

# Logic and phenomenology of incompleteness in illusory figures: New cases and hypotheses

BAINGIO PINNA<sup>1</sup>, STEPHEN GROSSBERG<sup>2</sup>

## *1. Introduction*

Why is it relevant to analyze the role of incompleteness in illusory figure formation? Incompleteness probes the general problems of organization of the visual world and object segregation. The organization problem is one of the most important problems in visual neuroscience; namely: How and why are a very large number of unorganized elements of the retinal image combined, reduced, grouped and segregated to create visual objects? Within the problem of organization, illusory figures are often considered to be one of the best examples to understand how and why the visual system segregates objects with a particular shape, color, and depth stratification. Understanding the role played by incompleteness in inducing illusory figures can thus be useful for understanding the principles of organization (the How) of perceptual forms and the more general logic of perception (the Why). To this purpose, incompleteness is here studied by analyzing its underlying organization principles and its inner logic.

Incompleteness has been proposed to be one of the basic factors in inducing illusory figures. Indeed, some influential authors have hypothesized that illusory figures are perceived if and only if the inducing elements are incomplete. Gregory (1972, 1987) suggested that illusory figures are similar to perceptual hypotheses postulated to explain the unlikely gaps within stimulus patterns. This idea is derived

<sup>1</sup> Facoltà di Lingue e Letterature Straniere Università di Sassari, via Roma 151 I-07100, Sassari, ITALY Email: baingio@uniss.it

<sup>2</sup> Department of Cognitive and Neural Systems and Center for Adaptive Systems Boston University, 677 Beacon Street Boston, MA 02215 - USA Email: *steve@bu.edu*

from Helmholtz's Likelihood principle (Helmholtz, 1867). The well known Kanizsa's triangle (Kanizsa, 1955, 1979) would then be created by a top-down cognitive hypothesis to explain the gaps (missing sectors of the disks and missing parts of the outline triangle) within the stimulus. Similarly, Rock (1983, 1987) proposed that fragments similar to familiar figures elicit the cognitive hypothesis that a surface is occluding missing parts of inducing elements. Symmetry, incompleteness, interruptions, gaps, alignments among interruptions, familiarity, expectations and general knowledge are cues triggering the cognitive problem-solving process. Thus, in Kanizsa's triangle the alignment among gap terminations and the familiarity of the fragments would elicit a cognitive hypothesis of a triangle occluding three disks and an outline triangle. Coren (1972) considered the incompleteness of the stimulus as a depth cue that elicits the hypothesis of an occluding triangle.

Starting from a Gestalt background, Kanizsa (1955, 1979) suggested that the necessary factor for the formation of the illusory triangle is the presence of incompletenesses, or open figures, which activate amodal completion and closure processes that "create" complete perceptual elements behind a partially occluding illusory triangle.

The role of incompleteness is studied in the next three sections by: (1) defining the inner logic subtended by use of the term "incompleteness", (2) presenting new cases to clarify the phenomenology of incompleteness as a necessary and sufficient condition, and (3) suggesting an alternative hypothesis to explain illusory figures after analyzing problems with the incompleteness hypothesis.

## *2. The logic and the paradox of "incompleteness"*

According to previous theoretical views, incompleteness was considered as a geometrical/structural factor that triggers illusory contour formation but, at the same time, as a perceptual property, beforehand, perceived as such and, afterwards, activating object hypotheses or completion processes. However, from a logical point of view if incompleteness is assumed as a geometrical factor:

(i) it cannot be defined as incompleteness, because the term “incompleteness” implies a perceptual phenomenon and not a geometrical property;

(ii) consequently, the use of the term “incompleteness” leads to the experience error (Köhler, 1947); that is, the implicit assumption that the structure of perceptual experience coincides with the optical array;

(iii) furthermore, as a geometrical property it does not require any solution, explanation or completion;

(iv) nevertheless, by assuming that incompleteness, open figures, or irregular elements can activate dynamical gestalt tendencies toward amodal completion and closure, as such, these tendencies should show two states and not just one as they do: the preceding uncompleted and open state, and the succeeding completed and closed one. This is even truer for the cognitive hypothesis. However, only one state is perceived. Thus, as a geometrical property, incompleteness cannot be a cause of itself as a perceptual phenomenon that in its turn determines something else, the illusory figure.

If incompleteness is assumed as a perceptual property, it implies that:

(i) as such it cannot be considered the cause of another perceptual property at the same epistemological level; that is, if incompleteness is perceived as incompleteness, there is no need to be discounted or completed to cause and elicit illusory figures, especially because incompleteness is in many cases a perceptual property independent from illusory figures;

(ii) it cannot be considered as such because as soon as it is perceived it is unperceived (*reductio ad absurdum*);

(iii) thus, the incompleteness of a perceptual object cannot be perceived because once it is perceived it is immediately completed and explained; that is, it is first perceived as incompleteness and then completed: to be completed it should first be perceived as incomplete. This is paradoxical: In fact, it is not perceived if and only if it is perceived, or it is perceived if and only if it is not perceived (the paradox of “incompleteness”). The same paradox can be also stated as follows: To perceive an incompleteness that has to be explained and completed, first, it should become a conscious phenomenal property and, then, it should become unconscious so that its perceptual result is annulled or completed. In oth-

er words, the incompleteness is not perceived (completed) only if it is perceived (not completed);

(iv) incompleteness considered as a depth cue implies that, as with all other depth cues, it should be perceived, but if it is perceived it is not perceived; thus, the argument is the same as that in point (iii);

(v) therefore, if it is a perceptual property, it is not a perceptual property. In other words, incompleteness can never be perceived because it should be always completed. Said yet another way, incompleteness should never be perceived even under conditions independent from illusory figures.

The previous arguments reject incompleteness as a factor for explaining illusory figure formation on the basis of merely logical reasoning. In the next section, the role of incompleteness is further weakened and redefined through new phenomenological conditions.

### *3. Phenomenology of incompleteness*

The aim of this section is to argue phenomenologically that incompleteness is neither a necessary nor a sufficient factor in inducing illusory figures. The demonstration of this statement follows four steps: (i) incompleteness is not a sufficient condition; (ii) illusory figures do not necessarily complete incompletenesses (reductio ad absurdum of the role played by incompleteness); (iii) the shape of incompleteness does not predict the shape of illusory figures; (iv) incompleteness is not a necessary condition.

In this section, the phenomenology of incompleteness is accomplished by demonstrating that gestalt principles of grouping and figure-ground segregation of boundary contour discontinuities and brightness inhomogeneities underlie, acting as parallel factors, the formation of illusory figures without invoking incompleteness.

To demonstrate the phenomenological arguments, the spontaneous descriptions of subjects were recorded under the controlled conditions described in the next General Method section.

### *3.1. General Method*

The stimuli were composed by the figures illustrated in the paper. The mean overall size of the stimuli was 10.8 x 8.6 deg of visual angle. The luminance of the white (background) paper under our test conditions was 80.1 cd/m<sup>2</sup>. Black components had a luminance contrast of 0.97. Stimuli were presented on a computer screen under Osram Daylight fluorescent light (250 lux, 5600° K) and were observed binocularly from a distance of 50 cm with freely moving eyes.

Different groups of twenty observers, if not otherwise stated, described only one stimulus. This was done to avoid the possibility that the perception of one stimulus might influence the perception of another. New experiments, not reported here, demonstrated that the following phenomenal descriptions could change by presenting different sequences of the stimuli.

The subjects were naive as to the purpose of the experiments. All had normal or corrected-to-normal vision.

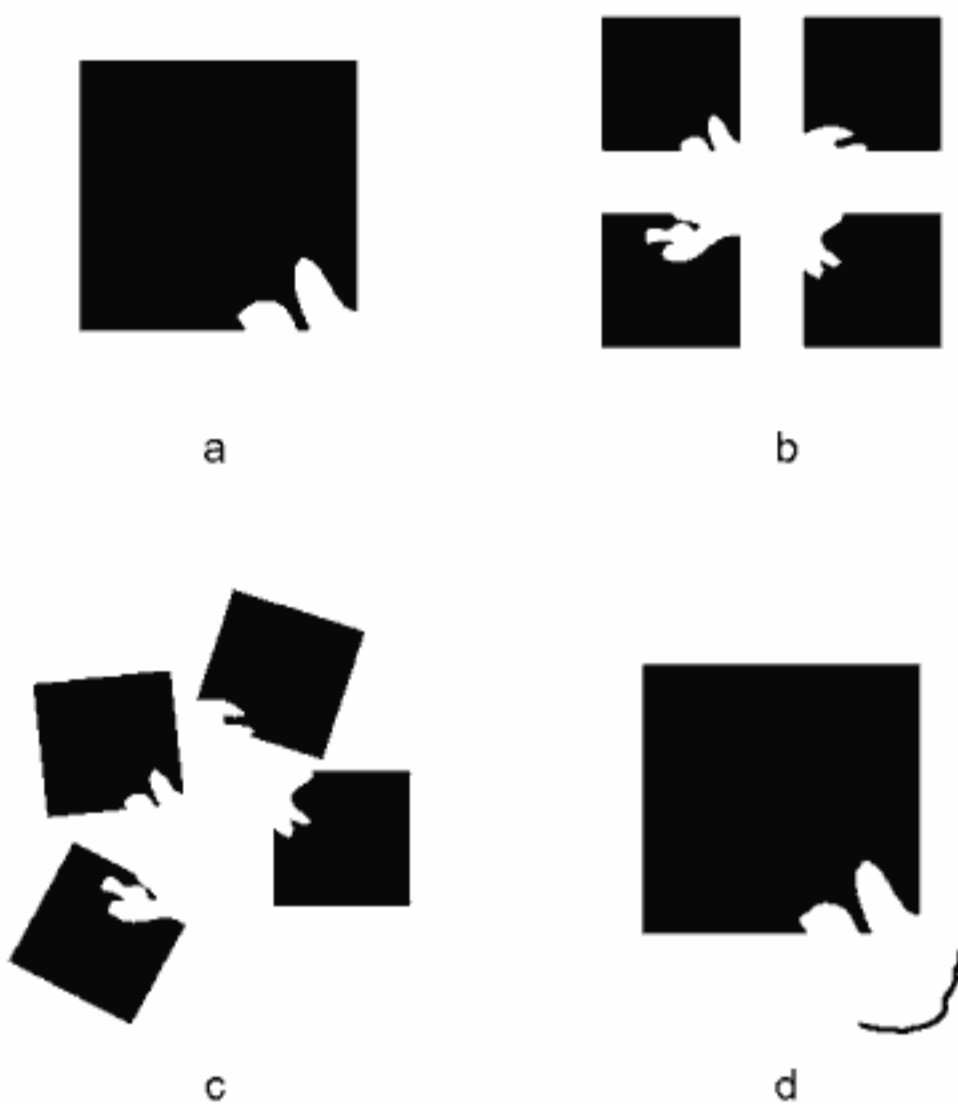
The subject's task was to report what they perceived by describing it. There was a training period preceding the experiment. During practice, subjects viewed some known figures from the illusory figure literature (*e.g.*, Kanizsa's triangle, etc.). Observation time was unlimited. All the observers quite promptly reported a description. Within the paper, if not otherwise stated, the reported descriptions contain the same words used by the subjects during the description of each stimulus and concern the phenomenal results obtained with a significant number of subjects (? 15). The subject descriptions are reported in italics and in quotation marks. In almost all studied conditions, the subjects were asked to sketch out what they perceived. Where necessary to clarify and specify the subjects' percepts, the results of the sketches are included.

### *3.2. Incompleteness is not a sufficient condition*

The first phenomenological argument states that incompleteness is not a sufficient condition in inducing illusory figures. A condition *A* (*incompleteness*) is said to be *sufficient* for a condition *B* (*illusory figure*), if (and only if) the truth (existence or occurrence) of *A* brings about the truth (existence or occurrence) of *B*. In other words, *A* cannot occur without *B*, or whenever *A* occurs, *B* occurs.

Even if the necessary logical condition cannot be easily disproved – namely, that all illusory figures contain incomplete inducing elements or that complete inducers cannot produce illusory figures (see Section 3.5), it can be easily demonstrated that not all occurrences of incomplete elements produce illusory figures (the sufficient condition). Within previous models, the sufficient condition is less interesting than the necessary one, but it is nonetheless important towards understanding the nature of incompletenesses and their organization.

**Figure 1**



Conditions showing that incompleteness is not a sufficient condition and the role of gestalt principle of grouping of concave discontinuities: (a) an incomplete square not inducing an illusory figure; (b) an irregular illusory amoeboid figure partially occluding four squares obtained by grouping incompletenesses; (c) by breaking the good continuation of (b) the illusory amoeboid largely disappears; (d) the articulation without rests factor segregates an illusory figure invading and partially occluding the black square.

Figure 1a is an example of a phenomenal incomplete square not producing an illusory figure. It is interesting to notice that Figure 1a is perceived simply as an “*incomplete square with two missing parts curved inward on the lower-right side and on the corner*”. The term “incomplete” is merely phenomenal. More specifically, this kind of incompleteness appears like a gnaw or a nibble.

From an epistemological and logical point of view, the distinction between the term “incompleteness” and a mere geometrical term, like, for example, “concave discontinuities” of the contours of a square-like shape, is necessary: This geometrical property is not subjected to the previous logical arguments and paradoxes. At the same time, the expression “concave discontinuity” can also have a phenomenal meaning. The concave discontinuities are perceived, but they do not require any completion and, more generally, they do not tend to any other perceptu-

al state. Thus, from an epistemological and phenomenological point of view, it can be stated that: “geometrical concave discontinuities, such as those illustrated in Figure 1a, induce the perception of an incomplete square”.

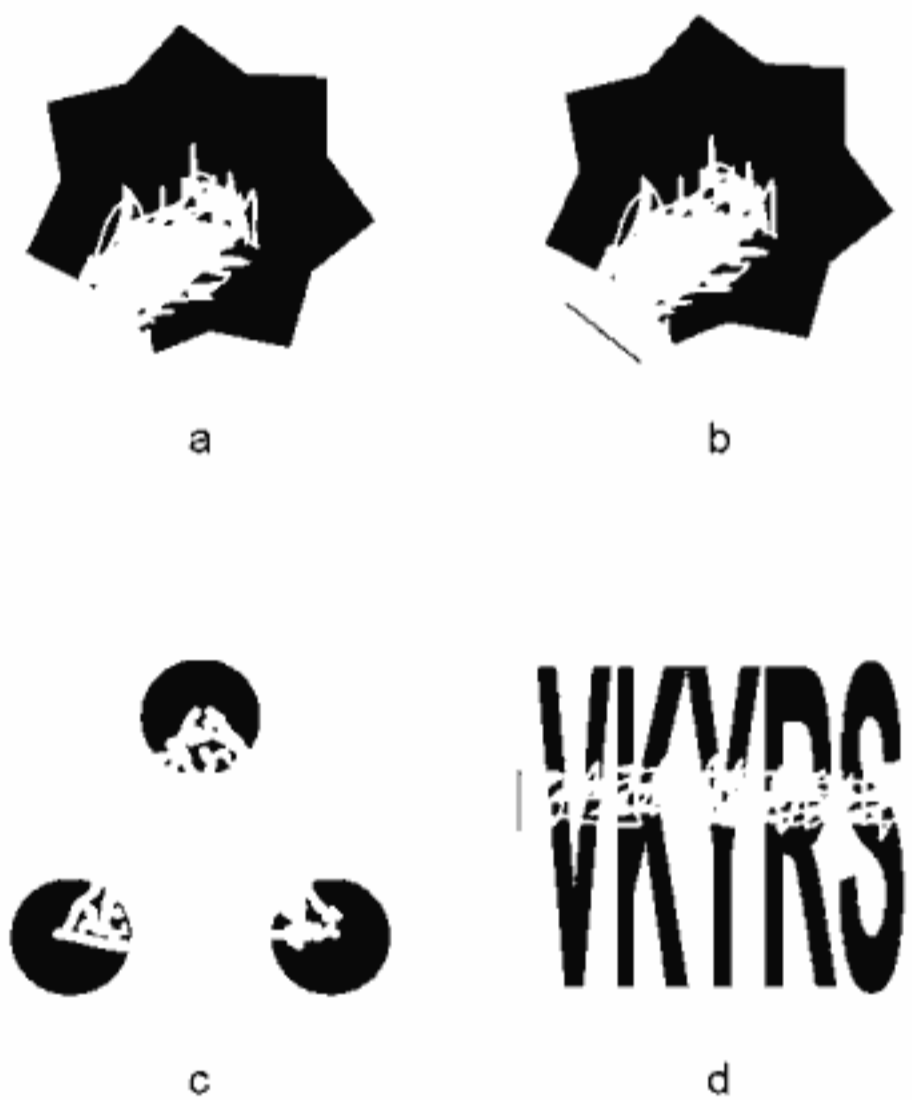
By saying “concave discontinuities”, our aim is not to define incompleteness. Instead, the term “concave discontinuity” highlights the role played by discontinuities along the boundaries that may be said to include incompletenesses, and that can be related to principles of grouping and figure-ground segregation. For example, if a concave discontinuity region segregates from other boundaries, because of similarity (or dissimilarity), they can group with similar concave discontinuous boundaries, as illustrated in the next figures. The replacement of incompletenesses with “concave discontinuities” is not considered either in geometrical or in phenomenal terms, but as a dynamic process of grouping and figure-ground segregation. It allows us to overcome the logical and phenomenal critiques that can be made against the term “incompleteness”. Furthermore, it allows one to suggest hypotheses that are not restricted to illusory figures and that are basic for the segmentation and organization process of vision. This alternative way to consider incompleteness will be clarified below.

Concerning the result of Figure 1a, in defense of the cognitive and Kanizsa hypotheses, one can say that the reason why the incompleteness in Figure 1a does not induce an illusory figure is that the incompleteness shown does not need to be completed. Since this implies that incompleteness is not a sufficient factor, such examples elucidate the role played by incompleteness and, more particularly, the problem regarding under what conditions concave discontinuities are perceived as incompletenesses or as illusory figures. Thus, if incompleteness is not a sufficient factor, then the specific question is: Under which geometrical conditions does incompleteness get completed, as suggested by Gregory, Rock, Coren and Kanizsa? A possible answer to the question is illustrated in Figure 1b, where by arranging the incompletenesses of four squares similar to the one in Figure 1a in a grid, “*an irregular illusory amoeboid figure partially occluding four squares is perceived*”.

By comparing these conditions with those in Figure 1a, the classical laws of organization in perceptual forms, as described by Wertheimer (1923), seem to play a basic role: “incompletenesses” or concave discon-

tinuities group on the base of proximity, closure, similarity of contours and good continuation factors, creating an amoeboid shape. Therefore, by breaking their good continuation, as in Figure 1c, “*the illusory amoeboid largely disappears*”. The roles of the closure factor and, in addition, of the articulation-without-rests factor are shown in Figure 1d. The curved line is the rest, included within the whole organization, assuming “*the perceptual role of the boundary of the illusory figure invading and partially occluding the black square*”. A similar result is obtained in Figures 2a and 2b.

**Figure 2**



Different roles of incompleteness in different form organizations: (a) an incomplete (gnawed or nibbled) black polygon; (b) an illusory white paste, as painted with a tempera, in the outer and inner edge of the polygon; (c) and (d) non-homogeneous paintings across and along the inducing elements.

Figure 2a appears as “*an incomplete black polygon, whose incompleteness is perceived as an erased part of the polygon*”, while Figure 2b appears as “*an illusory white paste, as painted with a tempera, in the outer and inner edge of the polygon*”. In Figure 2a, differently from Figure 2b, “*very weak or no illusory contours are perceived outside the polygon*”. It is worth highlighting that the incompleteness of Figure 2a assumes a specific form: “*Deletion or erasure*”. As a consequence, from a phenomenological point of view it is not a mere incompleteness but “*something*” at a more specific level and different from the previous incompletenesses: “*A gnaw or a nibble*”. Therefore, according to cognitive and gestalt models, the term incompleteness is an undetermined property that can assume a large number of forms. This uncertainty further

weakens the phenomenological role played by incompleteness as considered by gestalt and cognitive models. As can be observed in Figures 2c and

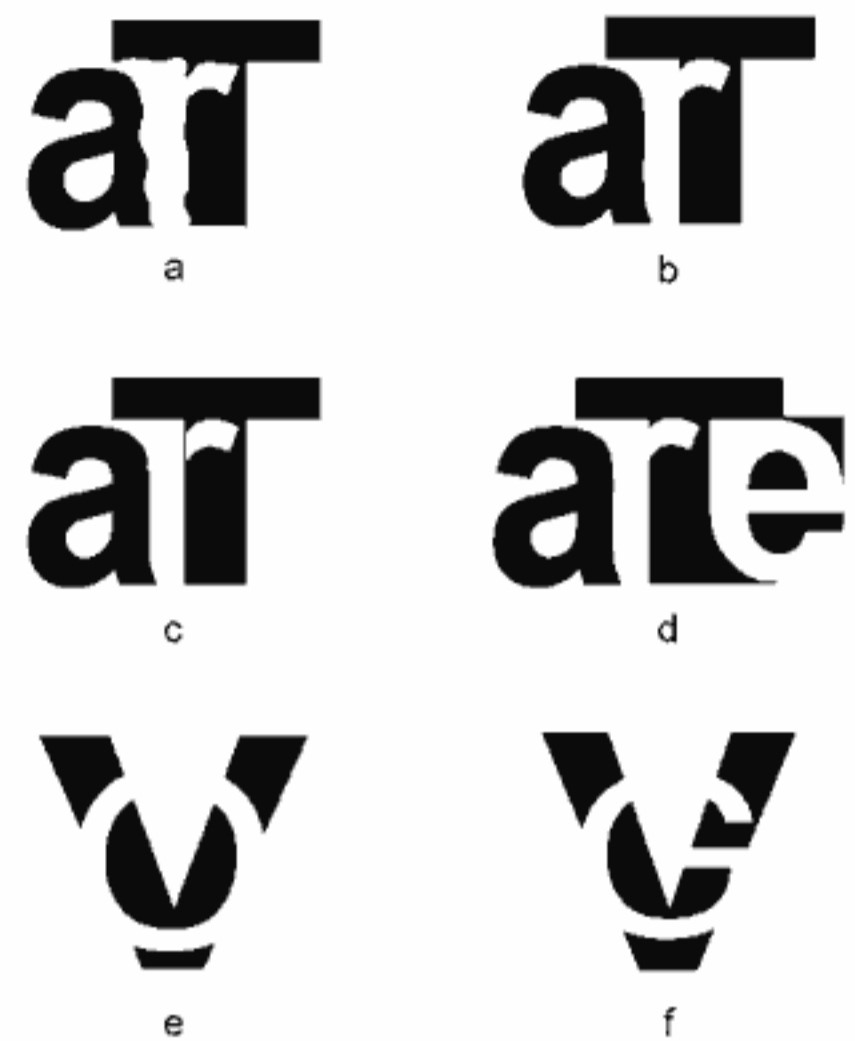


2d, “the illusory figures appear as non-homogeneous paintings across and along the inducing elements”.

Incompleteness can be reconsidered in the light of gestalt grouping principles even when it appears as a different and independent factor. In Figure 3a, “the word ART is perceived” (Pinna, 1990). The similarity/dissimilarity in the type and shape of the boundaries composing the R letter as well as the grouping of concave discontinuities, due to the good continuation principle, can be responsible for the perception of the word ART. In conjunction with similarity, the surroundedness principle of figure-ground segregation (Rubin, 1915, 1921) and past experience (Wertheimer, 1923) likely influence the pop out of the R letter. “The illusory R appears in front of the A and the T, that each completes itself amodally”.

The role of past experience is more obvious in Figure 3b, where the similarity/dissimilarity principle is weakened and where the incompleteness within the T groups with the empty space between A and T, that by virtue of the surroundedness principle tends to appear as a figure. The surroundedness principle is working as well within the component R that can be considered as the incompleteness of T, which in its turn can be considered as a concave discontinuity that is a special case

Figure 3



Gestalt grouping principles as alternatives to incompleteness: (a) the word ART is perceived due to similarity/dissimilarity in the type and shape of the boundaries composing the R letter; (b) the illusory R emerges due to surroundedness and past experience principles; (c) the line separating the component of the R within the T weakens the emergence and segregation of the word ART and the R does not appear as an illusory figure; (d) The word ARTE is perceived and the E letter pops out due to past experience, surroundedness, good continuation, convex discontinuities along the T letter, closure and articulation without rests; (e) and (f) due to proximity factor mutilated or incomplete O and the G do appear in front of Vs or, alternatively, two holes having V shapes partially showing a black background and a white O and G partially perceived through them.

of the concave grouping principle (Wertheimer, 1923). It is interesting to note that *“the R appears on the same plane of the A, while partially occluding the T”*.

In Figure 3c, *“the word ART emerges again but less strongly than in Figure 3b”*. The presence of a line separating the component of the R within the T, and the empty space between the A and the T, together weaken the grouping of the R and favor the amodal completion of the former component behind the latter. *“The R does not appear as a clear illusory figure, even when it is clearly recognized”*.

In Figure 3d, *“the word ARTE (Italian for ART) is now read”*. The letter E is perceived despite the absence of incompletenesses or local concave discontinuities of the R. On the contrary, on its right side the T presents convexities or additions. Both R and E pop out from the background as figures, acquiring clear figural qualities. *“The letter E emerges from a black (upper-right and lower-left corners) and white (upper-left and lower-right corners) square that appears as a background”*. *“The E appears with curved boundaries”*. The perception of the E and its background demonstrates that the boundaries belong unilaterally to the illusory E. The E letter pops out as a figure likely because of the following principles: past experience, surroundedness, good continuation, convex discontinuities along the T letter, closure and articulation-without-rests. Despite the fact that perception of the four alphabetical letters seems to be ruled by different figural principles, they group together making the reading of the word ARTE easy.

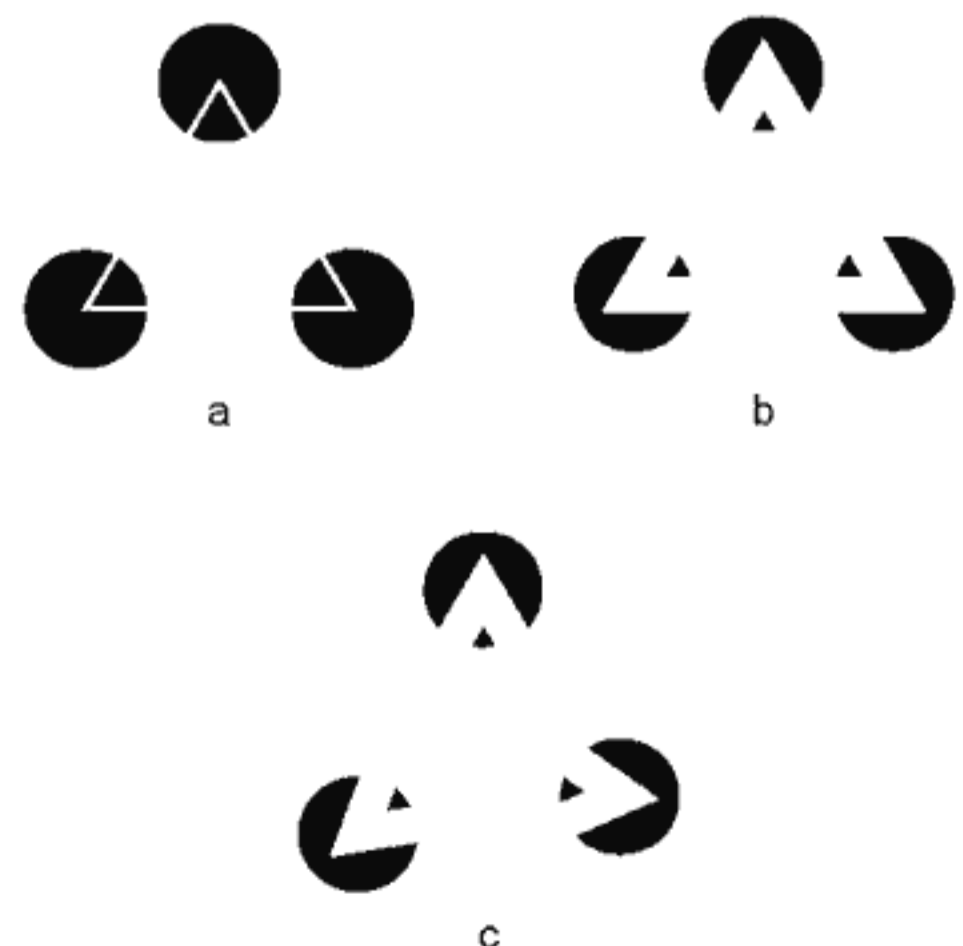
Because the convex discontinuities along the right side of the T are the opposite of the concave discontinuities on the left side that can be considered as the low-level description of the incompleteness, the illusory E letter is induced from something that is the opposite of incompleteness; i.e., convexities or additions.

Illusory figures are not completed in Figures 3e and 3f (Cocco, Pinna & Spillmann, 2000), where the best expected solutions to the incompletenesses on the basis of past experience are two black Vs, partially occluded, and an illusory O and G in front of them. However, *“illusory contours are not perceived in the outside edges of the Vs”* (20 out of 20 subjects for each stimulus). *“The O and the G do appear in front of Vs, but only partially, because they are seen as incomplete or mutilated”*.

Other possible percepts are “two holes having V shapes partially showing a black background and a white O and G partially perceived through them” (12 out of 20 subjects for each stimulus).

These results suggest that grouping and figure-ground segregation principles play an important role in the explanation of illusory figures and, more specifically, in the understanding of their perceptual organization. However, by grouping “incompletenesses” through the synergistic combination of several principles, an illusory figure is not necessarily perceived (Figures 3e and 3f). How and whether it forms may depend on factors that are linked to grouping principles. In Figure 4a, the three corners of a virtual triangle are not grouped to produce an illusory triangular contour across the white space between the circles. Rather, the percept is typically of “a white triangle partially perceived through three holes in a white surface on a black background”. “The disks become circular holes and their boundaries belong to the white surface, while their black color completes itself amodally becoming a homogeneous black background”. “The white space becomes a punched surface partially occluding a white triangle”. The effect is similar to the ones induced by Figures 3e and 3f, but it is interesting all the more so because each circular inducing element is perceived as an incomplete disk, not as a circular hole, when presented separated from others. It demonstrates the basic role of grouping principles that create emergent figures with new properties not reducible to the local components.

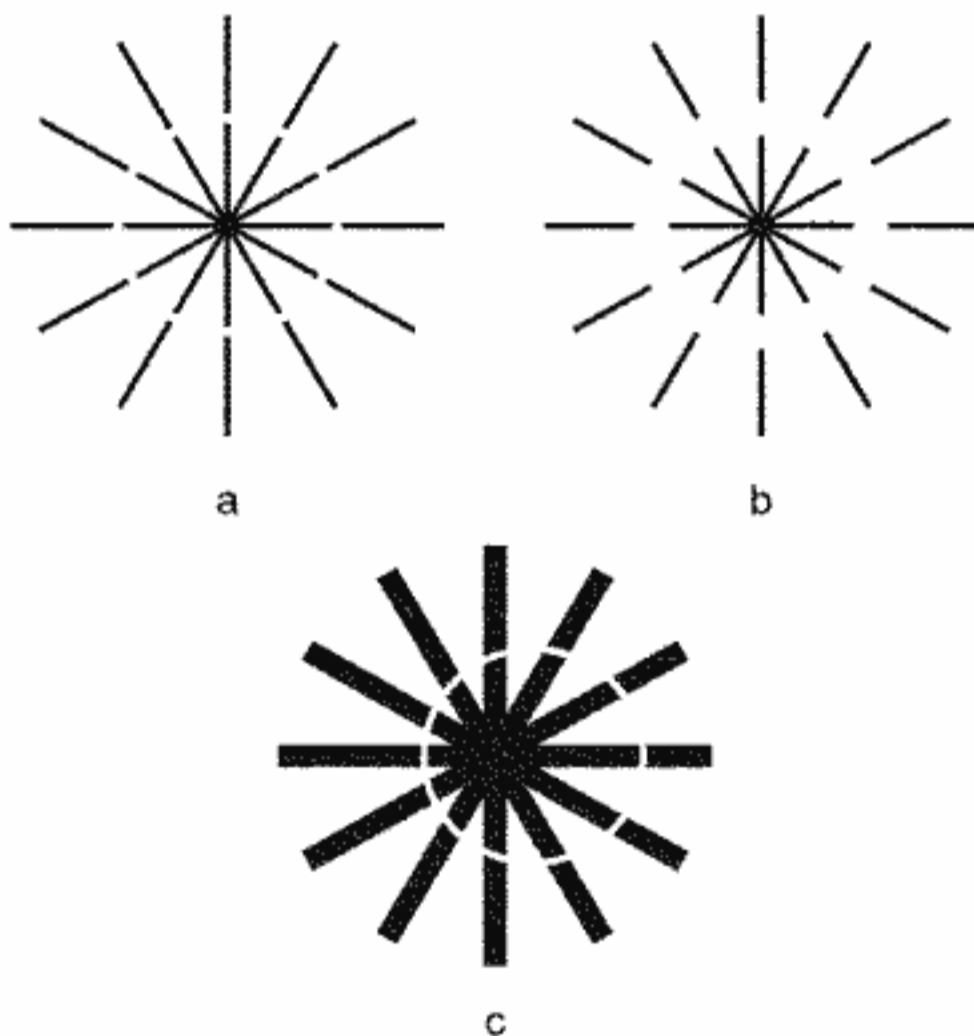
**Figure 4**



A special case of proximity factor induces: (a) a white triangle partially perceived through three circular holes in a white surface on a black background; (b) an illusory triangle; (c) an illusory triangle is perceived even when the good continuation factor is weakened.

Furthermore, these results demonstrate that, even if incompletenesses are aligned to favor good continuation, even if closure, proximity, and prägnanz factors work synergistically, even if the boundary contour of the triangle is thin enough to induce a strong figural effect (surroundedness and proximity principles of figure-ground segregation; Rubin, 1921), no illusory triangle may be created (Figure 4a). The opposite is perceived when viewing Figure 4b, where, by increasing the width of the boundary contours of the corners, “an illusory triangle is clearly perceived”, even if the grouping factors are weakened or pitted against it (Figure 4c).

**Figure 5**



Variations in the ratio between the width of each interruption and the distance between the successive radial lines induces no illusory circumference in (a), a strong illusory annulus in (b) and not any illusory circumference in the right side of (c) but only disjoint bright interruptions or dashes, while the opposite is true in the left side of the (c).

The same argument is illustrated in Figure 5a, where bright spaces, interrupting each ray (incompleteness as interruption) in approximately its center, create “a circumference that is virtual but not illusory”. In fact, “the spaces may appear as disjoint bright spots on the radial lines” (13 out of 20 subjects). However, “the lines do not look like holes, as in Figure 4a, and the spots do not complete themselves amodally behind the white surface”. This result is interesting in the light of the following possible counterargument, using Figure 4a, to the critique of incompleteness. This counterargument states that, even if in Figure 4a an illusory triangle is not created, the reversed and complementary effect (disks as holes, illusory triangle as amodal triangle, etc.) is induced as

an object hypothesis that can fill and explain the gaps within the stimulus pattern. Thus, the amodal triangle should represent the perceived solution to the incompleteness within the circular holes. Figure 5a provides

a counterexample to this counterargument because “*it does not complete the spots or bright interruptions, as does happen by increasing the width of the circumference in Figure 5b*”.

Without invoking the role of incompleteness, the factor that differentiates the percepts in Figures 5a and 5b is the ratio between the width of each interruption and the distance between the successive radial lines. By increasing the width of the amodal triangle of Figure 4a as in Figures 4b and 4c, or of the virtual circumference of Figure 5a as in Figure 5b, this ratio changes accordingly. All else being equal, by decreasing the distance (angle) between the radial lines, the completion of the bright interruptions becomes more likely and stronger, thereby creating an illusory circumference. As illustrated in Figure 5c, “*the right side of the figure does not show any illusory circumference but only disjoint bright interruptions or dashes, while the opposite is true in the figure’s left side*”.

The perceived difference between the left and right sides of Figure 5c is strong enough to overcome any tendency of good continuation to weaken the difference between the two sides and enhance the perceptual grouping. This ratio property is a special type of the proximity factor, which pits horizontal versus vertical proximity against each other.

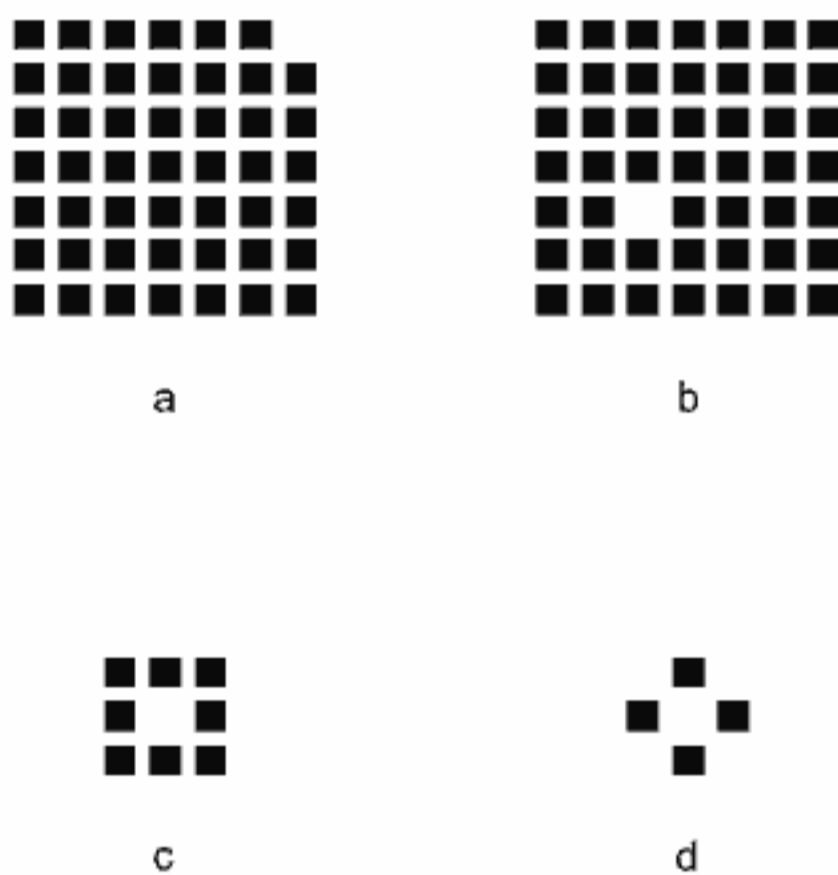
In summary, from a phenomenological point of view, one need not invoke completion processes of incomplete inducing elements to explain the previous results. They can be more easily explained in terms of perceptual grouping factors, suitably understood. In particular, it is not necessary that an illusory figure completes both local and global incompletenesses. Both these arguments are topics of the next section.

### *3.3. Illusory figures do not necessarily complete incompletenesses*

In Figure 6a (Pinna, 1990), “*a square matrix, made up of small squares with a missing element in the left upper corner*”, is perceived. This is perception of “incompleteness” without an illusory figure (not sufficient condition). In Figure 6b, “*the square matrix appears again incomplete but with an illusory bright square larger than the black ones and not occluding anything*”. The occlusion of one small square is more an inference than a perceptual result. Furthermore, “*the four crossed black squares, all around the largest bright one, do not appear incomplete or partially occluded*” even though they are connected through T-junctions with the illu-

sory square (as reported by the subject through a sketch) and are pairwise-colinear, which is a basic constraint that often leads to amodal completion. One may argue that the perceived incompleteness is global; i.e., of the square matrix and not of single black squares. Even if it were so, “*the square matrix does not appear completed*”. To be completed, a small square should be perceived behind the illusory large square, that “*does not appear occluding anything even if it is tangent to the sides of four black squares all around, that in their turn do not appear incomplete or partially occluded*”. To sum up, Figure 6b is a case of incompleteness that is not completed by an illusory square neither locally nor globally. This result represents a logical confutation of the role played by incompleteness if incompleteness is considered as the necessary condition.

**Figure 6**



Incompletenesses are not necessarily completed by illusory figures: (a) a square matrix with a missing element in the right upper corner; (b) an incomplete square matrix with an illusory bright square larger than the black squares and not occluding any element; (c) a square frame made up of black squares (control condition); (d) an illusory bright square occluding a black cross (control condition).

These perceptual results are particularly interesting even in the light of Figures 6c and 6d. By annulling the global effect of the matrix— that is, by leaving the just square frame around the large white square of Figure 6b, as illustrated in Figure 6c— neither the illusory figure nor the incompleteness is perceived, but “*only a square frame made up of black squares*”. This result implies a global effect of the grid on the illusory figure formation in Figure 6b. By comparing this result with the one of Figure 6d, where the squares in the corners of Figure 6c are missing, another perceptual result emerges: “*an illusory bright square occluding a black cross*”. Under these conditions, “*the black squares complete themselves amodally in a cross partially occluded by a large illusory white square*”. This result is not perceived in Figure 6b and demonstrates that even complete squares can induce an illusory

figure, contrary to theories that assert a necessary role for incompleteness.

However, a counterargument in favor of these theories states that, when the illusory figure is perceived, the inducing elements complete themselves amodally in a more global figure different from the geometrical inducing elements. Within this counterargument, incompleteness becomes an *a posteriori* result that can be defined and known only after the perception of the illusory figure. This kind of reasoning implies the same paradoxes defined in Section 2. Nevertheless, even accepting the logic of this counterargument, it is phenomenologically weakened by the perceptual result of Figure 6b, but it will be more definitively rejected in Section 3.5, when more probing counterexamples will be shown.

Figure 7 (Pinna, 1990) reports two conditions phenomenologically in agreement with the previous results: “*an illusory rectangular stripe behind the four black central squares*” (Figure 7a), and “*an illusory diagonal of five squares demarcating the separation between the two halves of an incomplete square matrix of squares*” (Figure 7b). Note that “*the illusory stripe of Figure 7a does not occlude any square, rather appears coplanar to the other squares on its sides above and below, yet appears behind the four black squares contained in its surface*”. Figure 7c shows two alternative results: “*a large bright square similar to the one perceived in Figure 7d, with four black squares in its inner edges arranged along the arms of a virtual cross*”; and “*five bright squares at the same plane of the black small squares all around them*”. These alternative percepts emphasize the role played by figure-ground principles in inducing illusory figures.

**Figure 7**

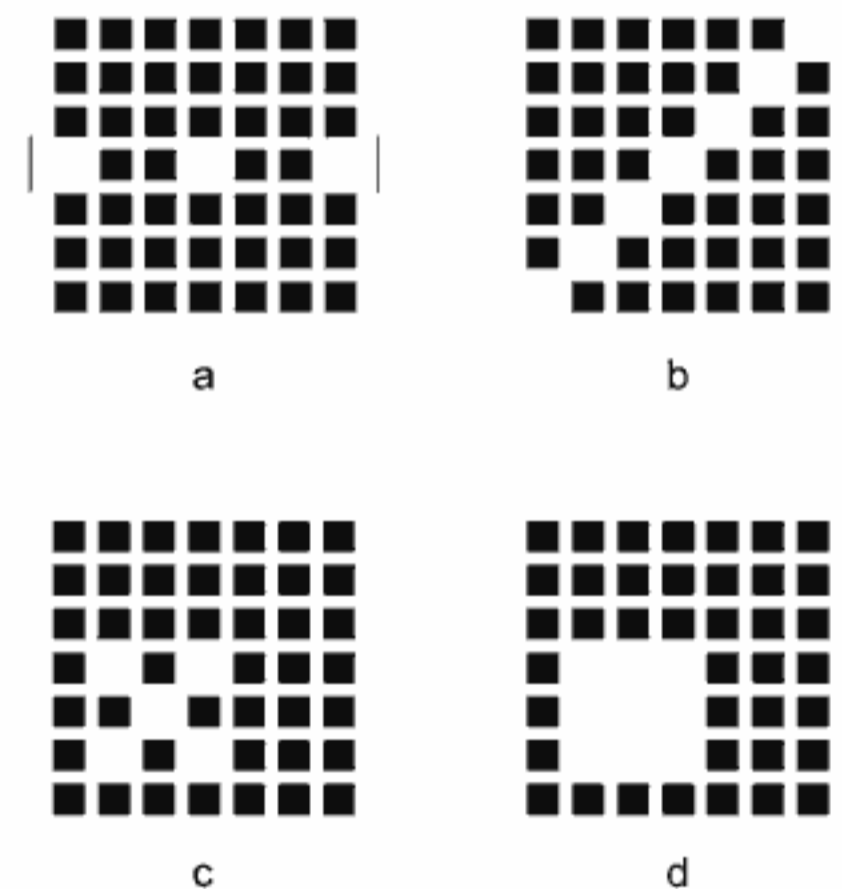
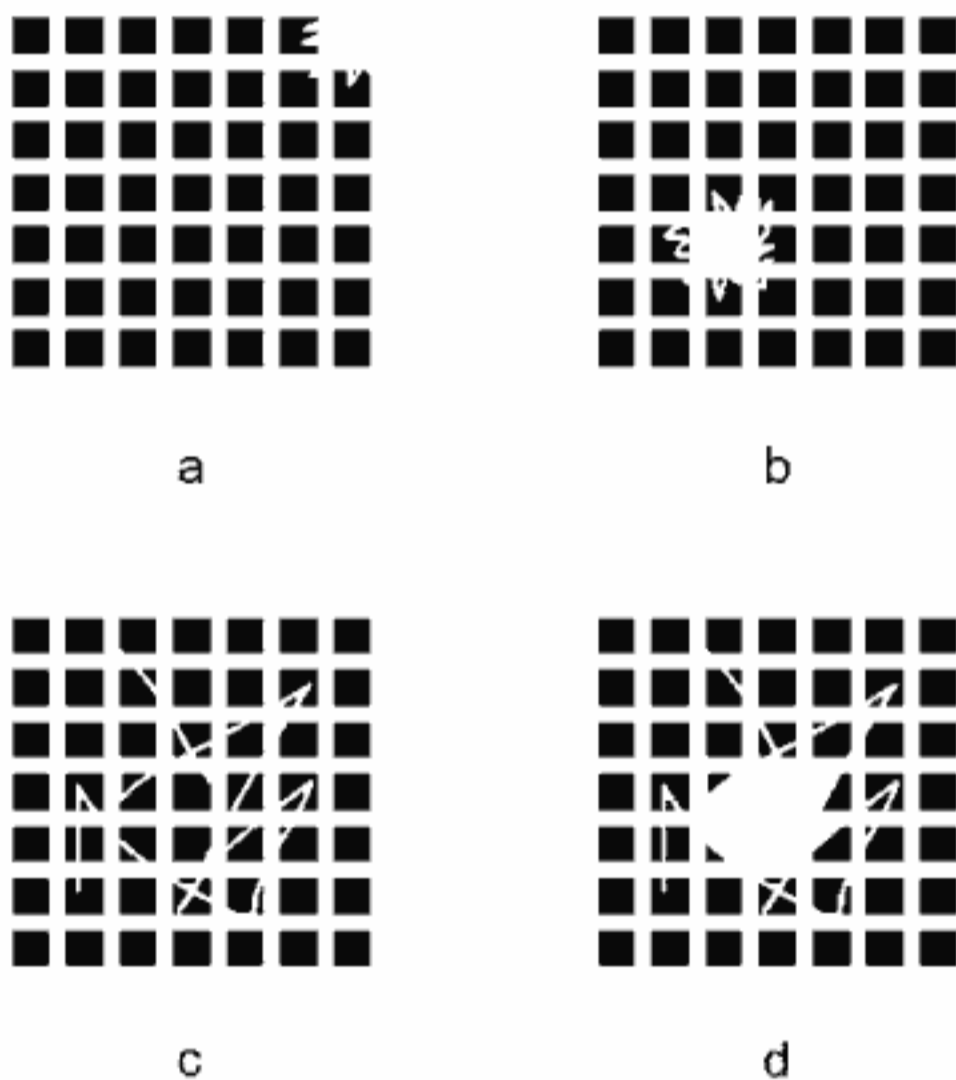


Figure-ground principles induce: (a) an illusory rectangular stripe behind the four black central squares; (b) an illusory diagonal of five squares demarcating the separation between the two halves of an incomplete square matrix of squares; (c) a large bright square with four black squares in its inner edges arranged along the arms of a virtual cross or, alternatively, five bright squares at the same plane of the black small squares all around them; (d) a large bright square.

The perceptual results of Figure 8 differ from those of Figure 6 in that “incompletenesses” are here accompanied by illusory figures similar to “*scribbles of white tint in front of one entirely occluded (Figure 8a) or some partially (Figure 8b) occluded squares*”. In the experiment, 12 out of 20 subjects reported that, in Figure 8a, “*the scribble does not occlude the entire missing square at the corner, but only partially the three around it*”.

The “*scribble*” perceived in Figure 8c, even if related to incomplete squares, “*appears to lie behind the crossed white bars of a window showing the dim interior of a room*”.

**Figure 8**



Different roles of incompletenesses in different form organizations: scribbles of white tint in front of one entirely occluded (a) or some partially (b) occluded squares; (c) the scribble lies behind the crossed white bars of a window showing the dim interior of a room; (d) the inner irregular white shape, similar to the body of an insect, appears in front of the partially occluded crossed bars while its legs appear intertwined in the bars.

described in Figure 4a. In Figure 8d, the inside edge of the scribble of Figure 8a is totally white and the ratio between distances is changed, so that phenomenally “*the inner irregular white shape, similar to the body of an insect, appears in front of the partially occluded crossed bars while its legs appear intertwined in the bars*”. Here, the bars are both occluded and occluding, depending upon the ratios.

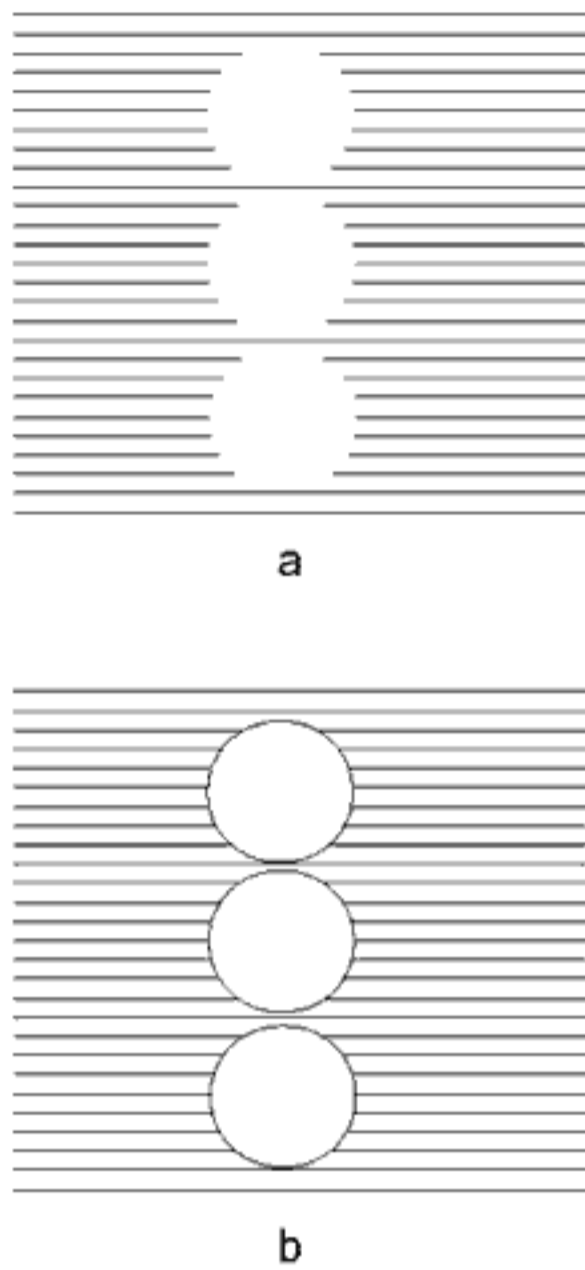
On the basis of these results, the question is: Which are the inducing elements, the bars or the squares? If incompleteness is a necessary factor, then the question has a paradoxical answer: The effect is cause of its cause. In other words, the incompleteness of the bars and not of the squares can be decided only *a posteriori* and it becomes the cause of the perception of the incompleteness of the bars and not of the squares. This is paradoxical only if incompleteness is considered a necessary factor. However, this criticism has in



the next Section 3.4 a further logical and phenomenological aspect from a different point of view. The new question is: Incompleteness of what?

### *3.4. The shape of incompleteness does not predict the shape of illusory figures*

Once the geometrical shape of “incompleteness” has been defined, can the shape of the illusory figure be predicted? More particularly, does the shape of the illusory figure correspond to the shape of incompleteness? And does the shape of the illusory contours agree with the shape of real contours when these complete the shape of the same incompleteness? Many experimental data demonstrate the equivalence of illusory contours with real ones. Illusory contours are like real contours in: producing geometrical illusions (Farnè, 1968; Pastore, 1971; Gregory, 1972; Bradley and Dumais, 1975; Bradley and Petry, 1977; Meyer and Garges, 1979); in being enhanced by kinetic depth information (Bradley and Lee, 1982); in being subjected to apparent and stroboscopic motion (Sigman and Rock, 1974; Grünau von, 1979; Ramachandran, 1985); in producing figural after-effects (Smith and Over, 1976, 1979; Meyer and Phillips, 1980); in being used as targets or masks in visual masking experiments (Weissten et al., 1974; Reynolds, 1981); and in serving in information-processing tasks as a landmark aiding the localization of elements in visual space (Pomerantz et al 1981). Von der Heydt, Peterhans, and Baumgartner (1984), and Peterhans and von der Heydt (1987) found that neurons in cortical area V2 of macaques respond at locations where illusory contours are perceived. These neurons respond with a similar slightly delayed excitatory response to both illusory and real contours that crosses their receptive fields, and both real and illusory contours produced similar orientation tuning in these cells.

**Figure 9**

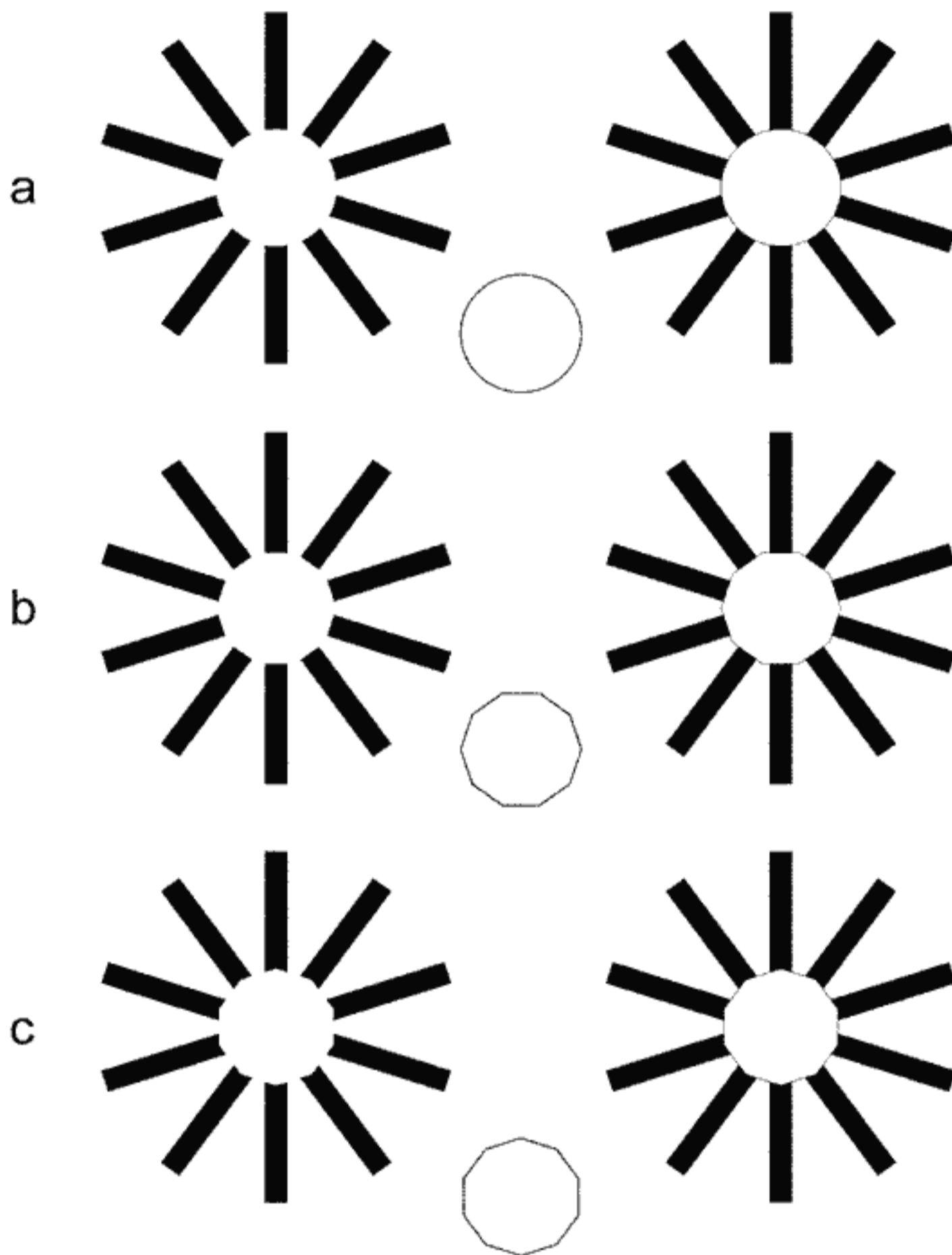
Illusory figure shape differs from the shape of the incompleteness. (a) An elongated or double lemon-like 8 amodally interweaved behind two single lines that appear curved is perceived despite the gaps correspond to three circles (b).

Despite these results, Figure 9 demonstrates differences between the two kinds of contours. In Figure 9a, a parallel distribution of horizontal lines encloses three circular gaps vertically arranged. However, they do not appear like three adjacent illusory circles but as “a double 8 amodally interweaved behind two single lines that appear curved”. Furthermore, “each circular shape of the 8 appears elongated or distorted with a shape similar to a lemon”. The “real” geometrical shapes of

the incompletenesses, shown in Figure 9b to be “three circles”, do not correspond to the shapes of these illusory figures.

The main point is: Why should three circular gaps be completed as described if the simplest figures that can solve the problem of incompleteness are three illusory circles? The complexity of the solution of the 8-like shapes, including their amodal completion, is far from being considered as the simplest solution. The general question raised by this figure is the following: If incompleteness is assumed to be a necessary factor, is it possible to predict the shape of the illusory figure that is induced to complete a gap in the simplest possible way? Figure 9a shows that the answer is No, and thus that real and illusory contours do not necessarily match.

Figure 10

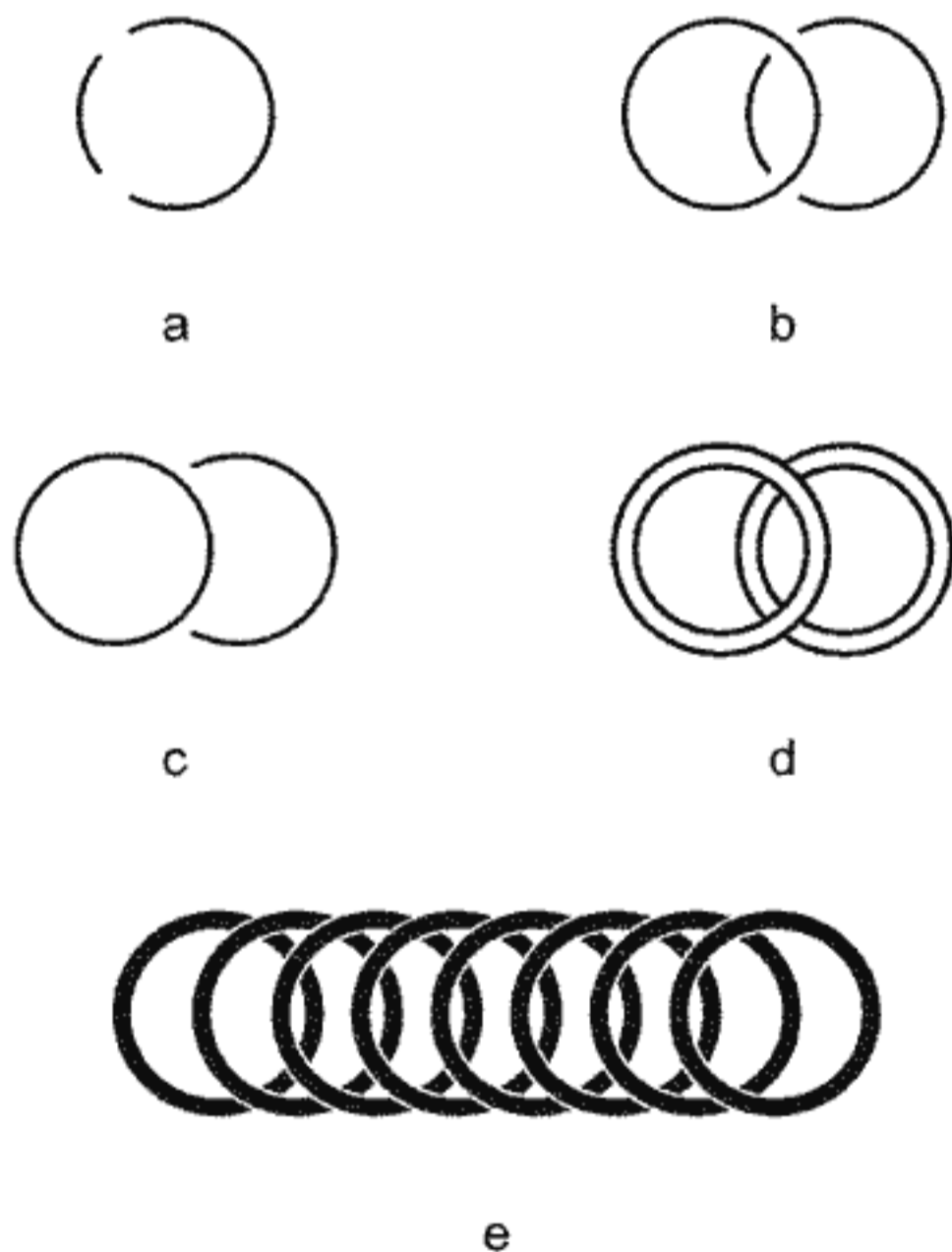


Illusion of angularity: the shape of the illusory figure concords with the shape of incompleteness, but real contours don't. (a left) An illusory disk – (a right) the circle appears to be polygonal with blunt angles directed towards the inside of the stripes. (b left) an illusory polygon – (b right) the sides of the polygon look convex with swellings inside the stripes and the vertices appear less pointed, blunter, and rounded off. (c left) an illusory polygon – (c right) the polygon appears more polygonal, pointed or sharper with the polygon sides appearing slightly concave and the vertices seeming to go even more inwards into the stripes.

Figure 10 sets the inverse problem: the shapes of illusory figures here are in agreement with the gaps, but, by completing the gaps with real contours, the perceived shapes do not match with the ones induced by the illusory figures. In Figure 10a left, “an illusory disk” is perceived filling the circular gap in the center of radial stripes. By replacing the illusory contours with real ones (Figure 10a middle), the “illusion of angularity” is perceived (Figure 10a right, Pinna, 1991). “The circle appears to be polygonal with blunt angles directed towards the inside of the stripes”. When the gap is a polygon with each vertex lying between two contiguous stripes, “an illusory polygon”, similar to the gap shape, appears (Figure 10b left). But when it is replaced by real contours (Figure 10b

middle), “the sides of the polygon look convex with swellings inside the stripes”. “The vertices appear less pointed, blunter, and rounded off” (Figure 10b right). By viewing globally, “the polygon appears more circular than the real circle” illustrated in Figure 10a right. If the gap is a polygon with vertices lying within the black stripes (Figure 10c left), “an illusory polygon is perceived”. But, when it is replaced with real contours (Figure 10c middle), “the polygon appears more polygonal, pointed or sharper with the polygon sides appearing slightly concave and the vertices seeming to go even more inwards into the stripes” (Figure 10c right). On the basis of these results, the question is: If the illusory figure is the solution to the problem created by the gaps, then why by replacing illusory with real contours – that is, by adding a real solution to the gaps – does the phenomenal shape appears different?

**Figure 11**



Inadequacy of incompleteness to predict how gaps should be completed. (a) A circumference with two missing arcs; (b) the white gaps become “something” (neither an illusory figure nor a gap) that allows one circumference to pass behind the other; (c) “something” that induce the incomplete circumference to be amodally completed behind the complete circle; (d) the amodal completion is less strong than in (b) and (c); (e) the gaps become the white illusory boundaries of the circumferences that appear as surfaces.

A demonstration from another point of view of the scientific inadequacy of incompleteness in predicting how gaps should be completed is shown by the illusory contours illustrated in Figure 11. A circumference with two missing arcs, as illustrated in Figure 11a, is not completed, but rather appears “broken even if within the gaps some weak brightness induction is

*perceived*". By inserting an identical circumference intersecting the gaps (Figure 11b), the white gaps are not perceived anymore as such but they become "*something that allows one circumference to pass behind the other*", that is "*the incomplete circumference is amodally completed behind the complete circle*". A similar effect is perceived in Figure 11c. What is this "*something*" is hard to define phenomenally, maybe an "illusory amodal completion". It is not an illusory figure in the known sense; "*it is not an illusory contour; it belongs to neither one nor the other circle; it does not appear as a gap or as incompleteness*". This illusory amodal completion "*is comparable or even stronger than the one illustrated in Figure 11d*". By increasing the amplitude of the gap, the strength of the amodal completion and the depth stratification effects increase accordingly.

By increasing the width of the woven circumferences and by decreasing the amplitude of the gaps (see Figure 11e), the illusory amodal completion persists but it assumes a different appearance: "*The gaps become the white boundaries of the circumferences that appear as surfaces*". Note that "*the bright illusory boundaries are perceived only along the crossover points and not everywhere along the circumferences*". They are "illusory" in the sense that they are detached from the real black region that they bound. These figures show that the real contours define a preferred orientation for attaching parallel illusory contours to their figure, even though these illusory contours, perceptually speaking, are real contours in the figure that bound, and thus complete, the black figures from which they are detached. In other words, these illusory contours define T-junctions with respect to the real contours from which they are detached. Again, these perceptual results and these phenomenal variations cannot be predicted from incompleteness as a sufficient condition for explaining illusory contour formation.

### *3.5. Incompleteness is not a necessary condition*

The most important logical condition to be studied is incompleteness as a necessary condition; that is, A is *necessary* for B if B *cannot* be true unless A is true. Consequently:

(i) if the inducing elements are complete, then no illusory figure should be induced or, in other words, a case of complete elements inducing an illusory figure can never happen.

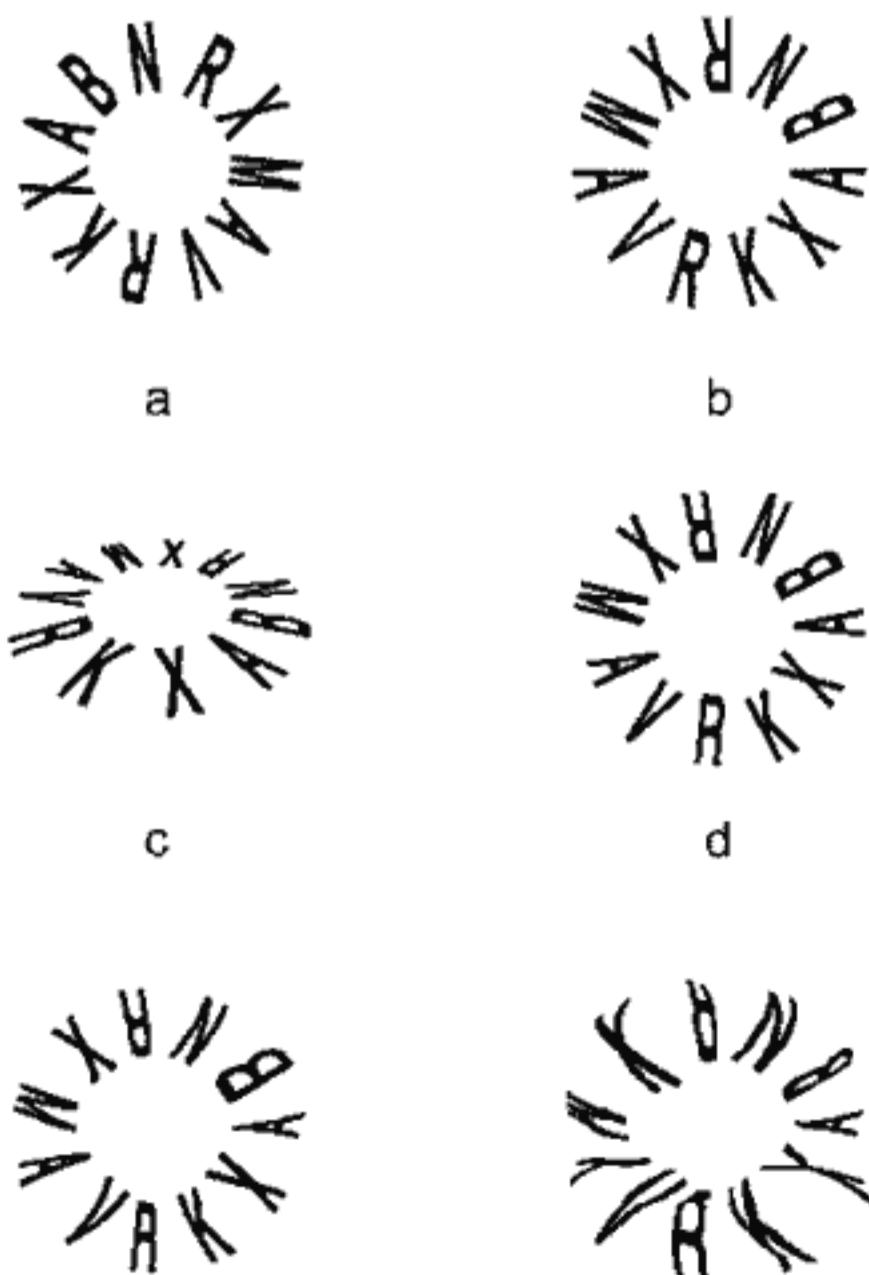
Within the logical rationale of cognitive and gestalt models, incompleteness is completed through depth segregation and amodal completion. Some consequences follow:

(ii) Whenever an illusory figure is perceived, necessarily the *depth segregation* of the illusory figure relative to the inducing elements, and their *partial occlusion* should be also perceived.

(iii) There should *never* be the case of an illusory figure *on the same depth plane* (coplanar) to its inducing elements.

At least three attempts have been made to disconfirm the necessary condition. One of them is the “Sun effect” by Kennedy (1976, 1978). By using triangles pointing towards a central open area, Kennedy demonstrated that illusory brightness can occur without amodal completion of the inducing elements. This is an interesting counter-example but does not completely disprove the role of incompleteness and completion. In fact, in the Sun effect, the illusory contours are perceived not as sharp boundaries but fuzzy ones, and the resulting brightness does not have the surface qualities of the Ehrenstein illusion, but rather appears diaphanous like a bright fog without defined depth segregation. Thus, this percept might be considered as a case of acute terminators inducing fuzzy illusory contours.

**Figure 12**



Purghé (1990) suggested another interesting case to refute the necessary condition. He arranged four black octagons in a way that the central illusory octagon appears that is tessellated to the other four all around it. This limiting case of amodal completion uses implicit Y-junctions between the illusory figure and the inducing elements. The strongest refutation of the necessary condition would contain T-junctions between the inducing elements and the illusory figure.

By modifying the Ehrenstein figure, Ehrenstein (1941), Pinna (1996), and Pinna et al. (2004) investigated