *Zeitschrift für Psychologie* **150** 83 - 91

Fiorentini A, 1972 "Mach band phenomena" in *Handbook of Sensory Physiology: Visual Psychophysics* Eds D Jameson, L M Hurvich (New York: Springer) pp 188 - 201

Frisby J P, Clatworthy J L, 1975 "Illusory contours: Curious cases of simultaneous brightness contrast?" *Perception* **4** 349 - 357

Grossberg S, Mingolla E, 1985 "Neural dynamics of form perception: Boundary completion, illusory figures and neon color spreading" *Psychological Review* **92** 173 - 211

Heydt R von der, Peterhans E, Baumgartner G, 1984 "Illusory contours and cortical neuron responses" *Science* **224** 1260 - 1261

Jory M K, Day R H, 1979 "The relationship between brightness contrast and illusory contours" *Perception* **8** 3 - 9

Kanizsa G, 1955 "Margini quasi-percettivi in campi con stimolazione omogenea" *Rivista di Psicologia* **49** 7 - 30

Koffka K, 1935 *Principles of Gestalt Psychology* (New York: Harcourt, Brace)

Petry S, Meyer G E, 1987 *The Perception of Illusory Contours* (New York: Springer)

Redies C, Crook J M, Creutzfeld O D, 1986 "Neuronal responses to borders with and without luminance gradients in cat's visual cortex and dorsal lateral geniculate nucleus" *Experimental Brain Research* **61** 469 - 481

Schumann F, 1900 "Beiträge zur Analyse der Gesichtwahrnehmungen: Einige Beobachtungen über die Zusammenfassung von Gesichtseindrücken zu Einheiten" *Zeitschrift für Psychologie und Physiologie der Sinnesorgane* **23** 1 - 32

Ware C, 1981 "Subjective contours independent of brightness contrast" *Perception & Psychophysics* **29** 500 - 504

Watanabe T, Oyama T, 1988 "Are illusory contours a cause or a consequence of apparent differences in brightness and depth in the Kanizsa square?" *Perception* **17** 513 - 521

Zucker S W, Davis S, 1988 "Points and endpoints: a size/spacing constraint for dot grouping" *Perception* **17** 229 - 247