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Perceptual organization of shape, color, shade, and lighting in visual and pictorial objects

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Abstract. The main questions we asked in this work are the following: Where are representations of shape, color, depth, and lighting mostly located? Does their formation take time to develop? How do they contribute to determining and defining a visual object, and how do they differ? How do visual artists use them to create objects and scenes? Is the way artists use them related to the way we perceive them? To answer these questions, we studied the microgenetic development of the object perception and formation. Our hypothesis is that the main object properties are extracted in sequential order and in the same order that these roles are also used by artists and children of different age to paint objects. The results supported the microgenesis of object formation according to the following sequence: contours, color, shading, and lighting.

Keywords: Shape perception, color perception, perceptual organization, shading and lighting perception, watercolor illusion, vision and art.

1 What is a visual object?

1.1 Figure-ground attributes

The answer to the question "what is a visual object?" starts from the figure-ground segregation first explored by Rubin in 1921, who studied the three main properties belonging to the figure, but not the background, in conditions based on simple contours. Through phenomenological experiments, Rubin discovered the following general figure-ground principles: surroundedness, size, orientation, contrast, symmetry, convexity, and parallelism. In his experiments, Rubin used line drawings to emphasize one aspect of the representation of such objects, namely, the 2-D outline—the external bounding contour, or silhouette.

In Figure 1 these properties are clearly visible. This figure can be described as follows: four wiggly rectangles, the larger one including the other three, smaller and similar to three biscuit-like surfaces upon a plate. The four rectangles assume the shape traced by the contours, implying that the contours belong unilaterally to each rectangle (border-ownership, see Nakayama and Shimojo 1990; Pinna 2010a; Spillmann and Ehrenstein 2004), not to their backgrounds—ie, the area surrounding the large rectangle and the area included in the large rectangle that is the background of the small rectangles.

It is worthwhile noticing that the inclusion of the three small rectangles inside the surface of the large one induces the perception of two other possible results as alternatives to the previous descriptions (ie, by perceiving one, the other is excluded and vice versa). These alternatives are the following: (i) the large rectangle appears as an empty space (some kind of window or simply as a wiggly contour) or as a hole while the small rectangles are perceived as surfaces and (ii) the small rectangles can be perceived as three holes upon the rectangular surface. These outcomes, even if possible and partially reversible, are not as strong as the previous main description that can be attributed to the size and surroundedness principles studied by Rubin.

The color/brightness of the large rectangle and of the small ones is perceived full like a surface and denser than the same physical color/brightness on the surrounding background that appears instead empty, therefore, 100% transparent (Rubin 1915, 1921). More specifically,

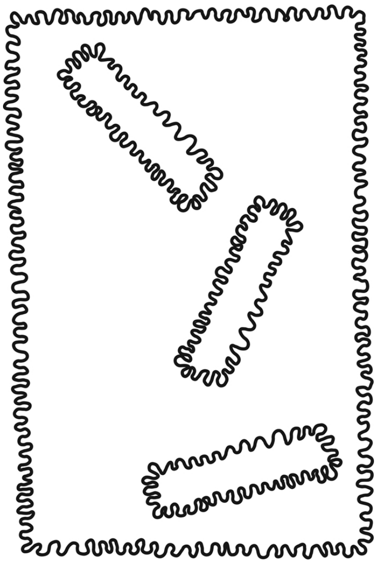

Figure 1. Four wiggly rectangles, the larger one including the other three, smaller and similar to three biscuit-like surfaces upon a plate.

the rectangles show a surface color/brightness property (*Erscheinungweise*, Katz 1911, 1930): the chromatic paste appears solid, impenetrable, and epiphanous like a surface; on the contrary, the background is not seen like a surface but empty, penetrable, and diaphanous, similar to a void (Katz 1911, 1930). The small rectangles appear like figures in relation to the large rectangle, which is perceived as a sort of "background" with respect to the small rectangles but like a figure or a surface if compared with the surrounding space, perceived instead as an empty background. Briefly, the large rectangle appears as a "background surface", on which the small rectangles are placed. The phenomenal notion of "background" emerging from the two conditions (empty space surrounding the large rectangle and large surface containing the small rectangles) belongs to two different domains: figure-ground segregation and part-whole (surrounding-included) differentiation. Thus some chromatic/brightness differentiations are perceived between the small and the large rectangles, but not in terms of full and dense versus transparent and empty as occurs with the large rectangle and surrounding space. These results suggest that every kind of figure-ground or part-whole segregation elicits a chromatic-brightness differentiation, whose phenomenal properties depend on the specific kind of segregation perceived.

Next, and joined to the previous figure-ground attributes—ie, the unilateral belongingness of the contours that become boundaries of the figure and the chromatic/brightness differentiation between figure and background—there is a third main attribute, namely, that figures appear closer to the observer than do backgrounds: thus, the large rectangle appears closer than the empty surrounding space, and the small rectangles appear closer than does the large one.

The perception of the three attributes is clearly related to the formation of the main object attributes, ie, shape, color, and depth (Rubin 1915, 1921), emerging when a figure-ground segregation occurs.

Figure 1 suggests that a single contour is perceived as a breakpoint differentiating the visual field in complementary (opposite) attributes related to shape, color, and depth. In other words, a contour induces a phenomenal asymmetry of figure-ground attributes. If this were not true, then it would be impossible to perceive Stravinsky's portrait in Picasso's drawing illustrated in Figure 2a or, more simply, an amoeboid *surface* in Figure 2b. Instead, the expected results would have been, in Figure 2a, a complex set of contours running in different directions and intersecting one another without showing any specific surface or object organization, and in Figure 2b, an undulated closed *contour*. It should be noted that Picasso's drawing shows both figure-ground segregation and part-whole organization as in Figure 1, demonstrating superimposed planes and layers of figures and surfaces completing amodally (Pinna 2008a) one behind the other.

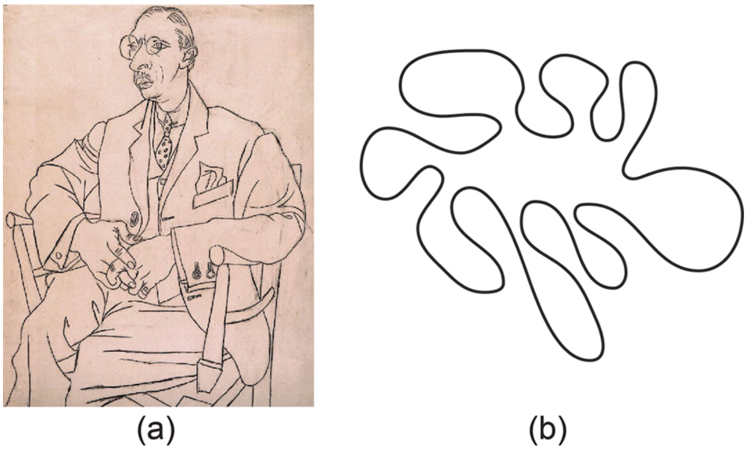

Figure 2. Stravinsky's portrait (1920) by Picasso (a) and an amoeboid surface (b).

The phenomenal organization of contours in figure-ground and part-whole organizations can be considered as the visual evolution of a contour in a surface. The perception of Figure 3a as an open figure rather than as an undulated contour clearly demonstrates this unavoidable evolution. The figural effect strongly persists. This result also occurs in Figure 3b, where the vertical undulated contour creates a figure-ground segregation on both its left and right sides. The three attributes of shape, color, and depth even if reversible on the two sides are distinctly perceived. In Figure 3c, the perception of a contour is enhanced at the expense of the surface evolution by interweaving its terminations. It is expected that the line perception from its ends fills the entire contour, thus eliciting the perception of an undulated line. This expectation prevents possible inner contradictions or antinomies within the contour continuation (see also Pinna and Reeves 2006). Nevertheless, this is not the main result: the undulated central component of the contour, the one not interweaved, is seen as a figure or as a surface similarly to Figure 2b and Figure 3a. Despite the uniqueness of the geometrical contour and of the good continuation principle as suggested by Wertheimer (1922, 1923), the line is perceived as such only in its terminations and becomes a surface (a boundary contour) in its central component. This figure shows the necessity to distinguish between line and contour perception, where the contour refers to the conditions where a line represents a shape or a surface.

It is worthwhile noticing that the global convexity of Figure 3c creates an inside-outside effect in the whole figure. However, the same distinction between line and boundary contour occurs also when the inside-outside effect is annulled in conditions similar to Figure 3b (Figure 3d). This demonstrates that interweaving versus untwine conditions are the most responsible for the presence within the same figure of contours that appear as lines or boundary contours along the same drawing.

This kind of discontinuation of contour and figure/surface perception can also be observed in Picasso's (Figures 4a–e) drawings. More specifically, in Figures 4d–e, the surrounding contours among all the ones illustrated become the boundary of the figures, while the inner ones appear like filling coloration or part-whole articulation. All the previous examples support the idea that the contours tend to become the boundaries of segregated surfaces,

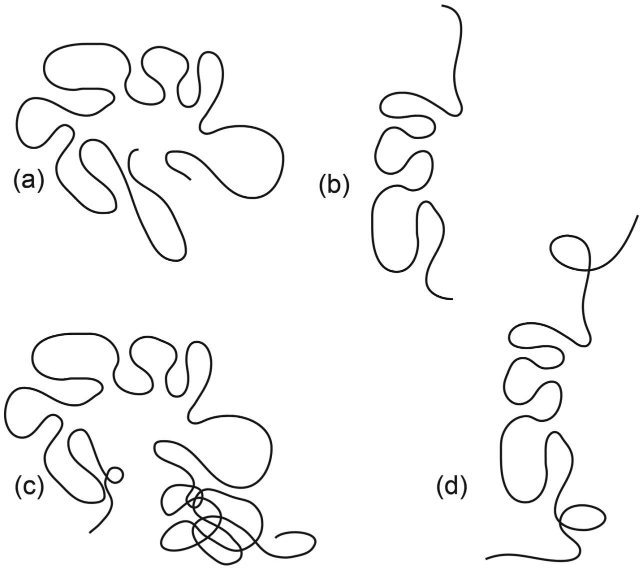

Figure 3. An open figure (a), figure-ground segregation on both left and right sides (b), the non-interweaved undulated central component of the contour appears as a figure (c–d).

even under unfavorable conditions like those illustrated in Figures 3c and 3d and Figure 4, thus creating asymmetrical and complementary figure-ground attributes.

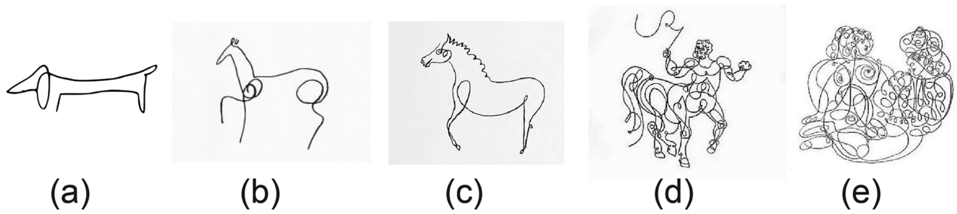

Figure 4. Picasso's drawings. (a) *The Dog*, 1907; (b) *The Horse*, 1907; (c) *The Horse*, 1912; (d) *The Centaur*, 1910; (e) *Women*, 1915.

The figure-ground segregation problem, posed by the previous figures, is related to the way the complementary properties are extracted and organized. The main questions we asked in this work are: Where are representations of shape, color, depth, and lighting mostly located? Does their formation take time to develop? How do they contribute to determining and defining a visual object, and how do they differ? How do visual artists use them to create objects and scenes? Is the way artists use them related to the way we perceive them?

2 General methods

2.1 Subject

For each set of figures different groups of 12 undergraduate students of architecture, design, and linguistics (regarding the descriptions of the figures reported within all sections, except section 4.2.1) as well as 12 children for each age from 5 to 18 years old (as regards the results reported in section 4.2.1) participated in the experiments. Undergraduate students had some basic knowledge of gestalt psychology and visual illusions, but they were naive both to the phenomena studied and to the purpose of the experiments. Within each group, subjects were about 50% male and 50% female, and all had normal or corrected-to-normal vision.

2.2 Stimuli

Stimuli were the different sets of pictures that are presented in the following sections of the article. Every set of stimuli was described by a different group of subjects. The overall sizes of the visual stimuli were ˜4 deg. The figures were shown on a computer screen with ambient illumination from an Osram Daylight fluorescent light (250 lux, 5600° K). Stimuli were displayed on a 33 cm color CRT monitor (Sony GDM-F520 1600x1200 pixels, refresh rate 100 Hz), driven by a MacBook Pro computer with an NVIDIA GeForce 8600M GT. Viewing was binocular in the frontoparallel plane at a distance of 50 cm from the monitor.

2.3 Procedure

Two methods were used with undergraduate students: one more qualitative (phenomenological task), similar to those used by gestalt psychologists, and another more quantitative (rating task). A new task (pictorial reproduction task) was used with children of different ages.

2.3.1 *Phenomenological task*

The task of the subjects was to report spontaneously what they perceived by giving an exhaustive description of the main visual property. The descriptions were provided by at least 10 out of 12 subjects and were reported concisely within the main text to aid the reader in the stream of argumentations. The descriptions were judged by three graduate students of linguistics, naive as to the hypotheses, to get a fair representation of the ones given by the observers.

Subjects were allowed to make free comparisons, confrontations, afterthoughts, to see in different ways, distance, etc, to match the stimulus with every other one. Variations and possible comparisons occurring during the free exploration were noted down by the experimenter. As concerns these tasks and procedure see Pinna (2010b).

2.3.2 *Rating task*

A new group of 12 subjects rated the adequacy of the edited results that emerged from the phenomenological task. They were instructed to rate (in percent) the descriptions of the specific attribute obtained in the phenomenological experiments. In other words, subjects were instructed to rate the relative strength or salience (in percent) of the descriptions of the phenomenological task as follows: “please rate whether this statement is an accurate reflection of your perception of the stimulus, on a scale from 100 (perfect agreement) to 0 (complete disagreement)”. Throughout the text, we reported descriptions, whose results of the rating task (mean rating) were greater than 80.

2.3.3 *Pictorial reproduction task*

The task of the children was to describe and make a painted copy (the order of the two tasks were randomized) of what they perceived on the computer screen (see the stimuli reported in section 4.2). Possible stages of development were defined by 100% of times that subjects represented the stimuli in a specific way. Children could use freely all the pastels, provided by the experimenter in a paintbox containing 36 different colors. All subjects were tested individually and video recorded to keep track of the temporal sequence of the pictorial reproduction. During the experiment, observation and painting time was unlimited. Reports for visual stimuli occurred spontaneously and fast, while painting time could change according to the children’s skills, age, and personal reproduction speed.

3 Boundary, color, shading, and lighting contours

3.1 Where are shape, color, and depth mostly located?

Some answers to the previous questions can be found by going back to the previous figures and by improving their figure-ground effects. As for the question "where are shape, color, and depth mostly located?", they suggested that, under these specific conditions, these attributes are placed along the contours. Because a single contour tends to be perceived as the boundary of an object, and because it tends to impart surface color/brightness attributes and depth segregation, it follows that the information about these three attributes depends and is placed along the contour.

A convincing demonstration of this general statement can be obtained by asking subjects to paint any object. It is expected that they take a black pastel and draw the boundaries of the object forming its shape. The drawing of the boundary contours is considered sufficient to create a visual object. It is sufficient because the addition of other information, such as color, shades, and lighting, is usually considered secondary with respect to the contours. The presence of contours is sufficient to create objects and events in many different domains like art (see previous drawings and the detail of Giotto's fresco of Figure 5a, detail of *Death of St Francis and Inspection of Stigmata*, 1320), comics (Figure 5b), Roman mosaics (Figure 5c), and Greek decorations (Figure 5d).

It is necessary because without contours no object can be created. This is also true under conditions apparently contradicting this statement, like in Seurat's paintings, where lines and contours are now made of discrete elements (points) instead of continuous lines. Therefore, these paintings can be considered in terms of visual scale and observation distance. The primary role of contours remains strong also after a very large magnification and even when only the dots emerge. In fact, under these conditions the tendency to group the dots in objects and create contours is immediate as demonstrated by gestalt psychologists.

In Figure 5e, Picasso's woman (*Blue Nude*, 1902) emerges not on the basis of the colors filling the canvas but mostly because of the contours that organize the chromatic paste to become different properties of the woman's body, ie, shade, surface color, and light. A further demonstration of the necessary condition is the fact that contours are depicted even where they are not physically required. This implies that contours are phenomenally but not physically necessary. In Figures 5f–h, respectively, two paintings by Schiele (*Self-Portrait*, 1910 and *The Artist's Wife*, 1917) and one by Botticelli (*The Birth of Venus*, 1482) show the use of the sharpness and strength of the contours and demonstrate their shaping effect placed everywhere in the figure even where contours are not necessarily required. Last but not least, as demonstrated by Rubin, all the figure-ground properties emerge immediately and automatically with contours and so without any need to paint them or to add shading or lighting. All these examples prove that the contours are of paramount importance in defining a visual object.

In spite of these arguments, by using only one black contour it is difficult or impossible to understand the visual organization of the figure-ground attributes, and thus some of the previous questions: Does their formation take time to develop? How do they contribute to determining and defining a visual object, and how do they differ?

To answer these questions, we suggest introducing along the contours some variations as demonstrated by the watercolor illusion (Devinck et al 2005; Pinna 1987, 2005, 2008b; Pinna and Grossberg 2005; Pinna et al 2001; Pinna et al 2003; Spillmann et al 2004; von der Heydt and Pierson 2006; Werner et al 2007; Wollschläger et al 2002). The set of figural properties emerging from this illusion depends on two factors: the juxtaposition of contours and the formation of asymmetrical luminance and chromatic conditions along the contours. The main argument is the following: because Rubin's figure-ground attributes emerge by virtue

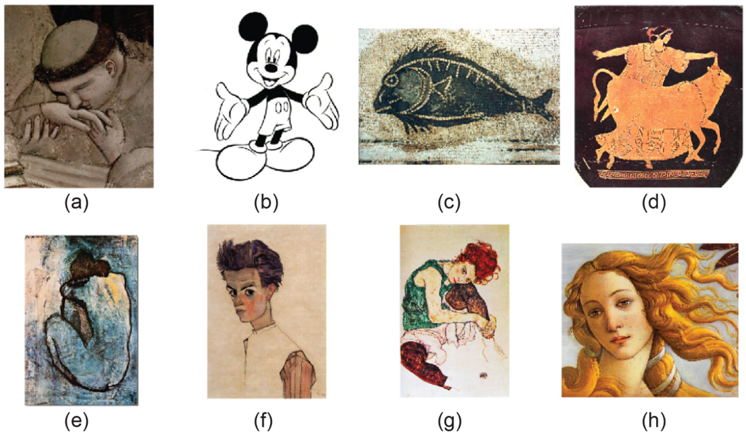

Figure 5. Examples of the primary role of the boundary contours in defining a visual object.

of the phenomenal complementation of the unilateral belongingness of the boundaries, the chromatic brightness induction and depth segregation produced on both sides of a contour, by creating a physical asymmetry (asymmetrical gradient) through a juxtaposition of contour, the complementary figure-ground attributes are expected to be enhanced and possibly attributed to different adjacent contours. This suggests different contour roles in the watercolor illusion.

3.2 Different contour roles in the watercolor illusion

3.2.1 *Shape and color with two contours*

One of the simplest conditions of the watercolor illusion induced by two adjacent contours is illustrated in Figure 6, where the black contours of Figure 1 are split into two adjacent purple and orange contours. Phenomenally, the three figure-ground attributes described in relation to Figure 1 are strongly improved. (i) The three biscuit-like surfaces and the large wiggly rectangle show now less ambiguously the unilateral belongingness of the purple boundaries to them, ie, their belongingness is now perceived univocal and not reversible. The other possible solutions described in Figure 1 become now impossible: both the large and small rectangles cannot be perceived as holes or empty spaces. (ii) The inner coloration of the figures appears epiphanous, like a surface color, and is distinctly perceived tinted with a light orange color that fills homogeneously the biscuits and the large rectangle. (iii) The part-whole organization is perceived univocal, ie, three small wiggly rectangles closer like bas-reliefs placed upon a large rectangle segregated in depth from the empty surrounding space.

Starting from this figure, a deeper phenomenological analysis advocates several general statements. First of all, the unilateral and univocal belongingness of the purple contours to the biscuit-like shapes and to the large rectangle suggests that *only one of the two juxtaposed contours becomes the boundary of the object*. Pinna (2005) and Pinna and Reeves (2006) showed that the contour with the highest luminance contrast tends to be perceived as the outermost boundary of the figure. We call this "boundary contour". In Figure 7, by reversing the colors of the two contours, ie, the purple becomes orange and vice versa, the boundary contour is also reversed, creating three biscuit-like holes within a large rectangular hole. "Holes upon a larger hole" is very different from "figures upon a figure". Only the second condition is logically possible. However, what is logically impossible can be phenomenally possible. The two domains obey different rules (see also Kanizsa 1985, 1991). It is worthwhile

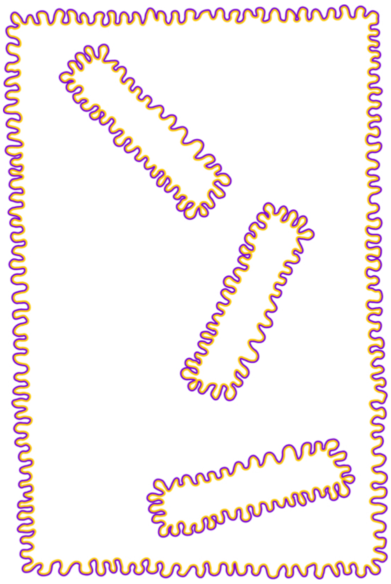

Figure 6. The watercolor illusion.

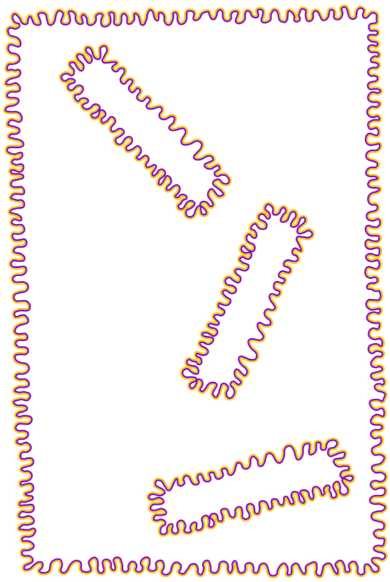

Figure 7. A variation of Figure 6 by reversing the colors of the two contours.

noticing that by perceiving these results the gaze spontaneously follows the contours in all their inner and outer components.

To better appreciate the perception of holes upon a larger hole see Figure 8. Here, the three holes are now placed on a large rectangular surface.

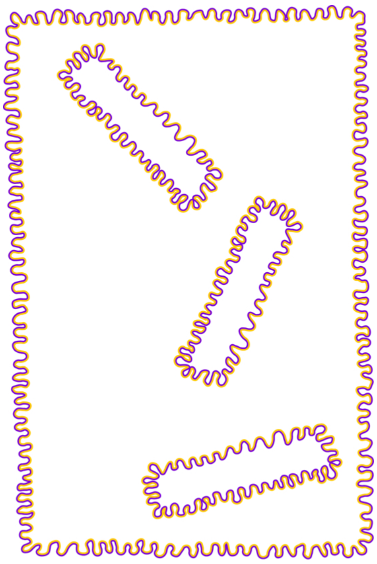

Figure 8. A variation of Figure 7 by reversing the colors of the large rectangle.

The second main statement derived by the previous figures and the first statement say that *if one of the two contours assumes one role, the juxtaposed one assumes a different role*. In particular, if the purple contours of Figure 6 are the boundaries of the objects, the orange contours define their color. We call this "color contour". A further demonstration of this general statement can be proven phenomenally by referring to the spontaneous descriptions of Figure 6: three orange biscuits overlapped to a large orange rectangle. What is striking about this description is what is not mentioned—ie, the color of the boundaries. Only the color contour has a noticeable color while the boundary contour, playing a boundary role, does not show its color. This does not mean that we cannot see the color of the boundary contours, but that it remains "unspecified" and unnoticeable like a background. Even if Picasso in Figure 5e used black contours to define the boundaries, nobody sees a black woman. The color of the boundaries—even when strengthened and therefore more visible like in Picasso's painting—appears chromatically unspecified. The boundaries are boundaries without color (ie, they manifest a unique role, just *boundaries*). In other words, the boundary contours define only the boundaries and not the color, ie, the inner coloration. In Figures 9a–c, the colors of the boundaries of Matisse's paintings are irrelevant because they are boundaries, so they pass unnoticed.

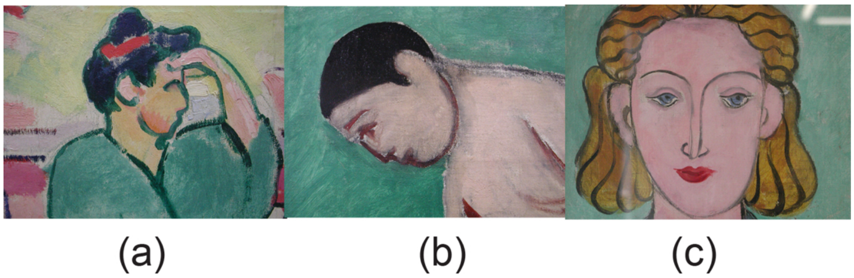

Figure 9. Matisse's paintings. (a) *Lady on the Terrace*, 1902; (b) *De jeu-de-boulesspelers*, 1908; (c) *Young Woman*, 1939.

Another way to demonstrate the specialized and unique role of the contours is illustrated in Figure 10, where a variation of Picasso's horse shows a couple of black contours (Figure 10a) slightly but clearly shifted in the oblique direction (see also Pinna 2011). The shifted contours show an effect of blur or duplicity of the boundaries of the horse. On the basis of the first general statement (only one of the juxtaposed contours, ie, the one with the highest luminance contrast, becomes the boundary of the object), given two black contours, none of them prevails on the other as a boundary contour and none prevails as a color contour but both are perceived as boundaries. The color contour can be assigned only after the boundary contour has been already assigned.

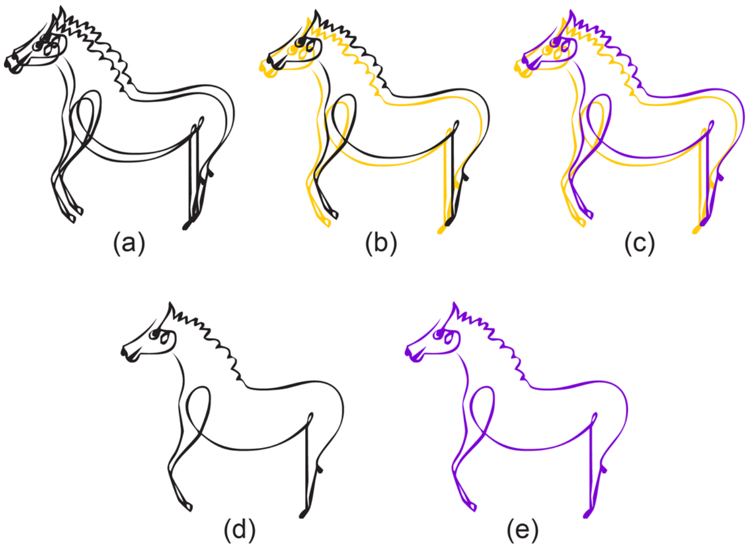

Figure 10. Variations of Picasso's Horse.

By replacing one of the two black contours with an orange one (Figure 10b), an orange horse is now perceived. It is very difficult to perceive a black horse. The black contour is predominantly perceived as the boundary of the horse, while the orange contour appears as its color. It is worthwhile noticing that the modal coloration of the watercolor illusion is now absent, but an amodal spreading of color is perceived. The difference between the two colorations is based on their phenomenal appearance: in the case of the watercolor illusion, the color is perceived as painted within the figure, in the case of the horse the orange color of the contour is perceived as its color without modal coloration, but giving anyway a sense of chromatic completeness, unity, and wholeness (Pinna 2008a). We call this "amodal wholeness of color".

When the black contour is replaced by a purple one (Figure 10c), the horse appears orange: the color of the purple contour passes unnoticed and can be discounted similarly to the black contour of Figure 10b. Therefore, the orange contour assumes again the role of color and the purple one the role of boundary. The role specialization emerges also from the fact that we perceive an orange horse and not a purple or a purple-orange horse. This suggests that the boundary role belongs to the contours with highest luminance contrast independently from its color. It is worthwhile saying that when there is only one contour as shown in Figure 10d and 10e, the first attribute that tends to be extracted and perceived is the boundary. Its color passes unnoticed because it assumes the role of boundary. Therefore, in both these conditions we perceive a horse and not a black or a purple horse.

The previous figures suggest a third general statement: *while boundary contours are geared to delineate, outline, and segregate an object locally and in detail along the subtle line that splits a figure from its background, color contours are aimed to complete and fill globally both modally and amodally the inner surface of a visual object.*

From the three previous statements it follows that the information needed to define shape and color of a perceptual object is placed on its external bonds and limits, thin like two juxtaposed contours and placed where the object segregates from the background. From the external contours these properties fill the whole object along the boundaries and within its surface.

Two controls with contours near equiluminance, illustrated in Figures 11a–b, corroborate these observations by demonstrating that the two contours show both boundary and color roles.

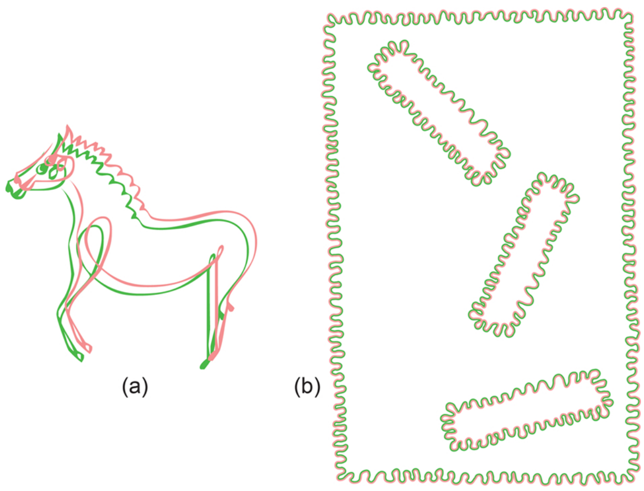

Figure 11. Controls near equiluminance.

3.2.2 *Shape, color, depth, and lighting with six contours*

By using two juxtaposed contours we can study the role of two (boundary and color contours) of the three properties of the figure-ground segregation. Under these conditions, the two roles appear clearly distinct. Nevertheless, the further distinction among boundary, color, and depth attributes cannot be effectively studied and, thus, understood by using only two juxtaposed contours. As a matter of fact, the orange contour does not show only color assignment but also shading and depth properties. The decrement of the luminance contrast perceived through the wiggly contours and the illusory coloration—the purple contour, the orange contour, and the light orange coloration—creates an asymmetrical luminance profile that provides a depth cue similar to that of the luminance gradients that govern the shape-from-shading (Pinna et al 2003; Spillmann et al 2004) and the Renaissance Chiaroscuro (Pinna 2005; Pinna and Reeves 2006).

The Renaissance artists used the chiaroscuro (see Figures 13a and 13c in section 4.1) as a standard set of rules to apply light and shadow to a shape in order to create an illusion of depth. A highlight marks the point where the light is orthogonally reflected. This is most often bright white, and it is the closest point to the light source where light is most concentrated. Highlights can be seen more easily on reflective or glossy surfaces. Moving away from this highlight, light hits the object less directly and therefore has a darker value of grey. The shadow is the dark region opposite the light region. The core shadow is the center of the darkened area. The reflected light area is the back edge of an object. It occurs in a shadowed area and is caused by the light being reflected from another area or created by a secondary light source.

To study and understand the organization of boundary, color, and depth attributes, it is necessary to add more adjacent contours (eg, for a total of 6 as illustrated in Figures 12a–b; due to the limited space and therefore to the size of the illustrations, the number of contours may not be perceived clearly, but they emerge when zoomed into). Pinna (2008a) demonstrated that by increasing the number of adjacent contours, (i) the unilateral belongingness of the object becomes stronger, (ii) the modal coloration effect decreases, and (iii) the depth segregation and the volumetric effects increase. The amoeboid objects appear like irregular undulated shapes with a 3-D appearance, similar to a high relief, illuminated by a bright light. The inner regions can be perceived as bright fuzzy whites, luminous and slightly whiter than the white of the backgrounds. Nevertheless, the colors of the whole objects are amodally perceived, respectively, as yellow (Figure 12a) and magenta/fuchsia (Figure 12b). Again, even if the modal coloration is almost absent, the amodal one can be clearly perceived. A control is shown in Figure 12c.

To judge the phenomenal strength of these results, we can try to perceive Figures 12a–b according to the following descriptions, which are alternatives to the previous ones: (i) two amoeboid objects, yellow and magenta in their periphery and white inside; or (ii) two amoeboid white objects, yellow and magenta in their periphery; or (iii) two amoeboid yellow and magenta objects, white in their center. These descriptions do not say anything about the organization of color, depth, and lighting. Indeed, what emerges are two-tone objects. More particularly, in the first description the colors of the objects are juxtaposed and are, respectively, yellow/magenta and white; in the second description, the white is the color of the whole object while the yellow/magenta are colors of a part of each object (the periphery); finally, the third description reveals a part-whole organization opposite to the second description: the yellow/magenta are colors of the whole objects, while the white is the color of a part of each object (the center) (see also Pinna 2008a, 2008b). Though phenomenally probable, these descriptions are not perceived as strong as the previous ones, where the inner white of each object appears homogeneous and depending on the different distribution of illumination upon the object based on its 3-D volume.

The *tendency to perceive a unique color filling in the whole object* can be considered as a fourth general phenomenal statement. This can be demonstrated again through the a priori unlikely perception of the following more and more analytical description, where the local conditions are not organized in a whole: two amoeboid shapes, whose boundaries start with black, continue with a short luminance gradient of yellow and magenta, and end with white within the large inner area of each object. This kind of description does not say anything about the organization of the contours in boundary, color, and depth. Even if phenomenally probable, it belongs to the most unlikely pole of the perceptual gradient (see Pinna 2010b).

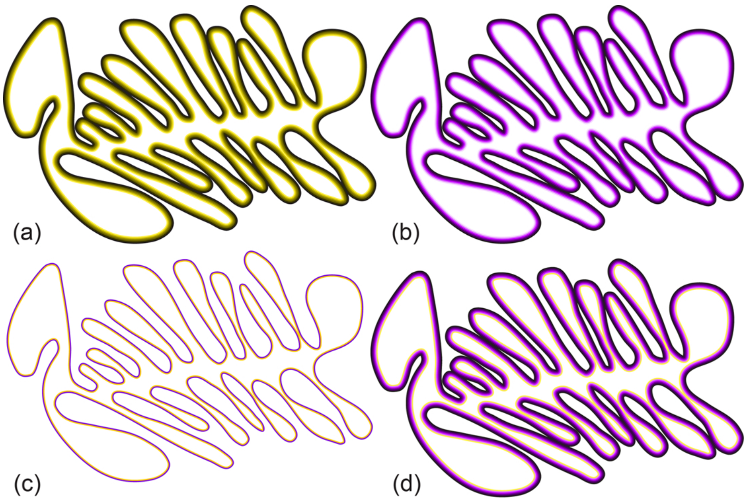

Figure 12. Boundary, color, depth, and lighting attributes obtained with six adjacent contours (for details see the text).

The tendency to perceive a unique color occurs also within the bunch of contours and not only between their color and the inner white. Not all the yellows and the magentas are perceived amodally as the color of the whole object but only one of them. This is clearly perceived and agrees with the second statement related to the specialization of roles. Phenomenally, the boundary contour appears to be followed by a bunch of juxtaposed contours with lower and lower luminance contrast modeling the volume by depicting and appearing like shades. We call this "shading contours". They precede the color contour responsible for both modal and amodal coloration. The location of the shading contours in between boundary and color contour suggests that they are aimed at enhancing the boundaries and the shape properties of the object. In other words, they belong to the shape domain, phenomenally different from the color domain.

The innermost contour at the extreme of the gradient with the lowest luminance contrast defines the properties of the lighting, its color and intensity, as shown in Figure 12d. We call this "lighting contour". The lighting contour is located in between the color contour and the brightest inner homogeneous area of the object. It belongs to the color domain. In other words, even if shading and lighting can be considered as part of the chiaroscuro, they are perceived as part of different objects: the shading enhances the unilateral belongingness of the boundaries by depicting its volume, while the lighting contour reveals the light and the illumination of the object.

The four roles, emerging from the adjacent contours (see also Pinna 2008b, 2008b; Pinna and Reeves 2006) under these simple conditions, suggest that most of the information needed to define shape, color, depth (volume), and illumination (under the conditions shown here) is placed along its boundaries, where the object is segregated from the background. The specialization of roles clearly demonstrates a new kind of perceptual organization of figurality.

The juxtaposition of contours reinforces and more strongly demonstrates the organization of these attributes but also adds a new property, the lighting, never mentioned by Rubin in these terms.

Now, if these roles are related to the main object attributes, the previous questions come back spontaneously: Does their formation take time to develop? How do they contribute to determining and defining a visual object, and how do they differ?

4 Microgenetic development of the object attributes

The previous questions, derived from the phenomenal specialized roles of adjacent contours, suggest that a holistic and integrated process like the figure-ground segregation can be segmented and broken up into different and individual attributes likely belonging to different neural pathways. These questions imply the idea of a microgenetic process that breaks up the holistic fabric of object perception into variably differentiated yet phenomenal meaningful attributes and relations among them. The term "genetic" refers here to the developmental dynamics of a psychological process (or "mental process"), not to a genome or to an adjectival use of the metaphor "genetic program".

By breaking up the continuous fabric of attributes, a microgenetic viewpoint invokes genetic precedence of continuum over discrete attributes and, at the same time, suggests their organization into specific forms on the basis of specific principles. The phenomenal precedence of continuum over discrete structures runs parallel and is accompanied by its opposite—ie, the phenomenal presence of discrete attributes forming the continuum of the perceived object. This statement of the problem goes beyond the idea of a reconstruction from elementary features because it embraces continuum and discrete, global and local, whole and parts, and object and attributes. These contraries are thus two ways of seeing the same thing. In this sense the answers to the previous questions suggest also a macrogenetic process—namely, the sudden integration of attributes producing a clear phenomenal variation in the structure of the object formation.

All the figures here considered cannot answer directly the previous questions, but the developmental dynamics of the process of formation and integration of attributes can mark out the way. We suggest that the visual organization of object attributes can be understood by studying how children of different ages and visual artists use these attributes to create objects and scenes. This implies that the way children, people, and artists paint is related to or is a reflex of the way people normally perceive and, thus, organize these attributes.

Microgenesis usually refers to development on a brief, present-time scale of a percept. This defines the occurrence of immediate experience as dynamic and unfolding and as differentiation in which the final experience is already embodied in the early stages of its development. This idea of microgenesis subsumes a cognitive approach according to which any process of perception is primarily a process of differentiation and development, rather than one of detection of a stimulus array or information, organization, and transformation of multiple primitive components. By studying the process of object developmental formation and thus by extending the dynamics observed from the few seconds to the minutes or hours necessary to create objects, we go beyond this controversy to being able to study both perspectives and point of views. The phenomenological and epistemological nature of this controversy will not be further considered in this work.

4.1 How do visual artists use figural attributes to create objects and scenes?

Figure 13a shows Leonardo's drawing (*Head of a Girl*, 1483) in different moments of the process of formation of a woman with the main object attributes.

Going from the outside to the inside of the figure, the number of object attributes increases more and more. On the right side, the boundaries are drawn as first and outline

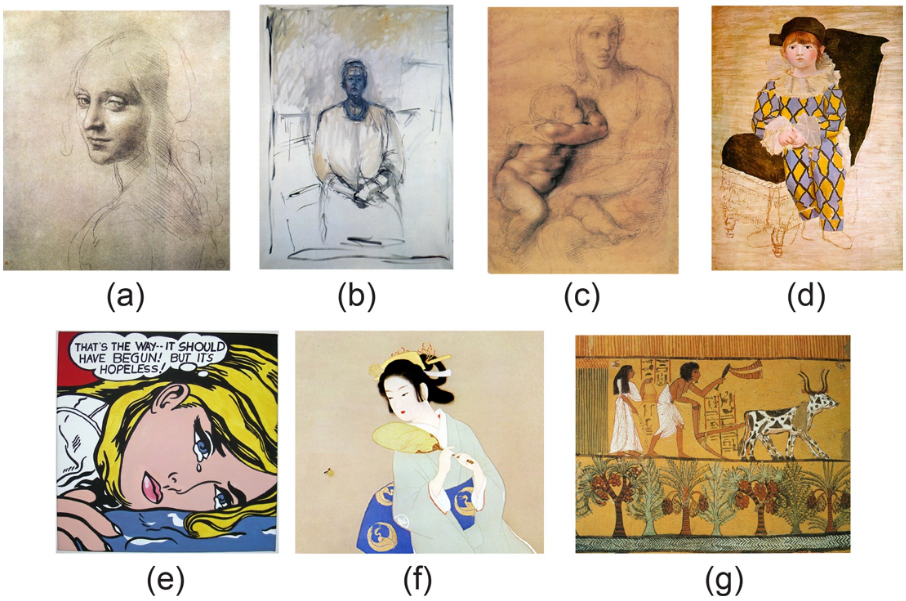

Figure 13. Organization of figural attributes used by artists in sequential order to create objects and scenes. Going from the outside to the inside of the figure, the boundary contours represent the first property segregating unilaterally a figure from the background and tracing its shape, then the color fills the inner edges, and finally, shading and lighting complete the figurality organization. (For details see the text.)

the whole shape, and then parallel oblique segments fill in the hair and part of the body of the woman. More internally, the shading models the volume of the face, cheekbones, and eyebrows, and finally, white brushstrokes create lighting effects in the upper-left eyelid and below the eyes. A similar organization of attributes is shown in Giacometti's (*Portrait of Marguerite Maeght*, 1961), Michelangelo's (*Madonna and Child*, 1525), and Picasso's (*Paul as Harlequin*, 1924) paintings illustrated in Figures 13b–d.

These figures suggest that the way artists paint objects is related to the specialization of roles and positions in the watercolor illusion. This idea is corroborated by the fact that a figure made up of contours can stand alone evocating all the figure-ground attributes as suggested by Rubin. All the more reason boundary and color can stand alone as demonstrated in Lichtenstein's (*Hopeless*, 1963), Japanese (*Shangchun*, 1024), and Ancient Egyptian (*Wall Painting in the Tomb of Sennejem*, Egypt)artworks of Figures 13e–g. Under these conditions, the boundaries are filled with homogeneous color without any shading and lighting. The results of Figure 13 and, more particularly, those of Figures 13a–c indicate that the boundary contours represent the first and most important property of a visual object segregating unilaterally a figure from the background and tracing its shape, then the color fills the inner edges, and finally, shading and lighting complete the figurality organization. These examples also imply that the object attributes are relatively independent.

A further demonstration of the strong relations between visual organization of figural attributes and object formation emerges from the way comics are created and addressed to children of different ages. In Figures 14a–c, the kind and the number of attributes used in the comic characters are clearly addressed to children older and older.

Also, the way shading and lighting are painted supports our hypotheses. In Figures 15a–b, the shading of the Marvel and Etruscan (Paestum wall detail) characters are represented without the chiaroscuro technique and instead by using mostly contours and surfaces, while the coloration is painted homogeneously. This demonstrates that the shading belongs to the

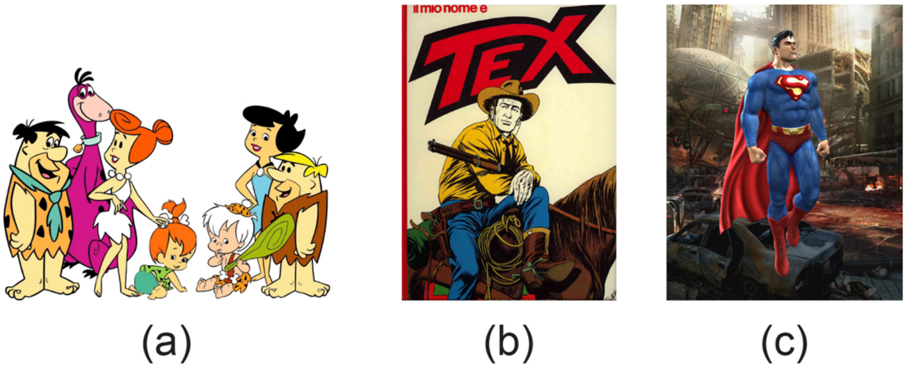

Figure 14. Cartoon and comic-book characters. (a) The Flinstones; (b) Tex Willer; (c) Superman.

boundary domain. It appears, in fact, like boundaries of concave and convex creases and folds outlining the volume of the object.

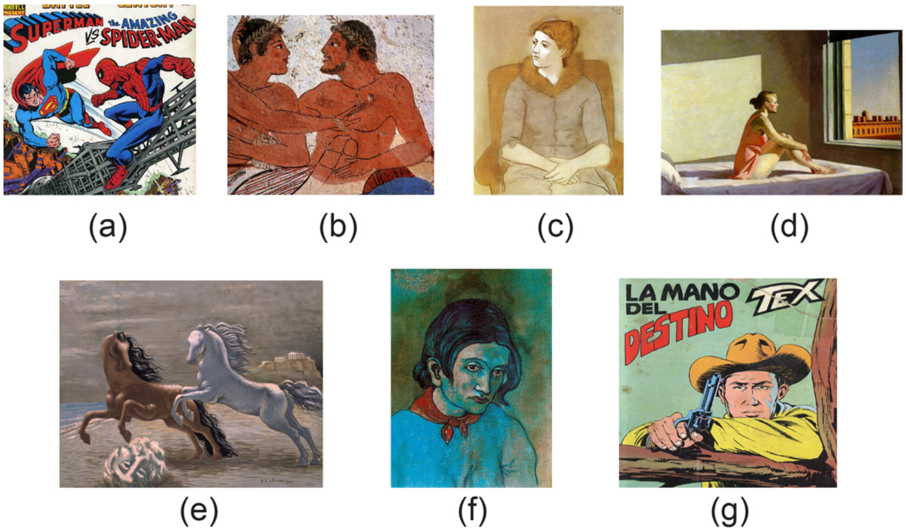

Figure 15. Ways of painting shading and lighting.

The lighting tends instead to be painted through a different color, usually white and, thus, brighter (Figures 15c–d, Pablo Picasso, *Madame Olga Picasso*, 1923 and Edward Hopper, *Morning Sun*, 1952) than the color filling the object, but this is not necessarily true as shown in Figures 15e–g (Giorgio de Chirico, *Cavalli in riva al mare*, 1928; Pablo Picasso, *Female Head*, 1902, and Tex Willer comic-book character), where the lighting is chromatically different from the one of the object. This suggests that lighting belongs to the color domain.

In addition, Schiele's paintings (Figures 16a–b, *Nude*, 1910 and *Portrait of Woman with Orange Hat*, 1910) demonstrate the primacy of the boundary contours, the use of modal (very close to the watercolor illusion) and amodal coloration, and the belongingness of the lighting (highlights) to the color domain.

A clear example of amodal coloration is illustrated in Picasso's painting (Figure 16c, *Nude Woman*, 1968), where even if the color does not fill modally the entire inner edge of the woman, amodally it does. Figure 16d shows the primacy of the boundaries even under non-figurative paintings like this *Last Judgment* (1912) by Kandinsky. The black contours become the boundaries of something not representational. They are something and nothing at the same time. All the other colors fill each something, adding further meaning. Even within a painting of Pollock's, the abstract expressionism of colors can very easily reveal boundaries of "something".

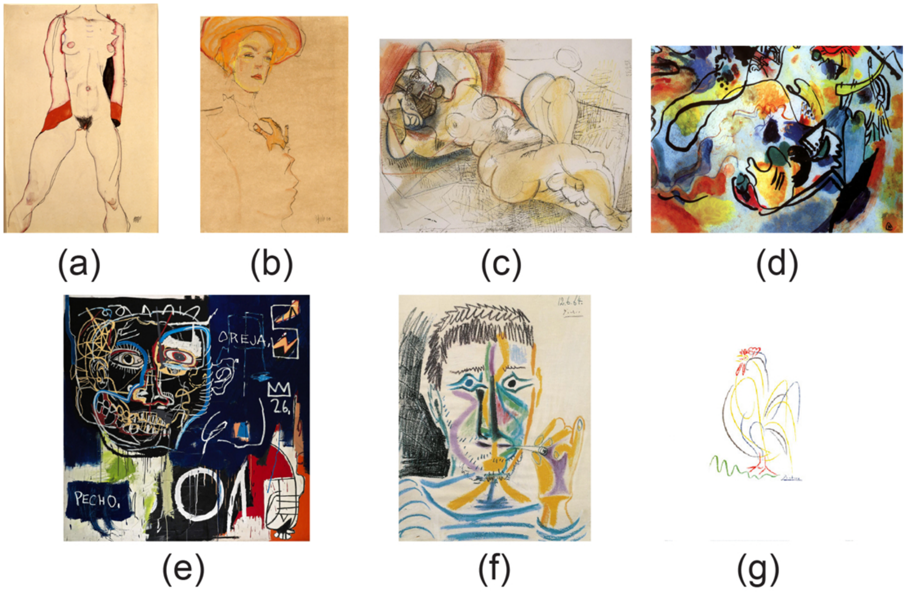

Figure 16. Examples showing the primacy of the boundary contours.

Finally, Basquiat's (Untitled, 1982) and Picasso's paintings of Figures 16e–g (*Self-portrait*, 1959 and *Rooster*, 1973) corroborate the idea of specialization of roles of adjacent and close contours in terms of figure attributes as shown in the watercolor illusion and in the horses of Figure 10 and Figure 11.

All these phenomenal results support the idea of a visual organization of figural attributes, their independence, the way they contribute to determine and form a visual object, namely their specialized roles/domains, and finally, how they are bound, namely through a sequential juxtaposition of roles structurally and phenomenally not very different from the watercolor illusion.

The previous paintings demonstrate that these properties are spatially juxtaposed one after the other, but also suggest a possible temporal juxtaposition. Unfortunately, these artworks cannot say anything about the sequential order of the attributes and the time needed to create them. This is where the microgenetic process, occurring during the visual organization of figural attributes, comes in.

4.2 How are objects organized in shapes, shades, colors, and lighting during visual and pictorial reproduction development?

To understand the temporal juxtaposition and organization of figural roles, we studied the pictorial reproduction of several artworks in which these roles are shown very clearly. The roles of boundary and color contours are clearly visible by watching children drawing a figure. With a black pastel, they first draw the contours of the object. Then, they use colored contours that fill the inner edges of the figure, following the direction of the boundary contours. In a first stage (4–5 years old) the coloration with color contours can get through the boundary contour and sometimes some parts of the figure can remain unfilled. This stage is the first case of amodal wholeness of color. Only in a second stage the action of filling with color contours becomes precise and stops when it meets the barrier of the boundary contours. It is worthwhile noticing that, even though drawing skills could be an important influence, it is obvious that the boundary contour still plays a primary role.

The development of drawing was previously studied by Parsons (1987, 1994) from a perspective different from ours and related to aesthetic reactions. Parsons suggested five stages of aesthetic development. The first stage, called favoritism, is an immediate enjoyment of art without any inquiry. Beauty and realism, in the second stage, describe the appreciation of art because of its resemblance to actual beautiful things. Expressiveness, the third stage, involves a particular interest in the topic and interpretation of art. Style and form, in the fourth stage, involve the observer assigning the artwork to its historical and cultural context. In the fifth stage, called autonomy, judgments about art become independent.

The pictorial artworks studied here, related to understand the temporal juxtaposition and organization of figural roles, were the following. Donaldson's drawing (Joseph Donaldson, *Old Man*, 1973) illustrated in Figure 17a shows contours and lines (see the distinction between contours and lines in Figure 3), intertwined like in a scribble. They appear organized in external boundaries (the whole shape of the face), internal parts (ear, eye, hair, etc), and volumes (of the nose, cheekbone, jaw, etc) creating a face in profile. This condition induces a visual organization of contours in boundaries, part-whole, depth, and volume. The question is: how do children organize and represent these figural attributes during the visual and pictorial development?

Figure 17b shows a detail of a painting by Matisse (*Nude with Raised Arms*, 1923). This work apparently violates the tendency to perceive/create a unique color filling in a whole object, described in section 3.2.2. Nevertheless, under these conditions the multiplicity of colors is related to a multiplicity of different roles: boundary, shade, color, and lighting. In other words, those colors can be easily assigned to different roles. The complex chromatic organization of roles in this figure suggests the same question previously asked. More specifically, how do colors get organized in figural attributes during the development of visual object representation?

Figure 17c shows a third condition (*Woman with the Hat* by Matisse), where the color organization of Figure 17b is taken to extremes. Now, the colors lose the figural roles, perceived more easily in Figure 17b, and appear like a chaotic chromatic distribution without any visual logic. A woman is easily recognized, but it is very difficult or impossible to assign figural roles other than multiple coloration to the colors depicted. They can also be perceived parceling out the wholeness of the shape (Pinna 2010c). How do these colors interfere with the whole shape formation of the woman at different ages? In other words, how do colors inhibit or oppose the primary role of boundary formation? How does the multiplicity of colors support or oppose the main function of color discussed here, ie, the filling in of the figure delimited by the boundaries?

A fourth painting, useful to answer our main questions, is illustrated in Figure 17d. It shows a painting by Manet (*Portrait of Victorine Meurent*, 1871), where colors fill amodally the blouse of the woman by shading the crease with a light blue color. They also represent the lit up color of the face and the shadow crossing one third of the face and half of the neck. The separation between these two regions contains a physical sharp contour, while the shape of the jaw does not show any clear contour. Therefore, the question is: How do children of different ages paint the amodal completion of color and the boundary, color, and shadow organization?

Lucien Freud's painting (*Reflection*, 1985), illustrated in Figure 17e, shows deep and sharp shading and lighting revealing a face seamed by wrinkles and the body signed by muscles. What is the whole amodal color that completes behind shading and lighting? How are boundaries, colors, shading, and lighting, so deeply and sharply represented, perceived and painted at different ages?

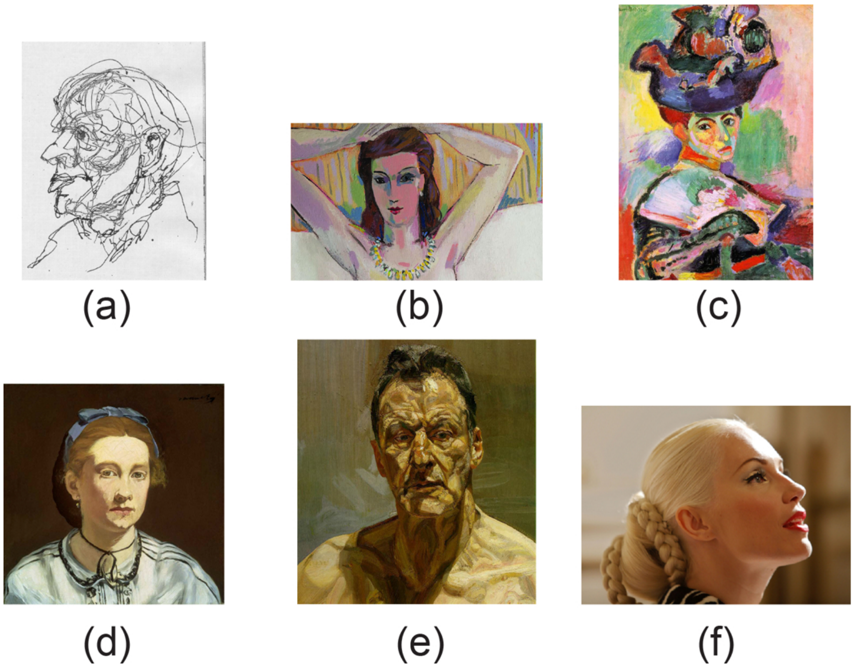

Figure 17. Stimuli.

Figure 17f represents a control for all the other works described in this section. This control is necessary to compare real and artwork conditions and the object attributes, their organization and strength. It shows a photographic real woman face in profile with complete figurality attributes and, more particularly, with clear lighting and highlights. The questions are the following: Does this photo show the same object attributes as the artwork conditions? How are boundary, color, shade, and lighting attributes of the two conditions represented at different ages?

4.2.1 *How do children use figural attributes to create objects?*

Each of the figures of the previous section, described and reproduced freely with colored pastels by different groups of 12 children from 5 to 18 years old, revealed three main stages in the development of the pictorial representation. These stages that we are going to describe briefly can be considered both as continuous and discontinuous. Nevertheless, we intend to go beyond this controversy because our data are not sufficient to discriminate between these theoretical and phenomenal problems. Therefore, by using the term "stage" we refer to both qualitative and quantitative differences in behavior without taking a stance on the continuous or on the discontinuous variation.

Figure 17a was reproduced by children according to the following stages. (i) Up to 6 years old the contours of this figure were represented mostly and uniquely as boundary contours. Therefore, the inner filling of interwoven contours was absent, discounted, and unnecessary (Figure 18a), according to the children's spontaneous descriptions. (ii) Gradually, up to 10 years old, the interwoven contours were represented more and more clearly as filling the inner edges defined by the sharp boundaries (Figure 18b). The inner contours were used like colors aimed to fill in the face in profile. (iii) The next stage showed the gradual emergence of the contours used as shades to create volume. This stage became a stable way of representing the face only with children of 14 to 15 years of age (Figure 18c). From 10 to 15 years old, children drew this figure in between a stage where the contours are used as boundaries and colors and a stage where they are used also as shadings. It is worthwhile noticing that in the first two stages children drew the figure starting from the external boundaries; then they drew the inner parts of the face (eye, ear, etc). Only in the third stage (18 years old) did young adults draw the face not necessarily starting from the external boundaries but also (though less often) from single components inside the face. In this stage the organization of the contour roles reveals a stronger integration of the figural attributes and a more flexible way of drawing the face.

(a) (b) (c)

Figure 18. Free reproduction of Donaldson's drawing by children at different ages.

The pictorial representation of the second stimulus (Figure 17b) revealed the following stages. (i) Children up to 7 years old painted the boundary contours with the black pastel, and then filled homogeneously the inner edges of the woman. The multicoloration of Figure 17b was totally absent in the reproductions and the colors assumed the unique role of filling in the figure. During this stage colors were not used to depict shading (shadows) and lighting. This phase supports the general tendency to perceive or use a unique color to fill in a whole object both modally and amodally (Figure 19a). (ii) From 7 to 14 years of age, children started gradually to enter the second stage, where the multicoloration of the stimulus was represented and used both as coloration and shade/shadow (Figure 19b). Subjects continued, though less and less frequently, to reproduce the stimulus similarly to the first stage until the age of 17 years old, when they started (iii) the third stage during which they used colors to represent more realistically shadows and lighting (Figure 19c) as emerged also from the descriptions. During the three stages the temporal representation sequence of the figural attributes was the following: black boundaries, color filling in the inner edges, and formation of shading/shadows and lighting.

(a) (b) (c)

Figure 19. Free reproduction of Matisse's painting by children at different ages.

The extreme chromatic conditions of Figure 17c showed again three developmental stages. (i) In the first stage, up to 7 years old, the boundary contours of the whole face and its components were drawn with black boundaries. While the face of the woman was filled with a single homogeneous color, the dress and the hat were painted multicolored (Figure 20a). (ii) In the second stage, up to 15 years old, the face was painted multicolored; however, the black boundary contours of the face and its components continued to be drawn (Figure 20b).

This suggests that the multicoloration is used like a coloration (with many colors instead of one) of the inner edges of the woman outlined by black boundaries. (iii) After this stage, also the boundaries were painted multicolored more and more frequently (Figure 20c), even if the tendency to use black contours persists. None of the children belonging to the third stage painted the woman through a juxtaposition of colored patches. Similarly to the previous stimulus, the time sequence of pictorial representation was the formation of black boundaries and then their filling in with the multicoloration.

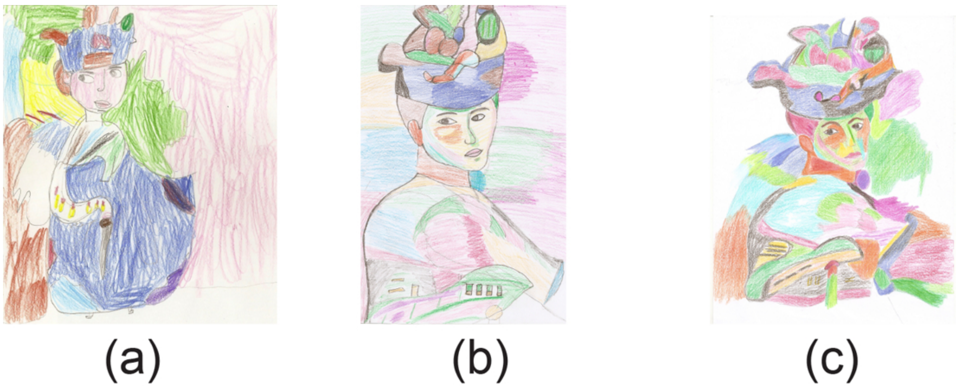

Figure 20. Free reproduction of Matisse's painting by children at different ages.

The reproduction of Figure 17d revealed again three main developmental stages. (i) In the first stage, up to 9 years of age, a black contour delineated the boundaries of the different components of the woman. Both the face and the blouse were colored homogeneously with only one color (Figure 21a). The uniqueness of the color completes modally by filling the entire component (face or blouse). The large shadow was never represented. In this stage the jaw was always outlined by a black boundary while the shadow was not, even if its boundaries are physically much more pronounced. (ii) The chromatic differentiation, traced without boundaries, started to emerge in the second stage at about 10 years of age, but it was sometimes represented as a maquillage, a making-up coloration, or as shading (Figure 21b). The coloration of the blouse remained homogeneous until the third stage. (iii) The representation of the shadow across the face, the neck, and the shades within the blouse emerged for the first time in 17 years old young adults. Nevertheless, the shades were not painted as a chiaroscuro but by using the black pastel that defined the direction and width of the blouse creases (Figure 21c).

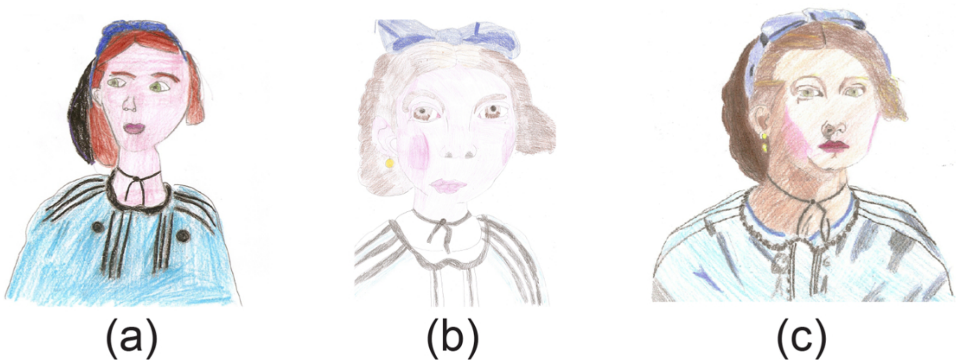

Figure 21. Free reproduction of Manet's painting by children at different ages.

Similar results emerged also in the reproduction of Figure 17e. (i) In the first stage, up to about 10 years old, the black boundaries were filled in by a homogeneous yellow that was the color perceived amodally. All subjects used the same yellow, illustrated in Figure 22a. It is worth noticing that the eyes were white, differently from the stimulus. Shading and lighting were not painted at all. (ii) In the second stage the shading depicting wrinkles and muscles were defined only through boundary contours (Figure 22b). This is a clear demonstration that shading belongs to the shape/boundary domain. (iii) Only at the age of 17 years did a representation of the shades similar to the chiaroscuro start to be used. In the three stages, children started painting from the boundary contours, and then filled in the shape with homogeneous color; after that they added the contours/boundaries of the wrinkles and muscles and, finally shaded these boundaries.

The results of the control condition, illustrated in Figure 17f, strongly supported those of the artwork stimuli. (i) In the first stage, up to 14 years old, children reproduced this face in profile firstly using a black pastel to draw the whole face, the jaw, the eye, and the nose, and then they filled the face and the hair with only one homogeneous color, pink for the face and yellow for the hair. The strong highlights in the forehead, in the nose, lips, and chin were not painted despite their strong physical boundaries. On the contrary, the jaw was clearly defined by a black contour even if its boundaries are physically much weaker than those of highlights (Figure 23a).

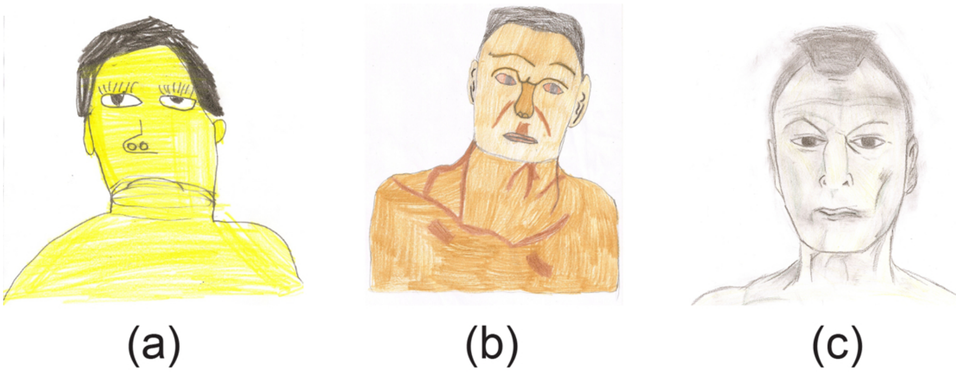

Figure 22. Free reproduction of Lucien Freud's painting by children at different ages.

(ii) The formation of shading starts the second stage from 14 to 18 years old. In the beginning the shading was similar to boundary contours or stains or spots (Figure 23b). Lighting and highlights were still absent. This result compared with the one of the shading demonstrates the independence between shading and lighting. (iii) In the third stage, at 18 years old, lighting and highlights emerged but without boundary contours, while the jaw was always defined with black boundaries. Similarly to the results of the previous stimuli, the temporal sequence of the pictorial reproduction was the same in all the stages: formation of black boundary contours, inner homogeneous coloration, formation of shading, and, finally, formation of lighting and highlights.

The results of the pictorial development will be summarized and discussed in the next section.

5 Discussion and conclusions

In the previous sections we showed new visual and artistic examples useful to understand the general problem of figure-ground segregation and its main attributes: unilateral belongingness of the boundaries, surface color/brightness induction within the boundary contours, and volume/depth emergence. We also introduced a new figural attribute: lighting. It was demonstrated that a single contour is sufficient to segregate two regions into figure and background and, as a consequence, into complementary attributes (border ownership,

(a) (b) (c)

Figure 23. Free reproduction of photographic face in profile by children at different ages.

depth segregation, and surface color). This is what many artists do when they create their work starting from a contour or when they use only contours.

In this work we suggested that the figure-ground segregation problem is related to the way the complementary properties are extracted and organized. This entails some questions, whose answers are the main topic of this work: Where are representations of shape, color, depth, and lighting mostly located? Does their formation take time to develop? How do they contribute to determining and defining a visual object, and how do they differ? How do visual artists use them to create objects and scenes? Is the way artists use them related to the way we perceive them?

To answer these questions, we focused our attention on the watercolor illusion with its juxtaposed contours. In fact, in this illusion the contour with the highest luminance contrast tends to be perceived as the outermost boundary of the figure, and it is called "boundary contour". The bunch of contours with the luminance contrast lower than the boundary contour and juxtaposed to it, model the volume depicting shades. They are called "shading contours". The "color contour", which defines the color of the whole object, follows the shading contours, and is responsible for both modal and amodal coloration. The innermost contour placed at the extreme of the gradient with the lowest luminance contrast defines the properties of the lighting (its color and intensity), and it is called "lighting contour" (see Pinna 2008b, 2010c; Pinna and Reeves 2006).

The main hypothesis of this work was that the specialization of figural roles of the juxtaposed contours in the watercolor illusion is related to the way the figural attributes are extracted and organized in human vision. To test this hypothesis, we studied the microgenetic process that breaks up the holistic fabric of object perception into differentiated yet phenomenal figural attributes and relations among them. In other words, to answer the previous questions and to test the main hypothesis, we investigated the developmental dynamics of the process of formation and integration of attributes. We assumed that the visual organization of object attributes is related to the way artists and children of different ages use these attributes to create objects and scenes. This assumption is true also in the opposite direction: the way people and artists paint is strongly related to the way people normally perceive and thus organize these attributes.

The phenomenal analysis of the watercolor illusion (section 3), of some artworks (see section 4.1), and the results of the development pictorial reproduction task (section 4.2.1) support this assumption and suggest the following answers to the main questions of this work. Rubin's figure-ground attributes are clearly related to shape, color, and depth perception. These are, in fact, the three main attributes used by artists and children of different age to create objects. They do not deplete the set of possible figural attributes. In fact, lighting (and highlights) completes this set, as suggested also by some variations of the watercolor illusion.

Furthermore, most of the information about the four figural attributes is located on the external bonds and limits (edges) of a figure, thin like the juxtaposed contours of the watercolor illusion, where the object segregates from the background. The figural attributes are relatively independent as clearly demonstrated by the watercolor illusion and by the temporal sequence of their occurrence during the pictorial reproduction made by each child and during the pictorial development at different ages. The temporal and developmental results demonstrated the following sequence and order among the figural attributes in creating a visual object: boundary contours, color, shading, and lighting. These sequence and order are marked by short and large lapses of time. The lapse from the use of color to the use of shadings and lighting requires much more time than the lapse from the boundaries to the color. Further studies are required to define more quantitatively the exact time structure of the stages here suggested.

This temporal sequence apparently disagrees with the one emerged from the watercolor illusion: boundary, shade, color, and lighting. This difference can be attributed to the fact that in the watercolor illusion the sequence is mostly spatial and not temporal. In fact, as we suggested several times in this work, boundary and shade belong to the shape domain, while color and lighting to the color domain. In this sense, it can be expected that the spatial organization of the sequence of attributes in the watercolor illusion is different from the temporal one. Temporally, it can be more important to extract and create information belonging to boundary and color, firstly, because these two attributes belong to different domains, and secondly, because they are more and differently informative for a visual system. This hypothesis suggests that the figural attributes are hierarchically organized in terms of visual importance, ie, by contributing with a different weight and meaning to the organization of visual objects. As a matter of fact, shape defined by boundary contours is more important for visual organisms in terms of adaptive fitness than are color, shading, and lighting. In fact, it warns the presence of an object. The primacy of the boundary contours is also phenomenally related to the fact that contours alone can signal information also about surface color and depth as proposed by Rubin. Once the presence of an object is coded, color adds further important but secondary visual properties. It favors the presence, identification, and salience of objects as a cue for species, sex, fruit, identification and so on. The information, provided by shading and lighting, gives further support to the one of shape and color, but signal properties noninvariant in the same way as shape and color.

The specialization and spatial/temporal sequence and organization of figural attributes can be related to recent studies demonstrating that neurons in V2 respond differently to the same contrast border, on the basis of the side of the figure to which the border belongs (Friedman et al 2003; von der Heydt et al 2003; Zhou et al 2000). These neurons are neural correlates of the unilateral belongingness of the boundaries. Other attributes of the figure-ground segregation are likely processed in areas V1 and V2 (Friedman et al 2003; von der Heydt et al 2003; Zhou et al 2000), in inferotemporal cortex of monkeys (Baylis and Driver 2001) and the human lateral occipital cortex (Kourtzi and Kanwisher 2001). This finding can be related to the chromatic/brightness complementation between figure and background (see also von der Heydt and Pearson 2006 about the watercolor illusion). The idea of specialized roles of the figural attributes and the phenomenal logic of their organization go beyond previous works and can shed light on the understanding of how neurons become more and more specialized by firing only for one figural attribute and how they are then integrated after a level of juxtaposition of attributes.

In conclusion, the answers to the main questions of this work can represent the starting points to explore a new domain focused on the microgenetic development of the figural attributes within the more general problem of object organization. Integrated and multidisciplinary studies, based on art and vision science, and visual/pictorial development, are desirable because they can strongly contribute to a full understanding (even in terms of neural circuitry) of the basic and common problem of perceptual organization of shape, color, shade, and lighting.

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