

Brightness alteration with interweaving contours

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Abstract. Chromatic induction is observed whenever the perceived colour of a target surface shifts towards the hue of a neighbouring surface. Some vivid manifestations may be seen in a white background where thin coloured lines have been drawn (assimilation) or when lines of different colours are collinear (neon effect) or adjacent (watercolour) to each other. This study examines a particular colour induction that manifests in concomitance with an opposite effect of colour saturation (or anti-spread). The two phenomena can be observed when a repetitive pattern is drawn in which outline thin contours intercept wider contours or surfaces, colour spreading appear to fill the surface occupied by surfaces or thick lines whereas the background traversed by thin lines is seen as brighter or filled of a saturated white. These phenomena were first observed by Bozzi (1975) and Kanizsa (1979) in figural conditions that did not allow them to document their conjunction. Here we illustrate various manifestations of this twofold phenomenon and compare its effects with the known effects of brightness and colour induction. Some conjectures on the nature of these effects are discussed.

Keywords: colour spreading, neon effect, filling out, colour saturation, luminance contrast enhancement, brightness illusions.

1 Introduction

The perceived colour and brightness of a surface are affected by the colour and brightness of an adjacent surface. The phenomenon is called “contrast” when the variations enhance the differences between the two neighbouring surfaces, whereas the term “assimilation” is used to indicate a stronger homogeneity. Simultaneous brightness contrast is the most common phenomenon belonging to the first category and is observed when similar targets are compared: one surrounded by a darker surface and the other by a brighter one. The first appears to be brighter than the second. Assimilation effects are visible when a white surface traversed by thin lines takes on the colouring (weaker) of these lines. Similar but stronger effects appear as “colour spreading” in some well-studied phenomena: “neon effect” (Van Tuijl, 1975; Varin, 1971), “watercolour effect,” (Pinna, Brelstaff, & Spillmann, 2001), and “flank transparency” (Wollschläger, Rodriguez, & Hoffmann, 2002).

This study will examine a particular manifestation of colour induction observed whenever the border of a surface is intercepted by an outline contour. The distinguishing feature of the phenomenon is that it is manifested with two opposite effects: grey or colour spreading in a region and brightness enhancement in the neighbouring areas. Figures 1–3 show demonstrations of this phenomenon in different figural organisations.

In Figure 1, purple rectangles are arranged perpendicular to an invisible twisting line. The longer sides are bordered by an orange outline. The background has an even white colour; however, an observer asked to compare the closed surfaces bordered by the ends of the rectangles (hereinafter “coves”) is very likely to answer that the central cove has a different brightness than the two lateral ones. The cause of the illusory difference in brightness can be found in the only figural difference between the two areas, i.e. the condition at the borders. The two side “coves” are bordered by outline ellipsoids partially overlapping the ends of the rectangles. These ellipsoids are not found in the central cove whose contour is formed by the shorter sides of the rectangles.

The important role these linear contours play in brightening a background region is confirmed by Figure 2, which shows outline ellipsoids overlapping the central region of horizontal wide bands. The interspaces traversed by the arcs appear brighter than the other regions of the background even the distant ones.

A third series of figures ([Figure 3](#)) are further confirmation of the idea that two opposite phenomena are involved in creating the illusions analysed here. In these figures, a series of outline ellipsoids are arranged in columns. The contour of each ellipsoid is divided into two halves of different thickness; the thin half is always black whereas the other half may be drawn in different colours. Each column is formed with the ellipsoids oriented in the same way, i.e. with the thin half on the same side as an imaginary vertical line. Each column is paired with a mirror image.

The background is divided into alternating bright and darker vertical regions corresponding, respectively, to the space traversed by the thin and thick arcs. The latter regions appear to be filled with a very desaturated shade of the same colour as the arcs.

The three series of figures document with different strengths the appearance of two concomitant effects: the darkening of the background (or the spreading of a desaturated colour) and the brightness enhancement (or perception of “whiteness”). The supplementary materials ([1](#) and [2](#)) further demonstrate the effects.

To verify whether this description of brightness/colour alteration is shared by more than one observer, I conducted a simple study aimed at measuring the depth of consensus on the appearance of the phenomena and the strength of their effects.

2 Empirical observations

Thirteen unpaid observers agreed to participate in the study. They were recruited among student and professors and were tested individually in a task that required them to examine different versions of [Figures 1–3](#) and report the differences they observed in the background’s luminance and hue. The tests were divided into three short sessions.

Session 1. Ten different versions of [Figure 1](#) were produced by varying the combination of the fringe-surface colours. Five pairs of colours (purple–orange, green–brown, orange–dark grey, green–purple, green–orange) were chosen to illustrate just as many combinations. A mirror image of each combination was reproduced in the surface-fringe colours. Four other stimuli reproduced some patterns from the previous group with the fringe erased. The orientation of the figure—identical to [Figure 1](#) or mirror-like—was randomly chosen, as was the location of the ellipsoids—inside the central cove or inside the two lateral ones. Some examples of this set of 14 stimuli are illustrated in supplementary material 1.

The figures appeared one at a time at the centre of a CRT screen with the visual angle subtending 17.06° horizontally and 13.6° vertically. Each figure was shown for 3 s, during which observers had to give their response. Before the beginning of the session, one of the 14 figures was displayed and the experimenter read the following instructions:

Please observe this configuration and compare the shades and colours of the surfaces embedded within the series of rectangles where they seem to form a “cove.” Tell me if you perceive any differences and, if so, indicate the region that appears to be brighter. Two arrows labelled “A” and “B”

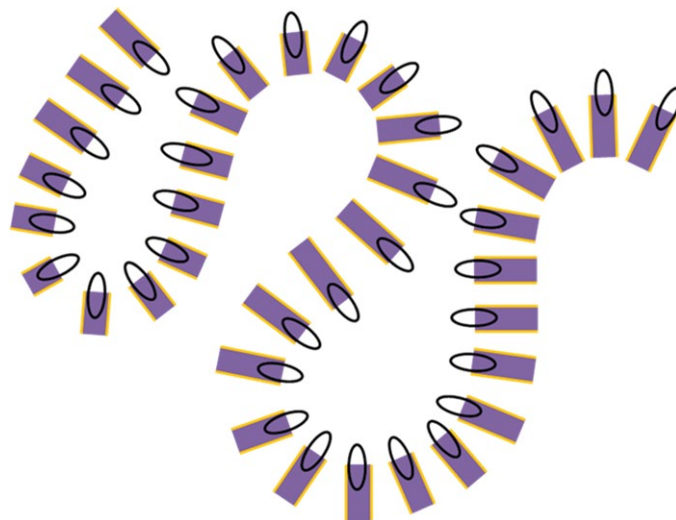


Figure 1. The rectangles are drawn on a homogeneous white background. The difference in brightness between the two lateral “coves” and the central one is illusory.

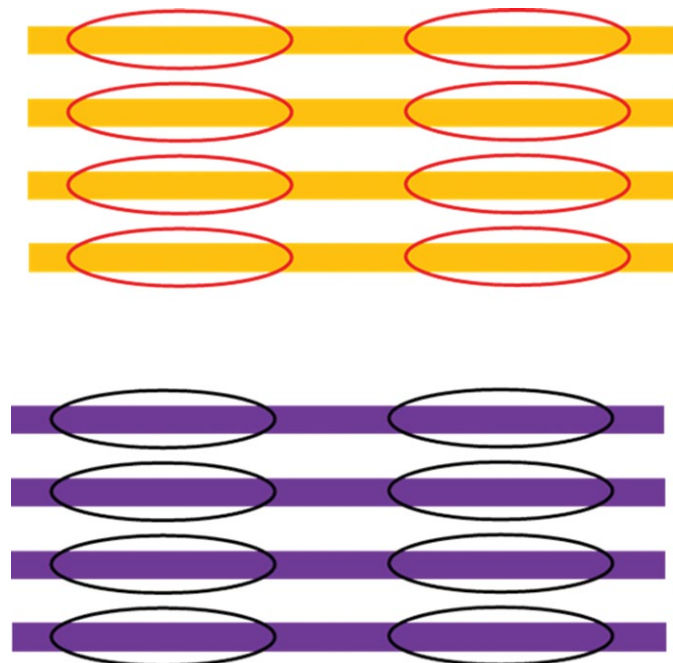


Figure 2. Coloured bars intercepted by outline ellipsoids. The homogeneous white background appears to change brightness, white in the region traversed by the ellipsoids, and of a desaturated colour in the adjacent regions.

point to two different covers, please say the letter that is at the beginning of the arrows pointing to the brighter region.

Session 2 followed. Observers were shown different versions of [Figure 2](#) where the bars were red, blue, green, or purple. They were intercepted by black outline ellipsoids in the middle or in one of the lateral regions. A total of 10 figures were obtained. Another four figures were drawn by reproducing some of the previous patterns with fringes bars. A stimulus subtended a horizontal visual angle of 13.5° and a vertical angle of 6.3°. Observers were asked to check whether the background appeared in the same even shade and colour. In this latter case, they had to specify the differences—in terms of brightness and colour—they noticed.

Session 3. Observers examined different versions of [Figure 3](#), each with a different colour for the thick arcs: black, blue, brown, purple, orange, and green. A stimulus subtended a horizontal visual angle of 15.3° and a vertical angle of 9.14°. They were asked to compare the brightness and colour of the vertical regions of the background that was traversed respectively by the thicker and thinner arcs. They were then asked whether they saw any differences and, if so, to report the colours they perceived.

In a final session, observers were asked to perform a task with two different reproductions of [Figure 3](#). The results of this task will be reported in Section 4.1.3 relating to the “neon effect.”

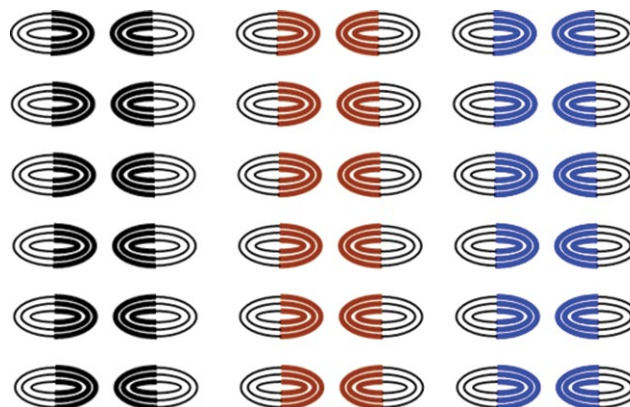


Figure 3. The columns of concentric ellipsoids are drawn on a homogeneous white background. The regions traversed by the thick arcs appear to be filled with a diffused greyness, brownish colour, desaturated bluish.

2.1 Results

Session 1 (Figure 1). Eleven observers demonstrated wide consensus in their estimations. A difference in brightness was reported in 92.2% of the cases. A full agreement was registered in indicating the region surrounded by ellipsoids as the brighter one. The remaining judgements (of “equal or uniform brightness”) did not focus on a set of stimuli that was homogeneous enough to identify a variable that may differentiate the responses.

Of the remaining two observers, all the estimations of the first observer were contrary to the directions given by the sample of 11 people. The second observer did not report any brightness alterations, except in two cases.

Session 2 (Figure 2). Twelve observers out of the 13 had the impression that the brightness of the background was not homogeneous. This occurred in 74.4% of the images shown to observers and in all these cases, the background intercepted by the ellipsoids appeared brighter. Four observers had the impression that this portion of the background was the whitest within the whole figural context.

Session 3 (Figure 3). Twelve of the 13 observers agreed that the space traversed by the thin arcs was brighter or “white” and that the adjoining space traversed by thick arcs was darker, or “greyish,” “bluish,” “brownish,” “purplish,” “greenish,” and “dirty orange.” One observer reported evident differences in brightness, but no impression of colour spread in the background.

The reports of the observers in the first two sessions mainly concentrated on the effects of brightness enhancement in the area of the background traversed by the outline ellipsoids. The consensus recorded can be interpreted as a demonstration of the generality and strength of the phenomenon. The results of the third session confirm the brightness-enhancing phenomenon, but show that it is associated with a spreading of colour. Nevertheless, this colour induction is not limited to the figural context of the narrow bars, since it can also be viewed on large surfaces (supplementary material 2).

Another important datum comes from the frequency of the impressions of “white” or “whiteness” elicited within the spaces traversed by thin arcs. This impression persists even when compared with the remote regions of the background. This may be interpreted not only as the inhibition of colour spreading but the appearance of an additional property that renders a portion of the background “white” instead of brighter than the other regions.

3 The antecedents

Bozzi (1975) and Kanizsa (1979) first observed brightness alterations similar to the ones illustrated in Figures 1–3 but in figural conditions that could not show the combined action of colour induction and spreading inhibition. Figure 4(a) reproduces a pattern used by Kanizsa (1979, pp. 168–9) to illustrate a case of achromatic induction.

The background is uniform white but the region between the grey half-ellipses appears to be filled with a diffused greyness. Kanizsa puts forward two possible hypotheses. According to the first hypothesis, the brightness alteration is the manifestation of an “assimilation effect.” This hypothesis, he argues, is ruled out by Figure 4(b) whereby the brightness alterations are not perceived despite the presence of a more extensive grey surface intercepted by the same black arcs shown in Figure 4(a).

Another hypothesis is suggested by the similarity of Figure 4(a) to Figure 4(c), a classic pattern generating an impression of perceptual transparency. Here a translucent film seems to intercept the central part of the two columns of ellipsoids which appear filtered by a brighter grey shade than the outer halves. Note that the grey halves in Figures 4(a) and (c) are identical to each other. The difference is that in Figure 4(a) the other halves of the ovals are made up of black perimeters, while in Figure 4(c), they are made up of filled ovals. The main luminance and figural conditions remain unaltered so that we expect a vivid impression of phenomenal transparency in both the figures. What we perceive in the central portions of Figures 4(a) and (c) confirms this prediction.

Bozzi (1975) analysed the brightness of illusions that appear when collinear outlines of different thicknesses join together at one end. In Figure 5, vertical outline rectangles are intercepted by a tilted rectangular frame. The outline contours continue inside the frame at a reduced width. Bozzi reports that observers describe this region as having a “milky white surface” that is whiter than the surround and with a “clear transparent property.” A second pattern drawn with the width ratios of the outline inverted, i.e. with the inner contours thicker than the outer ones, did not give particular impressions. Observers did not mention brightness alterations, but only an impression of “enlargement” on a few occasions.

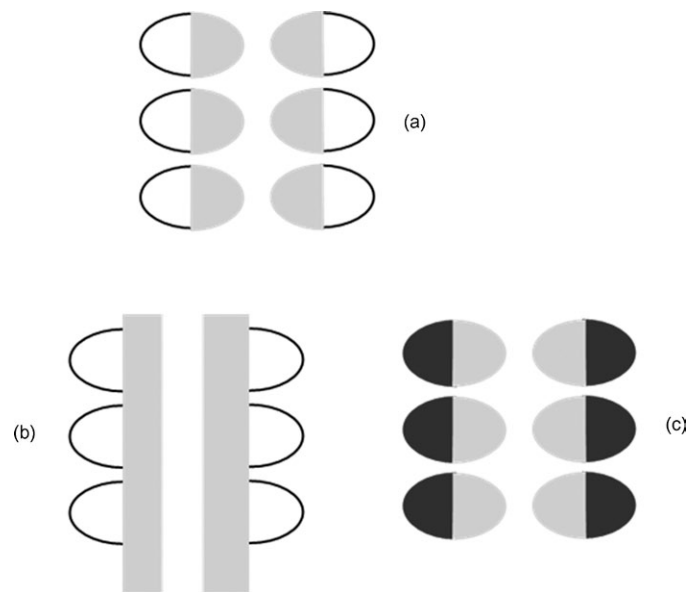


Figure 4. (a) A demonstration of Kanizsa (1979). The arcs and the half ellipsoids are drawn on a homogeneous background but they appear to have a diffuse greyness in the central space. (b) The same arcs as in (a) adjacent to vertical bars of the same grey shade of the half ellipsoids as in (a) (from Kanizsa, 1979; reprinted by permission). (c) The half ellipsoids in (a) with mirror-like shapes of a darker grey shade: the classic pattern that elicits the impression of transparency in the central region.

Even though their figural organisations are different, the two patterns in Figures 4 and 5 have a few common crucial features. Both contain thin outlines that intercept a wider figural unit, a grey surface in Kanizsa's figure, a thicker line in Bozzi's figure. The contact points are aligned along a straight visible or invisible line that phenomenally emerges as the border of a translucent layer. The observations of the two studies diverge in relation to the location of the transparent layer: in Kanizsa's patterns they are on top of the surfaces intercepted by outline arcs, while in Bozzi's figure they are located where the thin lines are drawn. Both researchers did not report particular effects or brightness alterations at the opposite sides of the transparent layer.

Wollschläger et al. (2002) provided an important integration to Bozzi's observations, demonstrating that a variation to Figure 5, series of parallel lines with a central bulging segment, gives the impression that the space occupied by these thicker units is darker than the bordering spaces. The authors did not report a complementary effect of brightness enhancement in the lateral region traversed by thinner lines. The failure to observe the two concomitant opposite effects—"whiteness" and colour spreading—is due to the simplicity of the configurations which highlight one effect, but let the opposite one blend into the background. Only a "repetitive pattern" such as those drawn in Figures 1–3 can highlight the alternation of the dark and light regions of the background.

4 Are brightness alterations parasite effects of illusory contours?

The illustrations analysed up to now have the conditions necessary for the formation of illusory contours, except for Figure 2. Figures 1, 4(a) and (c) have aligned straight margins that can extend

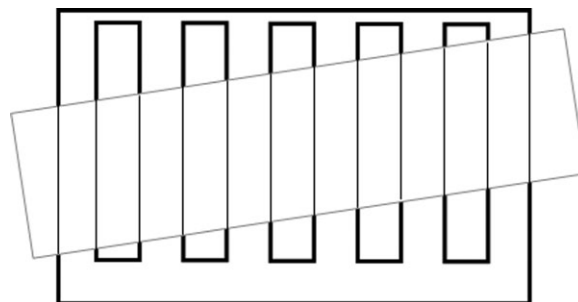


Figure 5. One of the figures drawn by Bozzi (1975) to demonstrate the rising percept of transparency (in the central oblique rectangle) with a variation in the thickness of the lines.

themselves and that form the illusory contours. In [Figures 3](#) and [5](#), these subjective contours run perpendicular to the aligned ends of the lines and arcs (end-line illusory contours). The direction of the brightness alteration observed in these figures is the same as the one seen in the classic patterns that generate illusory contours and the modal/amodal completion of the figures. In fact, greyness (or colour) spreads from the part of the contour where there are darker surfaces, while greater whiteness is perceived on the opposite side. Consequently, we are led to hypothesise that the illusion of brightness in [Figures 1–3](#) and also in [Figures 4\(a\)](#) and [5](#) is nothing but an enhancement in brightness contrast that normally occurs across an illusory edge.

This hypothesis is supported by the following illustrations that have been drawn by an anonymous reviewer who observed a vivid enhancement of two well-known phenomena—brightness enhancement and greyness diffusion—at the opposite sides of illusory contours (Kanizsa, 1979) in points where they are intercepted by outline ellipsoids. In [Figure 6\(a\)](#), the classical “Kanizsa square” phenomenon is illustrated: the space embedded within the four pacmen (inducers) appears to be surrounded by a contour separating a brighter inner surface from a darker surround. [Figure 6\(b\)](#) illustrates the opposite effect, i.e. the darkening at the side of the illusory contour occupied by the inducers (circles or portions of grey circles). [Figures 6\(c\)](#) and [\(d\)](#) reproduce [Figures 6\(a\)](#) and [\(b\)](#) with small outline ellipsoids intercepting the edges that join to form an illusory contour. It should be noted that the brightness alterations become more vivid than the previous configurations. The modally completed square ([Figure 6c](#)) is perceived as whiter than the corresponding square in [Figure 6\(a\)](#). The surface contoured by the ellipsoids appears to be filled with a diffused greyness that is darker than the corresponding surface in [Figure 6\(b\)](#).

[Figures 6\(a–d\)](#) lead to conclude that brightness and darkness induction are enhanced by the presence of outline figures across the edges but the primary source of brightness alteration comes from the

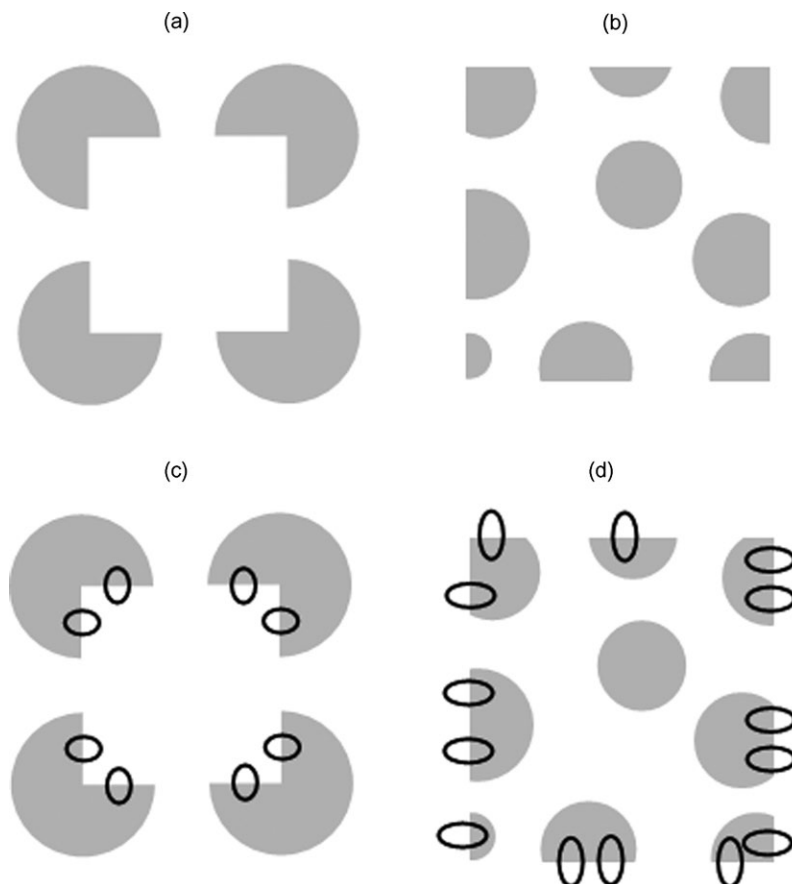


Figure 6. (a) The classical “Kanizsa square”: the illusory impression that a square brighter than the background is superimposed on four circles. (b) A group of grey circles appearing through a square frame that has the same background luminance. The white background seems to be filled with a weak greyness. (c) The same as (a) with the small ellipsoids intercepting the inner right angles. (d) The same as (b) with the outline ellipsoids intercepting the edge of the circle frame.

phenomena that generate the illusory contours. Nevertheless, further exploration casts doubts on the validity of the conclusion. In the following demonstrations, the condition of the appearance of illusory contours is not met. This nonetheless, the sides of the misaligned edges traversed by outline contours appear to brighten.

[Figure 7\(a\)](#) is made up of irregular polygons arranged in columns and drawn on a homogeneous white background. The conditions for the formation of illusory contours do not exist; however, when the ellipsoids appear to intercept the edges, a clear brightness alteration appears. The background has a white saturated tint when crossed by an outline and a diffused greyness at the opposite sides. The same brightness alterations perceived in [Figures 1](#) and [3](#) are observed, where the ends of the arcs are in contact with the edges forming an illusory contour.

The six pacmen in [Figure 7\(c\)](#) are oriented so that the extensions of the right sides (mouths) cannot merge and generate contour completion. Despite the absence of an illusory contour a vivid difference in brightness can be noted between the space contoured by the pacmen and the outer surround. The former appears to be filled with greyness, whereas a saturated white colour seems to spread from the concave corners (mouths) of the pacmen. The illustrations in [Figure 7](#) prove that the brightness/darkness inductions explored here do not require the formation of an illusory contour in order to appear. They become stronger or more vivid if observed at the opposite sides of these contours because their effect sums to the contrast enhancement effects generated by the formation of a subjective contour.

What then is the source and nature of these illusory phenomena? A brief review of the research on colour induction may help to answer this question. The following two paragraphs are a summary of the best known phenomena of colour and brightness induction.

4.1 Colour spreading phenomena

A spreading of colour from a surface to the surround has been observed in several conditions.

4.1.1 Assimilation

This phenomenon occurs when a grey surface looks darker (lighter) when crossed by black (white) stripes. Helson and Joy ([1962](#)) found that the transition from assimilation to contrast occurred with an increase in the stripe width, which gave observers the impression that the grey surface was darker when combined with the white bars. Walker ([1978](#)) measured the critical stripe width of a visual angle of 8 arcmin for the transition from assimilation to contrast. In a study that required observers to rate the colour hue and saturation of a target surface intercepted by parallel bars, Smith, Jin, and Pokorny ([1998](#), [2001](#)) demonstrated that assimilation occurs when the frequency of the grating line is higher than 4 cycles per degree (cpd). This measure is in accordance with Walker's calculation. On the basis of these results, we should only expect contrast effects in the gratings of [Figures 1](#) and [2](#) where the frequencies are approximately 0.76 and 0.97 cpd, respectively. Nevertheless, it is hard to make any predictions in this sector because the observations led to conflicting data. Ware and Cowan ([1982](#)) used the grating of an unequal duty cycle and registered only contrast effects. A series of assimilations are also observed when contrast is predicted (Bindman & Chubb, [2004](#); De Valois & De Valois, [1988](#); De Weert & Spillmann, [1995](#)). In light of these findings, we cannot predict whether contrast or assimilation phenomena will be visible in the background of [Figures 1–3](#).

4.1.2 Fringe-induced spread

If the bar gratings are contoured by a coloured line, the white interspaces appear to be filled with the same veiled, de-saturated colour. This illusion was observed by Broerse, Vladusich, and O'Shea ([1999](#)), who provided the following description: "When viewed from about three times picture height, some gratings should appear to be suffused with desaturated red, green, blue or yellow colours" (p. 1308). The colour induction is bidirectional, so the colour spreads both in the white background and on the surfaces of the bars.

A more vivid fringe-induced spread is visible in the "watercolour illusion" (Pinna et al., [2001](#)). The effect is unidirectional: two adjacent purple–orange lines generate an orange colour spread, but not an equivalent purple spread.

The colour spread in [Figure 1](#) could be considered a fringe-induced colour spreading from the orange linear contours, but further observations seem to rule out this hypothesis. In fact, the colour spreading can be observed in the surround of rectangles where the fringe has been erased (see supplementary material 1). Second, colour spreading occurs not only within the region embedded by a

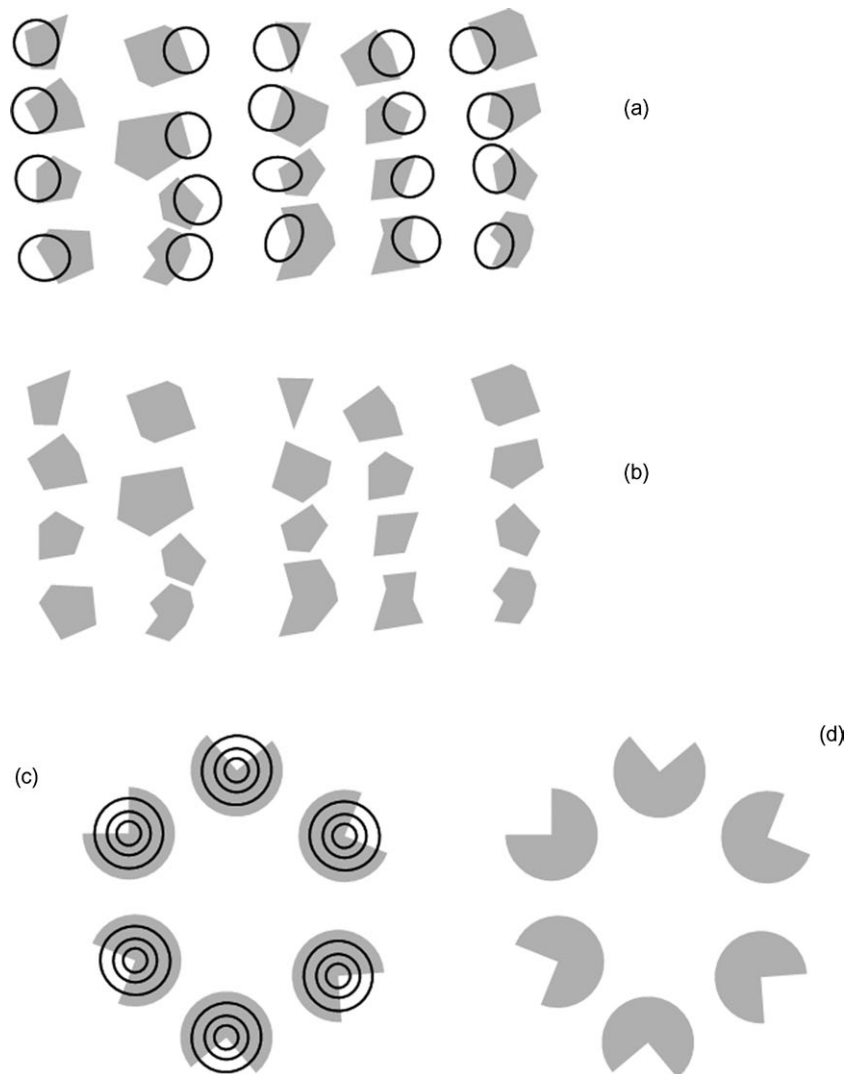


Figure 7. (a) Series of irregular polygons intercepted by circular outline contours. (b) The same as (a) with the circular contours erased. Note that the edges do not prolong to form illusory contours (see text). (c) Pacmen superimposed with concentric circles. (d) The same as (c) with the circles erased.

pair of fringes but also in the surround not bordered by this coloured outline: the “coves” in [Figure 1](#) are not contoured by coloured fringes. A colour spreading is also observed with non-contoured bars (see supplementary material 1). These observations show that the illusory effect described here does not belong to the fringe-induced phenomenon; however, a comparison between the two provides important information.

It is interesting to analyse how the fringe-induced effects are manifested in the present contexts and to compare them with the manifestations in the known contexts. In [Figures 8\(a\)](#) and [\(b\)](#) the pattern in [Figure 1](#) has been replicated with parallel bars. The two gratings have been drawn with the colours of the bars and fringes swapped around. Note how the interspaces appear to be filled by a diffused colouration in both the gratings, to a lesser extent in the lower one. [Figures 8\(c\)](#) and [\(d\)](#) show pairs of adjacent irregular lines coloured with bars and fringes in the same hues on the left to produce a watercolour illusion. Significant differences are observed when comparing the portions of the background embedded between fringes of the same colour. The gratings interspaced and bordered by orange fringes ([Figure 8a](#)) appear to be filled with a grey colour, whereas the corresponding space in the watercolour pattern on the right ([Figure 8c](#)) appears to have a saturated bright orange colour. When the fringes become purple (see figures below) a desaturated purple colour appears in the grating background of [Figure 8\(b\)](#) but no trace of colour spreading appears in the watercolour figure on the right ([Figure 8d](#)). [Figure 8\(e\)](#) allows verifying that the fringe-induction effects are visible in the

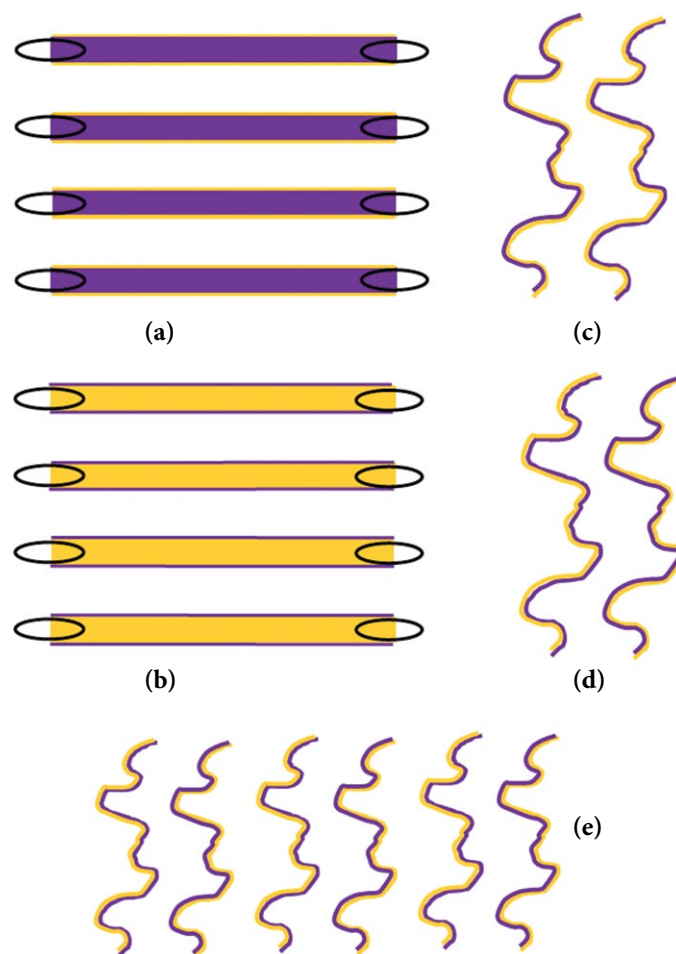


Figure 8. The gratings and irregular lines are drawn on a background of the same uniform grey shade. The irregular adjacent lines are a reproduction of the *watercolour* illusion: the space between the orange lines appears to be filled with the same colour. Series of gratings are reproduced in supplementary material 3 to allow the comparison of colour spreading and inhibition with or without outline ellipsoids intercepting the bars' extremities.

spaces embedded between the orange lines and are missing in the adjacent regions embedded between the violet lines. This is not the case in [Figure 8\(b\)](#) where the interspaces take on a diffused colouration resulting from a mixture of violet and orange.

In conclusion, the colour in [Figures 1, 8\(a\)](#) and [\(b\)](#) spreads from two independent sources: the bar surfaces and fringes. The perceived result is a diffused tint where the two streams mix.

4.1.3 Neon colour spreading

This phenomenon is the continuation of one coloured line in a second line differently coloured (van Tuijl, 1975; Varin, 1971). A variation of the classic figures is shown in [Figures 9\(a\)](#) and [\(d\)](#). Each of these figures is flanked by a second pattern that reproduces the figural and colouration details of the former with the exception that the black arcs appear narrower ([Figures 9b](#) and [c](#)). Colour spreading is visible in the backgrounds of the whole coloured arc but with noticeable differences. The colour appears to glow like a foggy neon in [Figures 9\(a\)](#) and [\(d\)](#) whereas in the figures to the side, the surface beneath the arcs seems to be more opaque.

Observers who participated in the informal study were asked to perform a final task of comparing some examples similar to [Figure 9](#) and give their impressions. Three observers out of 13 did not find any differences. All the other observers described the central column as being filled with an attenuated tint, but with these differences between the patterns to the side: with an invariant contour width, observers reported the impression of a transparent veil (three people) or a “hovering or suspended colouration” (two people), an “internal coloration,” a “neon light,” “coloured beam,” “phosphorescent beam,” “coloured streaking,” “radioactive psychedelic beam.” With the contour of a variable width,

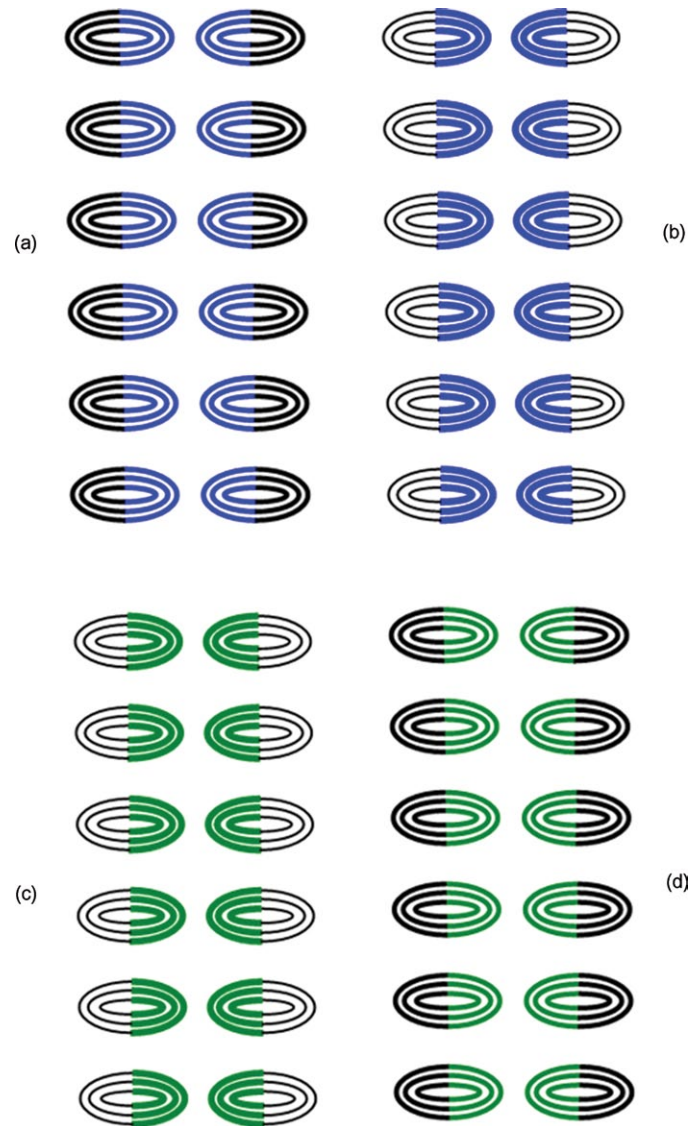


Figure 9. The black arcs of the figures have different thicknesses. The size and colours are the same for each pair.

some observers (4) reported the impression that the borders of the surface intercepted by the arcs were well defined and that this surface was filled with a bluish or greenish attenuated colour. With the exception of one observer who saw a transparent veil, none of the participants mentioned specific figural illusions such as foggy, neon, layering effects in [Figures 9\(b\)](#) and [\(c\)](#).

Overall, these judgements lead to the conclusion that the illusions illustrated in [Figure 3](#) cannot be classified as “neon effects.” Further exploration can provide useful information concerning the basic effects behind the colour-spreading phenomenon in [Figure 3](#).

In [Figure 10](#), the same pattern consisting of half ellipsoids of different colours and thicknesses is replicated four times with the black arcs progressively becoming thinner. The arcs in [Figure 10\(a\)](#) have the same width, which gives the impression of a stronger transparent veil covering the lighter arcs. As the black arcs become narrower in [Figures 10\(b\)](#) and [\(c\)](#), the transparency percept weakens, giving the impression that something “volumetrically” opaque replaced the grey veil. In [Figure 10\(d\)](#), where the black arcs have the smallest thickness, any impression of transparency vanishes in the central vertical region where a grey “pastel colour” seems to fill the whole surface traversed by the lighter thick arcs. The perceptual outcome of the progressive variation in thickness is the transition from phenomenal transparency to an opaque solid flat space. The conclusion is that the different illusory effects are the manifestation of the same basic phenomenon, i.e. a diffusion of greyness that emerges in the perceptual field as transparency if the figural condition of layering occurs (see Bressan, [1993](#)).

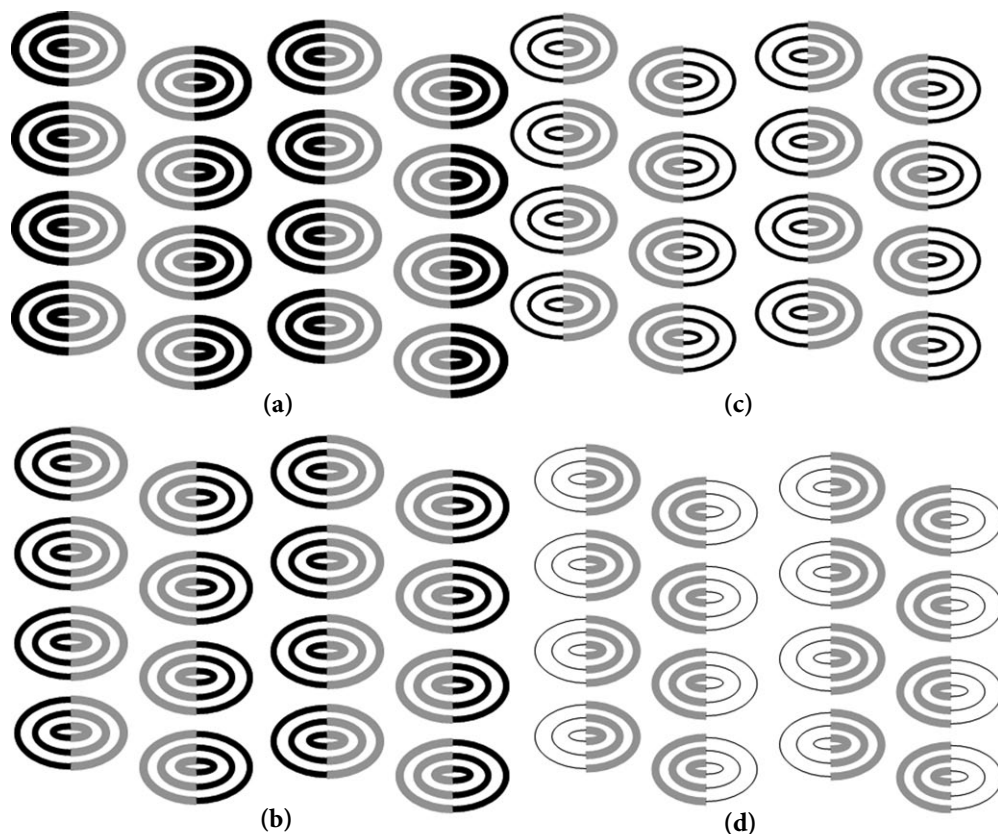


Figure 10. The same pattern in (a) is replicated three times with the black arcs progressively decreasing in width.

4.1.4 Flank transparency

Parallel coloured bars diffuse their tint when traversed lengthwise by black lines. The spreading effect improves when the pattern is viewed in motion (Cicerone, Hoffman, Gowdy, & Kim, 1995; Wollschläger, Rodriguez, & Hoffmann, 2001; Wollschläger et al., 2002).

The conditions in which the phenomenon is observed are similar to those present in Figure 3 but with some significant differences. The condition differs because in Figure 3 the wider arcs are not traversed by the thinner ones. As previously mentioned, the impression of transparency is only reported in exceptional cases. These attributes are not compatible with the term “flank transparency.” Furthermore, this can be considered a particular case of fringe-induced colour spread and what was stated in the paragraph above also applies to this illusion.

4.2 Conclusions

The review offers important suggestions on the distinctive properties of the colour spread observed in Figures 1–3.

The phenomenon is not limited to the assimilation conditions. First of all, the spreading diffuses from areas of any width (thin lines as well as wide bars or circles). It is not blocked by a contour (luminance gap) and is observed even with monochromatic figural units (Figure 3, left column).

The diffused colour is intense and desaturated. Both the surface and the contour contribute to colour the background that appears to have a mixture of both tints. The diffusion is homogeneous all around a shape whatever the contour extension may be in that region. The final property concerns the figural aspects. No layering or foggy effect is perceived. The colour has the aspect of a pastel colour filling the background surface. These are the same characteristics as the *watercolour* effect and the Broerse’s fringe effect.

4.3 Brightness induction/whitening effect

The surfaces traversed by the outline contours in Figures 1–3 appear brighter than the remaining background. Similar effects have been documented, a brief review will allow better understanding

whether the perceptual characteristics demonstrated here are the manifestations of known phenomena.

4.3.1 Saturation

Smith et al. (1998) observed an interesting phenomenon of colour alteration on a surface traversed by coloured strips. When matched with an isochromatic comparison area, this surface appears more saturated. The phenomenon occurs with wide strips (43 arcmin) as well as thin ones (7.5 arcmin). In the case of narrower strips, the phenomenon is inverted and the test surface becomes desaturated. The conditions in which this saturation effect is observed do not match the conditions where the whitening effect arises in [Figures 1–3](#). Here, only one thin achromatic contour is needed to cause the brightening of the surface it traverses. Nevertheless, the two phenomena are likely to derive from a common cause: if we replace the wide bars in the Smith et al. pattern with distantiated thin lines, the condition common to [Figures 1–3](#), the saturation effect persists.

4.3.2 Contrast effects

We cannot exclude the possibility that brightness enhancement may be a manifestation of a simultaneous brightness effect. Nevertheless, the colour spread observed with isoluminant arcs in [Figure 3\(a\)](#) shows that simultaneous luminance contrast does not seem to play a role.

4.3.3 Brightness enhancement

[Figure 11](#) illustrates some well-known effects. The completed modal figure (Kanizsa, 1955) appears to have a brighter grey shade than the isoluminant background ([Figure 11c](#)) and the area of convergence of radial lines, as well ([Figure 11d](#) or Hermann's phenomenon; see Ehrenstein, 1987). The circular region of convergence of radial pointed bars (Kennedy, 1987) is brighter ([Figure 11e](#)), as is the surface embedded between the luminance ramps ([Figure 11b](#), self-illuminated patterns; see Zavagno & Caputo, 2001).

We compare these brightness effects with what we see at the centre of [Figure 11\(a\)](#), where the bars are intercepted by the ellipses. This circular area appears to be brighter than all the others. But a particular "quality" catches our attention: this area is of a saturated "white," a colour that is not perceived elsewhere on the page even in the outer surround of the radial patterns where there seems to be no induction phenomena.

The "whiteness effect" is visible even in figural contexts with strong brightness induction. Agostini and Galmonte (2002) demonstrated strong effects of luminance enhancing at the centre of a circular surface that progressively darkens as it approaches the centre.

[Figures 12\(b\)](#) and [\(c\)](#) reproduce this configuration with a light grey circle on top of the central region. The circle is the same in the two figures, but with a different brightness: when the ellipses intercept the circular border, the inner region appears to be filled with a saturated white colour.

"Whiteness" can be considered the distinctive character of the brightness illusion in [Figure 11\(a\)](#) that assigns it to a different category of similar phenomena. However, it could be a more intense manifestation of the same brightness induction phenomena occurring in the other patterns of [Figure 11](#). The following illustrations demonstrate that "whiteness" is associated with figural effects that are different from the ones emerging after the formation of illusory contours ([Figures 11b–d](#)).

In [Figure 13](#) radial bars are interrupted by a small gap. The configuration elicits the percept of a thick ring superimposed on the radial pattern. If the gap is bordered by a luminance ramp ([Figure 13a](#)) the ring becomes a self-illuminated glowing ring. In the two cases, the impression of an in-depth stratification is clear: in [Figure 13\(a\)](#), but particularly in [Figure 13\(b\)](#), the ring appears as a whole unit superimposed on radial bars occluded for a short distance by it. The same pattern is reproduced in [Figure 13\(c\)](#) with the extremities of the gaps intercepted by ellipsoids. The whitening effect is evident but this is not associated with the appearance of a clearer percept of a ring-like shape. The ring has vanished as a unitary percept. This shows that the ellipsoids produce contrasting figural and brightness effects: the first weakens, whereas the second enhances.

The intercepting ellipsoids interfere with the processes of illusory unit formation (modal completion of the ring). This demonstration is further confirmation of what was observed before, i.e. the relative independence of the brightness/darkness induction investigated here from the phenomenon of illusory contour completion. An empirical investigation will provide further support to the hypothesis that the outline ellipsoids play the main role in generating the "whiteness" effect.

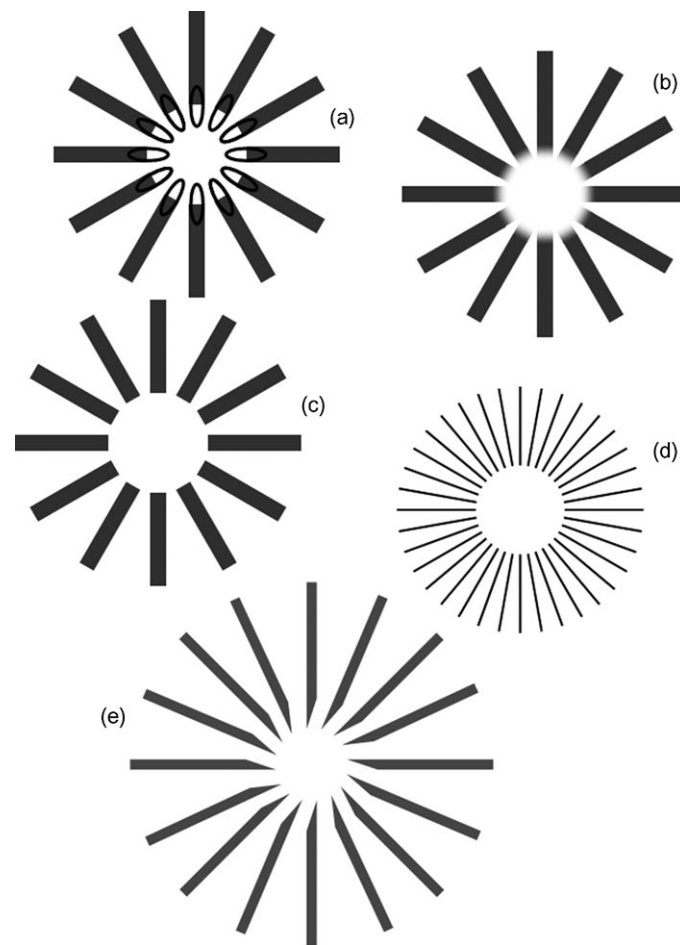


Figure 11. Radial configurations reproducing different effects of brightness alteration at the convergence of the shots. (a) The central region appears brighter than the white surround. This is the brightening effect examined in this paper. (b) Effect of “self-illumination” at the convergence of dark to light luminance ramps. (c) Brightness enhancement in the centre of the modal completed polygon. (d) Brightness enhancement in the centre, Hering effect. (e) The “Kennedy effect”: brightness enhancement where the ends of the pointed bars meet.

5 Experiment

An experiment was conducted with the aim of checking the relationship between the perceived “whiteness” and the spatial extension of the outline ellipses on the background. A series of patterns similar to [Figure 11\(a\)](#) were drawn with the ellipses protruding at different distances inside the central circular area. The pairwise comparison method (Guilford, 1957) was used with subjects asked to compare two stimuli and indicate the one where the central circular area appeared brighter.

5.1 Observers

Five naive volunteers—aged 21–32—participated in the experiment.

5.2 Stimuli

Note that 35×4 mm bars contoured in their length by a 1.4-mm lighter fringe were used to draw a radial pattern of 104-mm diameter. Twelve equidistant bars bordered with their inner extremities a central circular empty area (34 mm diameter). Outline ellipsoids (20×4 mm) were drawn at the inside extremities of the bars, collinear with their major axes with the bars axes. An initial stimulus was created with the ellipsoids entirely superimposed to the bars (zero protrusion). A second stimulus was obtained by displacing the ellipsoids towards the centre so that their extremities were 3.6 arcmin of visual angle far away from the bars’ extremities. This operation was replicated seven times in order to create nine stimuli with the ellipsoids progressively protruding in step of 3.6 arcmin of visual angle in the central empty area.

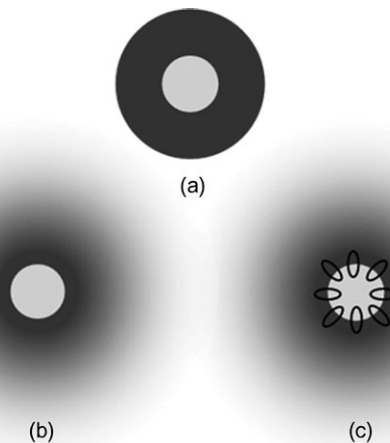


Figure 12. (a) A light grey disc occupying the central region of a dark grey circle. (b) The same disc as (a) surrounded by a circular area radially increasing in luminance. The contrast at the edge of the disc is the same in the two figures, but appears brighter (Agostini & Galmonte, 2002). (c) The same as (b) with the edge of the discs intercepted by outline ellipsoids. The disc appears brighter.

The last (10th) stimulus was the one that the ellipsoids entirely went out of the bars to the central area. Luminance magnitudes were chosen as follows. White background: 45.5 cd/m². Yellow background: 30.7 cd/m². Bar: 4.3 cd/m². Fringe 12.2 cd/m². Outline ellipsoids: 0.38 cd/m².

5.3 Procedure

Ninety pairs of stimuli were created from the two permutations of 10 stimuli (10!/(10-2)!). They appeared at the centre of a CRT screen for 2 s, then disappeared and were replaced by a masking stimulus that was followed, 2 s later, by a second pair of stimuli. The experiment initiated with a familiarisation section during which subjects were shown some stimuli. They were asked to focus on the central areas and report whether they saw differences in brightness. A training session was then held where some pairings appeared and subjects were instructed to respond by indicating the side (left or right) where they saw the brighter central area. They had to give an answer even if they were uncertain which stimulus was brighter.

The 90 pairs appeared at a viewing distanced of 80 cm in random order and in two sessions. In one session, the background was white, and in the other it was light yellow.

5.4 Results and discussion

The results are summarised in Table 1, where the judgements in two different stimulus backgrounds are pooled. The row R_i reports the means of the Z transformations of the proportion of estimates relating to the “stronger brightness.” Negative numbers were eliminated by adding a positive number to each mean corresponding to the same value of the absolute value of the lowest mean rating. The first datum is the progressive increase (although not linear) of the brightness with the degree of overhanging of the ellipsoids inside the central area. The minimal rating coincides with the first step in the protrusion contrasting with the prediction that this should have occurred with zero protrusion. At this very short degree of interaction, the effects in the area of the ellipsoids are too weak to allow an exact evaluation.

The only conclusion we can draw is that the brightening enhancement is visible even with a small protrusion of the ellipsoids and its intensity increases as the protrusion advances.

The second datum is the rating of brightness in ellipsoids that do not intercept the bars. They show a vivid effect of brightness enhancement, although not at the highest degrees.

In conclusion, the “whiteness” effect analysed here has distinctive characteristics that differentiate it from the brightness induction phenomena already known. The first difference relates to the size of the luminance and colour: the effect that I have called “whiteness” is both an effect of greater brightness and also of more saturated colour (“white”). The second difference relates to the size of the figure: the organisation of depth is such that the surface from which the impression of “whiteness” emanates does not emerge in relief like the modal figures surrounded by illusory margins, but remains part of the background. However, it is likely that the “saturation” effect discovered by Smith et al. is the same as that generates the impression of “whiteness.”

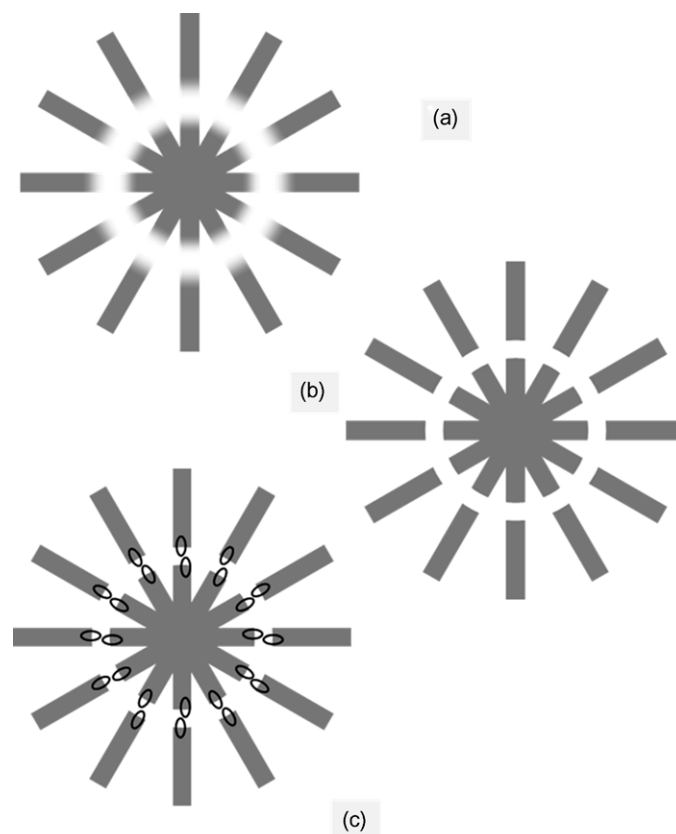


Figure 13. Radial patterns interrupted by a gap. (a) Blurred gap: an illusory blurred ring seems to be suspended on the bars. (b) O ring (He & Ooi, 1998). A ring seems to overlap the bars. (c) The same as (b) with the inner extremities of the radial bars intercepted by outline ellipsoids.

6 Conclusions

By intercepting an edge—even a very short one—with a thin outline generates a luminance contrast enhancement across the edge. This effect is caused by two opposites: the brightness enhancement (it appears as “whiteness” in several circumstances) at one side and colour spreading on the opposite side. I have tried to answer two questions: are these phenomena unobserved and what is their nature. To answer these questions, I analysed the studies by Bozzi and Kanizsa who first documented the illusions as isolated, unrelated effects. I also reviewed the phenomena of brightness enhancement and colour induction. I concluded that the hypothesis by Bozzi–Kanizsa stating that phenomenal transparency plays a primary role in the appearance of illusions is not plausible. Second, of the reviewed phenomena, the “saturation” effect documented by Smith et al. is likely to be the cause of the “whiteness” effect. As it concerns colour spreading, it could be the manifestation of a “rudimentary” basic form of spreading that has been theorised by some researchers (Bressan, 1993; Wollschläger et al., 2002) and that appears as different phenomenal “objects” or impressions (see Figure 10).

What is the role of the outline ellipsoids in the appearance of one or the other? They are likely to play different roles. They play a “direct role” by saturating the portion of the background they traverse, generating the impression of “whiteness.” Consequently, a border appears separating the saturated

Table 1. First row: portion (in visual angle) of the ellipsoids overhanging in the empty central region. Second row: means of the columns of the scale-separation matrix Z for the 10 stimuli. Third row: R_j values relating to the 10 stimuli. They indicate the mean intensity of the brightness resulting from the judgements of the subjects to the 10 stimuli.

Protrusion (arcmin)	0	3.6	7.2	10.8	14.4	18.0	21.6	25.2	28.8	Tenth stimulus
M	−0.99	−1.61	−0.56	−0.75	0.02	0.57	0.51	0.89	1.89	0.036
R_j	0.62	0	1.05	0.86	1.63	2.18	2.12	2.50	3.50	1.65

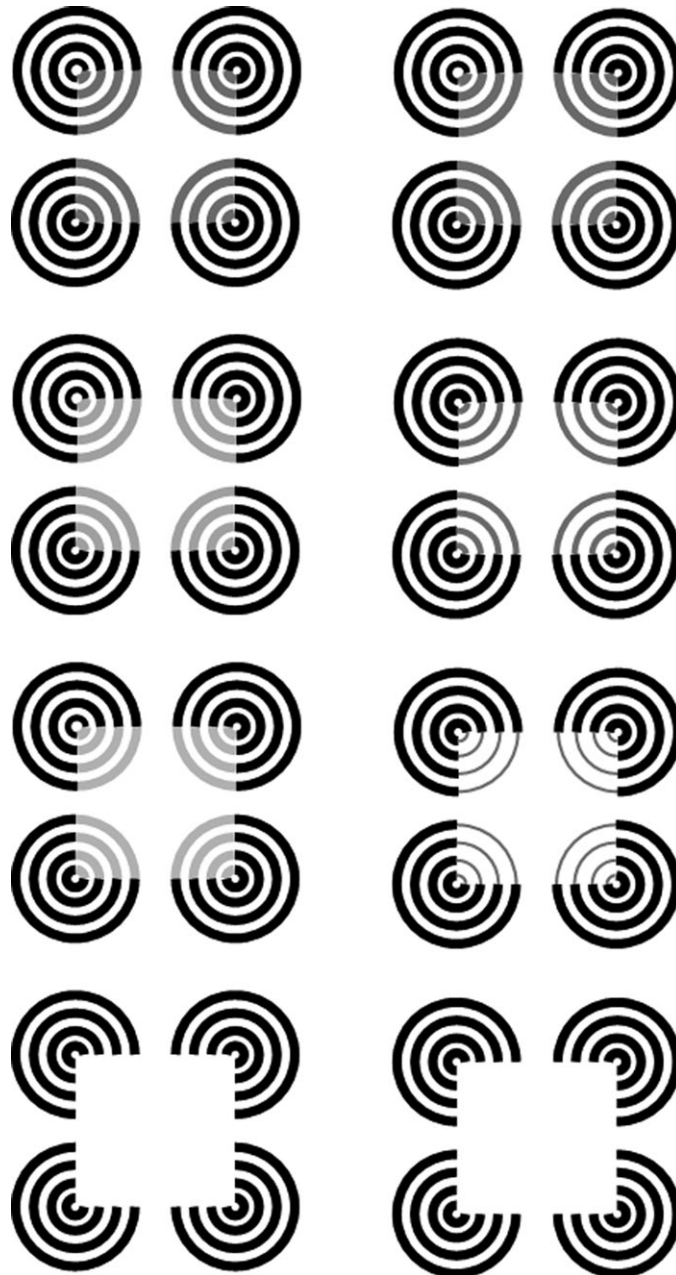


Figure 14. Varin-like patterns. The inner arcs are lighter than the outer ones. Left column: the arcs retain their width and progressively become lighter. Right column: the inner arcs retain their brightness and progressively become narrow.

surface from the coloured one. The colour spread, which could not be detected due to uniform spreading and intensity, now appears to stop at the border of the saturated region. Some additional “indirect” effects can also be hypothesised.

A first hypothesis may be based on the assumption that the outline ellipsoid or arc to the side of a wider figural unit reproduces a condition of high/low brightness on the opposite side of an imaginary border. The side traversed by thin arcs is supposed to be processed as a lighter surface and the opposite side, filled with dark figural units, as a less illuminated surface. In other words, if an imaginary line separates thin lines from wider figural units, a signal is sent to the visual system that there are differently illuminated regions on the opposite sides. Does the visual system “react” to differences in density or thickness in the same way it “reacts” to differences in brightness? A pattern introduced by Varin (1971) is suitable for comparing the phenomenal outcome of the variations in thickness and brightness (credit to an anonymous reviewer). We can compare the perceptual outcomes of the systematic variations in arc brightness and thickness.

In [Figure 14](#), variations have been made to Varin-like figures, specifically on the inner arcs of the outline circles. The left column shows four of these patterns in which the inner arcs become lighter and lighter until they have the same background luminance. In the right column, the same Varin-like figures are reproduced four times with the inner arcs progressively becoming narrower, until the width is null in the pattern furthest to the right.

Moving downwards along the two rows, we encounter different phenomenological outcomes. In the left column, the neon-transparency effect dominates. As the luminance of the inner arcs becomes similar to the background, the impression of transparency increases, i.e. the impression of opacity of the layer is more vivid. In the right column, we perceive an increasing brightness that is not associated with a percept of transparency or layering or neon. The pattern with the thinnest arc thickness (the third in the right column) shows the maximum of the “whiteness” effect: the central area is whiter than the corresponding area in the bottom pattern, but is also whiter than the corresponding areas in the left-hand-side pattern.

In conclusion, the effects of the progressive lightening of the arcs are different from the effects of progressive narrowing of their width: in intensity and in figural appearance. A neon surface appears as a veil when we perceive a “white surface” traversed by thin lines where the in-depth stratification is absent or inverted.

A second hypothesis is based on the assumption that the saturation effect alters the perceived contrast at the edges, so that the visual system is “induced” to compute higher luminance where saturation occurs, and shadowing at the opposite end. In my opinion, conditions exist for the edge-based theory of surface brightness. According to this theory, the brightness of a surface is the result of filling-in signals derived from the edges (Grossberg, 2003). Brightness signals become diffused in the region traversed by saturating arcs and darkness signals become diffused in the opposite direction. These two streams of signals overlap the other effects: the saturation effect adds to the brightness induction to generate the “whiteness” percept, whereas the spreading of darkness in the opposite direction desaturates the pre-existing colour diffusion.

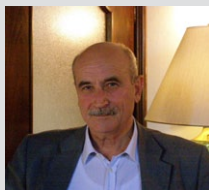
This hypothesis requires further testing and in-depth exploration. The phenomenon of saturation needs to be explored further in order to check its occurrence in a wide range of conditions. The illusory contrast enhancement effects seem to extend from the edges to propagate in the background, generating something similar to phantom borders rather than illusory borders (Kitaoka, Gyoba, & Sakurai, 2006). If this similarity can be demonstrated, we could have important suggestions on the phenomena underpinning the illusions in [Figures 1–3](#). Finally, we need to know more about colour spreading, its direction, and the figural units that play the role of inhibitors. Some studies (Hamburger, Prior, Sarris, & Spillmann, 2006; Kanai, Wu, Verstraten, & Shimojo, 2006) demonstrate that there are still many unanswered questions.

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