Journal of
Imaging

MDPI

Article

Illusion and Illusoriness of Color and Coloration

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Received: 24 November 2017; Accepted: 22 January 2018; Published: 30 January 2018

Abstract: In this work, through a phenomenological analysis, we studied the perception of the chromatic illusion and illusoriness. The necessary condition for an illusion to occur is the discovery of a mismatch/disagreement between the geometrical/physical domain and the phenomenal one. The illusoriness is instead a phenomenal attribute related to a sense of strangeness, deception, singularity, mendacity, and oddity. The main purpose of this work is to study the phenomenology of chromatic illusion vs. illusoriness, which is useful for shedding new light on the no-man's land between "sensory" and "cognitive" processes that have not been fully explored. Some basic psychological and biological implications for living organisms are deduced.

Keywords: color vision; visual illusions; watercolor illusion; neon color spreading; illusion and illusoriness

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1. Introduction: From Real to Illusory Colors

The perception of colors is one of the most interesting psychological experiences. A world without colors, as partially experienced in black-and-white photos, appears to be missing important qualities. For example, the play of colors during a spring walk in a public park reveals the light reflected in the still water, filling in the basin of a fountain and showing leaves, plants, and trees reflected on the water underneath a morning blue sky. It can be easily imagined that the same experience with achromatic colors would contribute to missing some of the very essential perceptual qualities. For example, the spring colors of plants would disappear, the morning blue sky would be absent, the vibrations and reflexes of the light on the water and on the surrounding plants and objects would be barely perceived, the water itself would be almost invisible, and more, the different phenomenal depth planes revealed by the colors, e.g., among the trees and the sky, and above the still water where the leaves and plants are reflected, would not be clearly defined and segregated. On the contrary, the play of chromatic colors shows the beauty and expressiveness of the components and of the reflected lights that are totally absent in the achromatic picture. More importantly, colors not only add important information to define what a specific portion of the visual world is, but also they create unique and emerging expressive qualities that cannot be otherwise induced.

Impressionist artists, like Claude Monet, knew how to create "impressions" by using colors. In fact, he depicted the transient effects of water and sky and the reflected colors of its ripples by employing many colors and varied textures. His purpose was to reproduce the manifold and animated effects of sunlight and shadow, as well as recreate those other ones perceived under direct and reflected light. This was done by reproducing immediate visual impressions and by using complementary colors in shadows, in place of using whites and blacks. Furthermore, he also made large use of discrete flecks of pure harmonizing or contrasting colors, in order to evoke the broken-hued brilliance and the hue variations produced by sunlight and its reflections. As a consequence, objects in his paintings appear dematerialized, shimmering, and vibrating within their multiplicity of chromatic colors. Indeed, his atmospheres and reflexes would be completely invisible and inaccessible if painted achromatically.

Despite the extraordinary experience of color perception, all colors are mere illusions, in the sense that, although naive people normally think that objects appear colored because they are colored, this belief is mistaken. Neither objects nor lights are colored, but colors are the result of neural processes. In fact, the physical properties of colors are different from the way colors are perceived. Newton first knew it when in 1704 wrote: "for the rays to speak properly are not colored". The perception of colors starts with the spectral content of the light that triggers a long chain of neural reactions, starting from three classes of cone photoreceptors in the retina and, finally, involving specialized areas in the brain. Only at an unknown end or at some extremes of the physiological chain in the brain, the experience of color emerges. The study of color perception allows the understanding of the chain of neural processes and lastly of the brain that creates this unique and extraordinary result that is not necessarily restricted to the mere primary and sensorial processes.

Stating that colors are mere illusions means that they are related to a mismatch/disagreement between the geometrical/physical domain and the phenomenal one [1–3]. More generally, the basic condition for the perception of an illusion is the discovery of this mismatch. Despite the presence of the mismatch, it can be considered as necessary (I, if M; I whenever M and I when M, where I is illusion and M mismatch) to perceive an illusion, although it is not sufficient (if I then M or I implies M); in fact, not all the kinds of mismatches reveal the attribute of being illusory with the same strength.

These preliminary observations point to a first set of problems that is useful for revealing the complexity of the notion of visual illusion. More specifically, the illusion and the attribute of being illusory (the sense of strangeness, deception, singularity, mendacity, and oddity), i.e., the "illusoriness", can be considered as belonging to different perceptual issues. As a matter of fact, when the illusion is ascertained, the phenomenal attribute of being illusory does not necessary emerge. Even by perceiving the mismatch between different domains, the illusoriness can be weak or totally absent. On the other hand, a strong illusoriness is not necessarily related to the presence of an illusion and, thus, to a mismatch between different domains.

A second set of problems suggests that the perception of an illusion is a process that mostly occurs over time. Accordingly, the perception of the property of being illusory requires free observations, comparisons, afterthoughts, many ways of seeing, etc.

Although all colors are illusions, they usually do not appear illusory. Nevertheless, under certain sensory conditions colors and their attributes can also appear illusory. The appearance of being illusory is a perceptual attribute, whose values are arranged in a long phenomenal gradient going from the condition where colors are not perceived as illusory (e.g., the color of the objects in front of us) to the condition where colors are immediately perceived as a mere result of the visual process. As shown in the next sections, in between these two extremes there is a complex set of possible color appearances that deserve to be studied to understand the phenomenology of color perception and the way color is coded and processed by the sensory and cognitive systems.

Even though there is a very large literature related to the huge and increasing number of visual illusions and to their possible classifications [4], actually there are no studies that focus on the inner complexity of visual illusions as previously described. More particularly, the term "illusoriness" and its phenomenal notion have been totally unnoticed up to now.

The purpose of this work is to show effective examples of illusory colors, to demonstrate the distinction between chromatic illusion and illusoriness, and to direct the scientific attention to the complexity of "sensory" and "cognitive" processes concerning the perception of colors in an extended acceptation similar to that previously described during a spring walk in a public park.

This distinction will be shown to have important psychological and biological implications for living organisms. In short, each organism uses visual strategies to create illusions and illusoriness, for example, to deceive prays or predators, to attract conspecifics, or to reject, dissuade, or repulse them. They play with illusions to change and manipulate their appearance and influence other organisms. To be effective, the biological illusory strategies should reduce the sense of illusoriness that could signal the deceiving structure or coloration. It is within a complex equilibrium between illusion and illusoriness that the adaptive fitness is played.

2. General Methods

2.1. Subjects

In the experiments described in the next sections, different groups of 12 naive subjects, each ranging from 20 to 27 years of age, were involved for each stimulus, if not otherwise reported. Subjects were about 50% males and 50% females and all had normal or corrected to normal vision. They also had normal color vision tested on the Ishihara 24 test plates and on the Farnsworth-Munsell 100 hue Color Vision Test. Subjects were recruited under previous informed consent signed by all the participants in compliance with the Helsinki declaration.

2.2. Stimuli

The stimuli were the same as the figures shown in the next sections. The luminance of the white background was ~122.3 cd/m^2. Black contours had a luminance value of ~2.6 cd/m^2). The stimuli were displayed on a 33 cm color CRT monitor (Sony GDM-F520; Sony: Tokyo, Japan; 1600 $\times$ 1200 R, G, and B subpixels, refresh rate 100 Hz), driven by a MacBook computer (Apple: California, USA) with an NVIDIA GeForce 8600M GT (NVIDIA: California, USA), in an ambient illuminated by a Osram Daylight fluorescent light (250 lux, 5600 K). They were viewed binocularly and in a front-parallel plane at a distance of 50 cm from the monitor.

2.3. Procedure

Phenomenological task—the subjects had to report spontaneously what they perceived for each stimulus. They were expected to give as much as possible, an exhaustive description and, if necessary, to answer the questions asked by the experimenter. Subjects were also instructed to scale the relative strength and salience in percent (100 is the maximal salience, while 0 is the minimal) of the perceived results, if there were any. The relative confidence and appropriateness of their responses were also taken into account.

Scaling task—subjects were asked to report if they perceived a chromatic/achromatic illusion and to scale the relative strength or salience of the perceived illusion in percent. The reference values of the scale were as follows: 0 represents the absence of the chromatic/achromatic illusion, in other words, not any illusion is perceived at all; 100 represents the maximal strength of the illusory appearance, indeed, here, the color is perceived illusory, and therefore not present in the pattern of stimuli but only as a product of vision.

Relevant descriptions are included in the following sections, within the main text, in order to help the reader in the stream of argumentations. The edited descriptions reported were judged as the best example to provide a fair representation among those provided by the observers. When not specified, the descriptions reported in the next sections were those spontaneously communicated by ten out of twelve subjects, considered highly appropriate (more than 90%) and receiving a scaling value higher than 90%.

During the experiments, subjects could make free comparisons, confrontations, and afterthoughts; additionally, they were allowed to see in different ways, and to make variations and comparisons in the observation distance, etc. Subjects could also receive suggestions/questions from the experimenter.

Subjects were tested one by one. No time limit was set on the descriptions and their scaling, which occurred spontaneously and fast. The stimuli were shown continuously during the description task. All the details and variations concerning the experiments and related to the subjects, the stimuli, and the procedure will be reported more in details in the next sections. Besides, together with the results of each phenomenological experiment, a theoretical discussion will also be provided.

3. Results

3.1. Illusory Colors and Colorations

As stated in the Introduction section, visual illusions are usually associated with a mismatch/disagreement between the geometrical/physical and the phenomenal domains [1–4]. The necessary condition for the occurrence and the perception of an illusion is the "discovery" of this mismatch, which is mostly a cognitive process. This general and well-accepted definition of "visual illusion" is postulated either explicitly or implicitly when a new phenomenon is discovered and first published in a scientific journal.

This simple definition of illusion, apparently clear, reveals several inner ambiguities that we start here to investigate phenomenologically. First of all, the ambiguities involve both domains. What is physical and what is phenomenal? In this work, the complexity of the meaning of the physical domain is skipped to prevent a regression to a too long and already explored epistemological issue [5] and, at the same time, to keep our rationale as simple and direct as possible. Here, we will especially focus on the phenomenology of a colored object starting from the most simple questions that could be asked to a subject during a visual experiment: "What is it?" and "What color is it?". Through these questions, apparently trivial, we will explore the phenomenology of illusory colors, when colors are or are not perceived as illusory.

The first question, "What is it?", was asked by showing Figure 1a. The most frequent answer was "an undulated circular shape" (9 subjects out of 12).

Within the phenomenological approach here adopted, the scientific interest not only is related to what emerges and is immediately described by the subjects, but is also related to what is implicit, taken for granted, and not described. The distinction between explicitness and implicitness, together with the gradient of phenomenal appearance, is absolutely crucial to understand the gradient of visibility and also the hierarchical organization of the object attributes [6]. In fact, the gradient of visibility not only shows what is perceived at first sight and most saliently, but also puts in evidence what is seen as secondary, what stands in the background, or what is completely invisible. However, what is implicit or not statistically relevant and meaningful can be phenomenally even more important for the understanding of the object organization than what is immediately perceived.

Under the conditions of Figure 1a, only shape attributes were spontaneously mentioned. The color was not acknowledged at all. This does not mean that it is invisible, but that color attributes fade into a lower level of visibility and are kept implicit in relation to the primacy of the shape. They become invisible on the foreground visual/linguistic level. Even more implicit/invisible was the color (white) of the surrounding background, which was never reported by the subjects and, thus, placed at the lowest level of visibility.

The second question "What color is it?" was rephrased as follows "What about the color?". This question was asked to minimize any suggestions and to leave subjects free to describe which, among the three colors (the white of the inside object, the white of the outside object, and the black of the boundary contours) is the one that spontaneously and explicitly emerges, and which instead remains implicit. The most immediate and common outcome (9 out of 12) was "the undulated object is white". As a consequence, only the inner color of the perceived shape emerged explicitly. Both the colors of the boundary contours and of the background were kept implicit/invisible. It is essential to highlight the reaction of 2 out of 12 subjects soon after they answered the question: they manifested surprise becoming aware that there might be other options. Despite these further options, mostly considered as related to the color of the boundary contours, they selected the following one: "the undulated object is white", and thus not black.

The explicitness and implicitness of visual attributes are more likely related to the biological need for an organism to organize the visual world into a gradient of visibility, eliciting the emergence of the most significant information in terms of adaptive fitness to the detriment of the less important visual information. This entails that the background is less important than the segregated object, and that the color of the inner edges of the object is more important than the color of its boundaries. Moreover, the shape of an object is more important than its color.

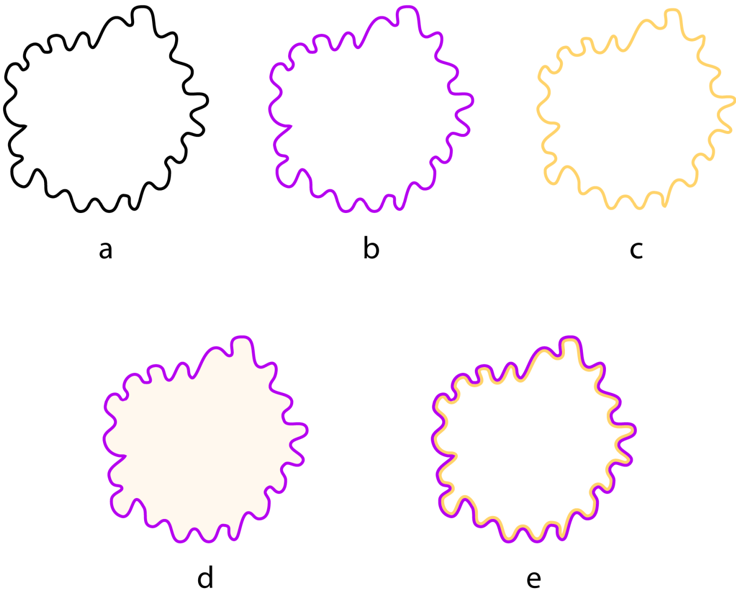


Figure 1. Undulated circular objects. (**a**) Black; (**b**) purple; (**c**) orange; (**d**) purple filled with orange; (**e**) illusory watercolored.

It is worthwhile mentioning that 3 out of 12 subjects answered the previous question as follows: "the undulated object is transparent (1 out of 12); it is empty or made only by its boundary contours like a wire (2 out of 12)". At a first sight, they appear as the most correct answers to the given conditions. However, the transparency and the absence of an inner surface of the object implies that the background can be perceived through it, but this also means that the color seen behind it is white. In other words, though these descriptions appear very different and more plausible than the most common ones, they are conceptually and structurally the same. As a matter of fact, not any subject mentioned the color of the boundary contours. Moreover, by saying "transparent" or "empty", they are describing an inner property of the object, not the properties of its contours, and this is exactly what the majority of subjects reported by stating that the undulated object is white. In short, since the inner property is in one case "white", in the other two, transparent or empty, the phenomenal structure is the same (*quod erat demonstrandum*).

The results of this first set of data can be summarized according to the next general statements: (i) Color can be implicit, unnoticed, or invisible; shape cannot (principle of primacy of shape against color); (ii) the color of the boundary contours is phenomenally "invisible".

By replacing the black contours of Figure 1a with purple ones (Figure 1b), the outcomes reported by a different group of subjects were similar to the previous ones, although 4 out of 12 subjects mentioned the purple color of the boundary contours. Nevertheless, the answer to the question "What about the color?" was again "white" not purple. These results suggest that chromatic attributes of the boundary contours are more easily noticed than the black ones, although they do not influence the outcome. This is *a fortiori* true when the boundary contours are orange as shown in Figure 1c. Now, 8 out of 12 subjects mentioned the orange contours but defined as white the color of the object. The larger number of subjects under this condition is related to the lower contrast of the orange with the white background. This point will be cleared up when the watercolor illusion will be discussed.

For the three previous stimuli, a third question was asked: "Do you perceive any color illusion?". The answer was definitively "no" for each stimulus. Actually, Figure 1a–c manifests two chromatic illusions of invisibility: the one concerning the contours and the other one related to the white background. The implicitness of the color of the boundaries and of the white background might be considered as a clear mismatch/disagreement between the geometrical/physical and the phenomenal domains. By making subjects aware of these mismatches, i.e., by pushing the color of the boundaries and of the background above threshold, they manifested a sense of illusoriness due to the unaware omission and oversight induced by the stimulus.

Under our work, the illusoriness can be defined as an independent perceptual attribute emerging from a multiplicity of visual outcomes within the same stimulus pattern, not necessarily related to the presence of a mismatch, and perceived by itself like a sense of strangeness, deception, singularity, mendacity, and oddity.

In Figure 1a–c, no illusoriness was perceived spontaneously; therefore, no illusion was reported in spite of the discrepancies previously described and mostly located within the linguistic domain of the description task due to unaware oversights. As previously stated, a sense of illusoriness emerged only when subjects were made aware of the invisibility of the two other colors. Though subjects considered this effect mainly as a lack within the description, a surprise was manifested by all of them. This suggests that the visual attribute of illusoriness of these figures can be perceived, even if weakly, and it is related to the mismatch related to the illusions of invisibility. This entails weak illusoriness with weak illusion.

Similar results were collected with a different group of subjects through the spontaneous descriptions of Figure 1d. Again, the answer to the first question ("What is it?") was "an undulated circular shape" (6 out of 12) and, only after the second question ("What about the color?"), the inner color of the shape emerged ("the undulated circular shape is orange"), but neither the color of the contours nor the one of the background was mentioned. As before, subjects did not perceive any color illusion nor any illusoriness, unless suggested by the experimenter. The illusoriness of Figure 1d is weaker than the one of the previous stimuli, since the inner color is not white but clearly different from the background.

The inferred general statements are now the followings: the color of the boundary contour plays a different role from the one of the inner surface, and their roles are, respectively, shape and color. Since the boundary contour defines the shape of the object, its color belongs to the shape domain and it assumes this role, i.e., it is only shape not color. On the contrary, the color of the inner surface is not shape, but it appears as the color or coloration of the object defined in its shape by its boundary contours. Therefore, the inner color is just color and not shape. From this statement, a corollary can be deduced: the color of the boundary contours is not the color of the object; therefore, as color, it is "invisible" or implicit. It is visible or "explicit" only as boundary or shape of the object.

These statements are based on a more general assumption of a specialization of roles, according to which a specific region can assume only one role. Therefore, if a role is assumed by one region, the other assumes a different and complementary role (principle of unicity and separation of roles). This role specialization fits with the more general tendency of the brain to create the simplest, most non-ambiguous, non-ambivalent, and economical phenomenal results in the basis of given stimulus conditions [7].

The principle of unicity and separation of roles can explain both the absence of illusoriness within the spontaneous outcomes and the emergence of the illusoriness when other possible options were suggested to the subjects. As a matter of fact, this principle works by switching one set of univocal roles to an alternative set of roles, both of which are mutually exclusive.

Finally, a further general statement related to all the previous results is: the color of the background is unnoticed, implicit and, thus, invisible.

Apparently similar but substantially different from the previous conditions is the next stimulus in which the purple and orange contours of Figure 1b,c are now combined and placed adjacent. By presenting Figure 1e to an independent group of subjects, the results were the same as those obtained in all the previous conditions. As a matter of fact, also under those circumstances, the answer to the first question was "an undulated circular shape" (8 out of 12) and, only after the second question, the inside color of the object was mentioned, but neither the one of the contours nor the one of the background emerged. As it happened in the previous case, subjects did not notice any color illusion nor any illusoriness. The inner color was perceived as it is physically depicted within the shape. These results are corroborated by the answers to the further question "What is the color of the inner region of the undulated circle?". The answer reported for this question was "an orange color slightly lighter than the one along the boundaries".

After these preliminary tasks and reports, subjects were informed that Figure 1e is a visual illusion. The new task was to disclose the hidden illusion. After a first momentary astonishment and confusion, subjects guessed about the inner coloration of the shapes, although all of them needed to check closely the figure in order to be sure and realize that indeed the illusion occurred. In spite of this feedback, they were not totally sure that the inner coloration was the illusion suggested by the experimenter. Four out of 12 subjects questioned and challenged the request of the experimenter. The inner coloration appeared to be real, as it was actually depicted on the computer screen. A few subjects (5 out of 12) proposed to consider as illusion the circular shape, which appears as such although it is very irregular and different from a circle. According to these results, the watercolor illusion, illustrated in Figure 1e, can be considered as an illusion without illusoriness.

The watercolor illusion [8] can be briefly described as a long-range coloration effect sending out from a thin colored line running parallel and contiguous to a darker chromatic contour and imparting a strong figural effect, similar to a bulging volumetric effect, across large areas [8–11]. Although the watercolor illusion manifests two main effects only, the coloration was noticed, and the second hidden "illusion" (the figural effect) was never detected, although the experimenter suggested the presence of a second illusion to be discovered. In between the two main effects, the long range homogeneous coloration is more prominent as an illusion. The primacy of the shape against the color [12,13] makes it more difficult to acknowledge its possibility to be an illusion and its illusoriness.

The figural effect can be made explicit by comparing the bulging volumetric effect of the undulated circular objects of Figure 1b,e or through the inverted figure-ground organizations illustrated in Figure 2, where the same pattern of stimuli, with purple and orange contours reversed, shows complementary figure-ground segregation, i.e., crosses vs. stars.

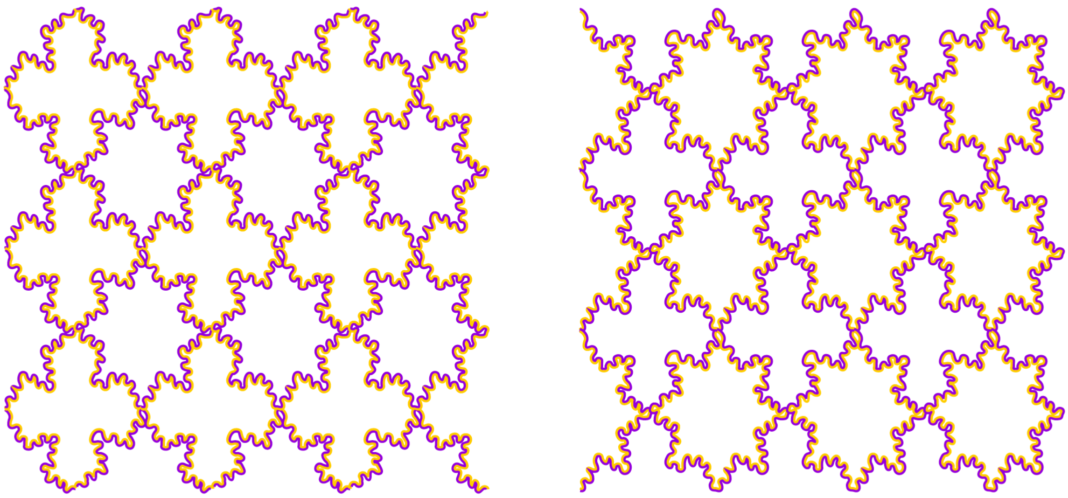


Figure 2. *The watercolor illusion*: purple and orange contours reversed show complementary figure-ground segregation, i.e., crosses vs. stars.

In Figure 3, transparent watercolor objects and holes placed on a gray rectangle are shown. The discovery of the illusoriness of this more complex condition required more time for our subjects, and it was related to the antinomic proximity of objects and holes, not to the figural and coloration effects of the watercolor illusion.

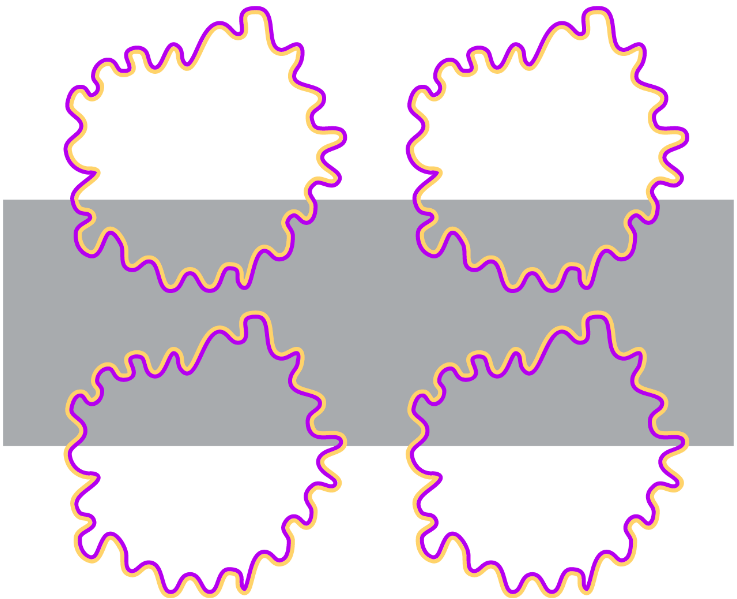


Figure 3. Transparent watercolor objects and holes.

The figural and coloration effects of the watercolor illusion was more salient in Supplementary Materials, in which the complementary peninsulas and the coloration are switched by reversing the contrast of adjacent contours and by changing their color at the same time. The dynamical switch is accompanied by a phenomenal enlarging and shrinking, a "breath" of the figures while emerging and fading. However, the true illusions are the figural and coloration effects; it was the breathing outcome that was considered by the subjects as the main source of the perceived illusoriness. Only partially (4 out of 12) the illusoriness was assigned to the "true" illusions.

Actually, the breathing is not a true illusion, since the contour with the highest contrast, perceived as the boundary contour of the figure, changes its spatial location from the position of one contour to the position of the other. As a consequence, the boundary contour location appears to move laterally, as it really does, by inducing the enlarging and shrinking effect along the vertical direction of the stimulus. Under these dynamic conditions, the illusoriness is stronger without the need to be revealed to the subjects. However, the perceived illusoriness occurs without illusion. Therefore, within Supplementary Materials there are two illusions (figural and coloration effect) without illusoriness and illusoriness (the breath) without illusion.

The general emerging statements are now: the illusoriness is a phenomenal attribute independent from a mismatch between geometrical/physical and phenomenal domains; moreover, suggestions and cognitive processes can favor the emergence of both illusion and illusoriness.

The general statement related to the two juxtaposed contours and to the previous figures is as follows. Given two adjacent contours as in the watercolor illusion, the one with the higher luminance contrast in relation to the surrounding regions is seen as the boundary contours of the object, while the contour with the lower luminance contrast is seen as the color of the figure [12–14]. In more general terms, the assignment of the role is due to the relative contrast between the two adjacent contours. This explains the differences between Figures 1b and 1c previously described.

In Figure 4-top, subjects described the pattern of stimuli as an amoeboid shape. As in the previous conditions, the color was poorly mentioned (5 out of 12 subjects). The answer to the question "What about the color?" was "orange". However, the answer to a further question "What is the color of the inner region of the amoeboid shape?" was "white". "What kind of white?": "a white similar to the white of the background (6 out of 12), more dense and solid" (4 out of 12), "slightly darker than the white of the background" (5 out of 12), or ''white but slightly yellowish" (1 out of 12). These results suggest that, while the color of the amoeboid shape as a whole is orange, the color of its inner region is not orange. This contradiction suggests that part and whole colors can be different.

Figure 4. The illusion of discoloration.

None of the subjects perceived any sort of illusion or illusoriness. When Figure 4-bottom was shown to the same group of subjects, the outcomes were very different: they perceived a dark gray amoeboid shape. The results did not change significantly by asking the same questions to a new group of subjects. Again, not any kind of illusion or illusoriness was perceived.

First of all, this suggests that in Figure 4-top the inner orange surrounding the external boundaries of the shape was perceived as the color of the whole figure, although the inner region is white or slightly darker than the white of the background. So, a tiny chromatic portion of the figure assumes the role of color for the whole shape [15].

Second, the orange color of the boundaries of Figure 4-bottom was not mentioned at all. It was implicit and invisible. This is related to the basic assumption of the visual system, according to which two different regions of figure cannot assume the same role. Therefore, the color of the boundary contour and the one of the inner surface assume different roles, i.e., shape and color. The outer orange was in some way "discolored" and considered only as a contour and more specifically, as the boundary contour of the shape (on the different assignment of contour roles see also Figure 5).

Third, Figure 4-top shows the discoloration illusion [16] according to which the inner region appears white, although it is physically filled with the same gray of Figure 4-bottom. The gray is indeed phenomenally discolored. The same illusion occurs with chromatic inner coloration (not illustrated). The phenomenal discoloration can be considered as a phenomenon opposite to the coloration effect of the watercolor illusion.

The phenomenal attribute of the illusion of discoloration is different from the "discoloration" of the orange contours of Figure 4-bottom, where the "discoloration" is part of the visual/descriptive assignment of roles. The discoloration of Figure 4-top is, in fact, visually effective and "real" as it "really" occurs. This implies that the kind of discoloration of Figure 4-bottom is part of the perceptual syntactical organization of shape and color. In Figure 4-top, the discoloration is rather related to an earlier kind of visual process and perceptual organization that occurs before the syntactical one, in which the visual language operates and from which the spoken language picks up its atoms and components.

A different kind of illusory coloration can emerge under totally different geometrical and phenomenal conditions as shown in the following variations of Picasso's *Yellow Cock* (Figure 5). The three figures were described simply as roosters. When the color was asked, Figure 5a,b were described as yellow roosters, while Figure 5c was seen as a black rooster. Therefore, the black contours were perceived as the boundaries of the rooster's body, while the yellow contours were defined as its color. When the subjects were asked to compare Figure 5a,b, the consequence of the role assignment was that the rooster of Figure 5b was described as much slimmer than the one illustrated in Figure 5a. This is related to the fact that the black contours are now included within the yellow ones. Since the black contours were perceived as the boundaries of the yellow rooster, the rooster should also be perceived as slimmer than the one in Figure 5a, in which the black contours include the yellow ones. By replacing the yellow contours with black ones, the rooster was perceived as black and fat (Figure 5c). These results demonstrate that it is not the spatial position of the contours that determines their roles (boundary or color) but their difference in the luminance contrast as it occurred in the watercolor illusion.

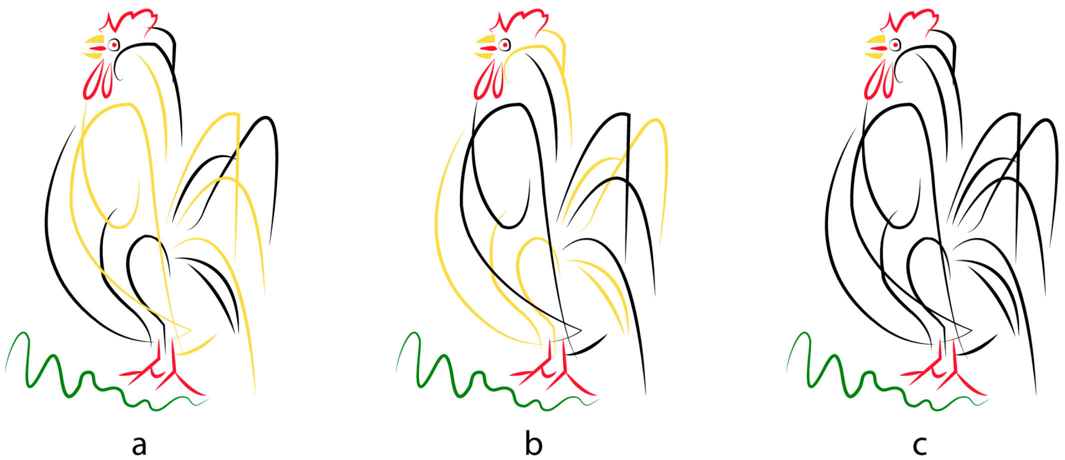


Figure 5. Variations of Picasso's *Yellow Cock*: *the fat-slim illusion*. (**a**) Yellow rooster; (**b**) slim yellow rooster; (**c**) fat black rooster.

It is worthwhile noticing that, although the coloration does not fill the whole inner edge of the shape, the roles are assigned anyway by the visual system. The general statement can be synthesized as follows: the perception of the color of an object does not require the full and perfect coloration of its inside edges [12,13].

In spite of the huge discrepancy between the geometrical/physical pattern of stimuli and the phenomenal results, the subjects did not report any illusion nor illusoriness. The outcomes appeared obvious and trivial. Only after a full and deep explanation of the differences were the meaning of the illusion and the illusoriness noticed, although they was mostly related to what apparently seems to be a fat vs. a slim rooster (the fat-slim illusion).

The illusoriness was perceived more saliently in Figure 6, in which a variation of the watercolor illusion without the figurality effect is illustrated. The red and light-blue colorations spreading and filling in the space among the circles (in reversed order between the two patterns) were spontaneously reported as "apparent", "illusory", "as an impression", or "as a result of brain processes". According to subjects' comments, this coloration was perceived as illusory, since it does not appear as belonging to a surface but because it is more similar to a light, a fog, or "a strange" color. Under these conditions the illusoriness emerged immediately revealing the sense of strangeness, deception, singularity, mendacity, and oddity.

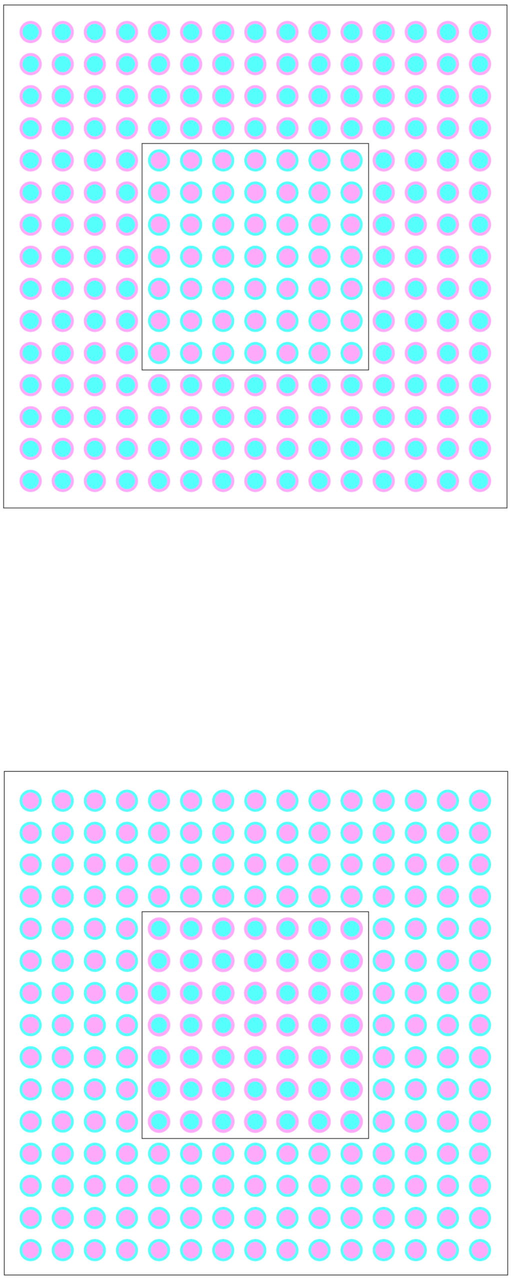


Figure 6. Reversed chromatic variations of the watercolor illusion.

This is also the case in Figure 7a,b, in which new variations of the neon color spreading [10] are illustrated. Under these conditions, the inner green/orange and green/black spreads with phenomenal qualities are analogous to those of Figure 6. These qualities induce again the emergence of the illusoriness as a sense of strangeness and the singularity of the color that is unexpected and different from the way it appears most of the time.

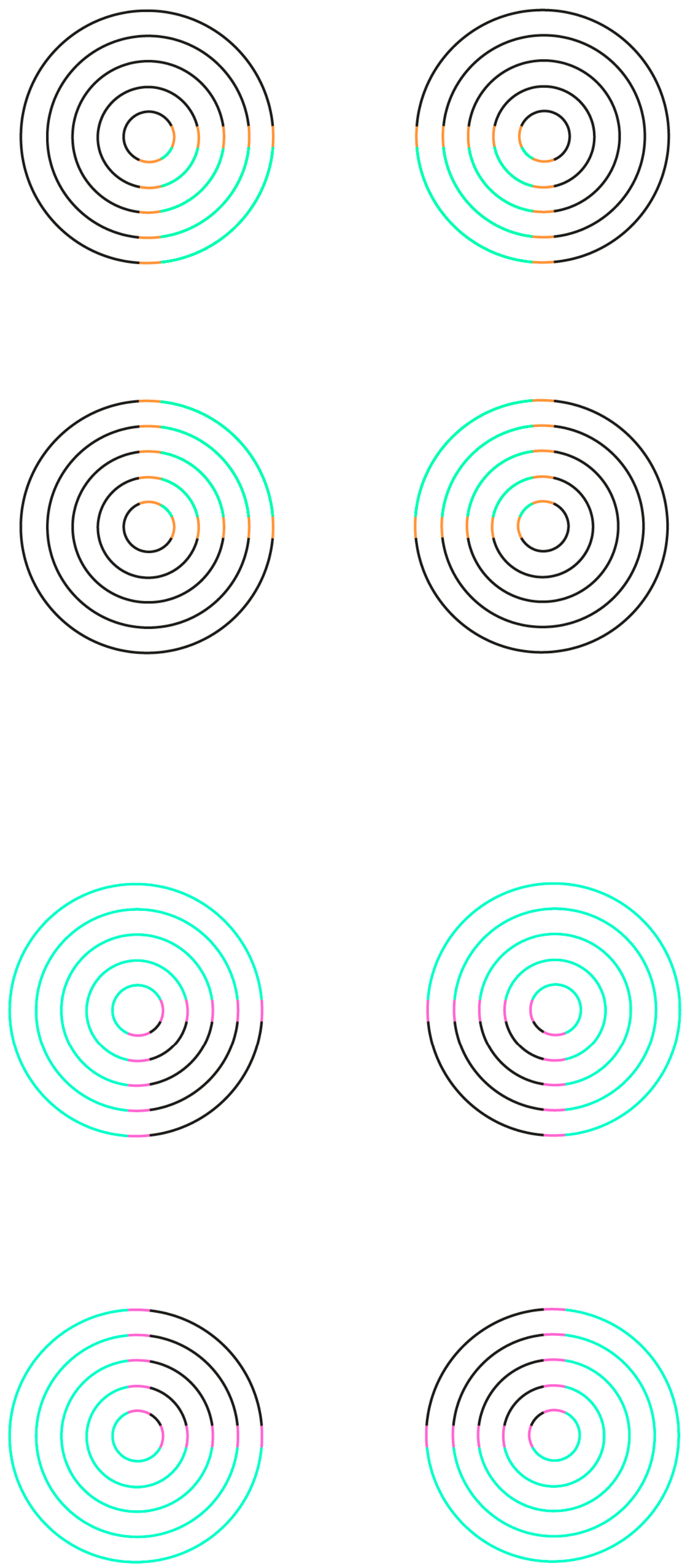


Figure 7. Variations of the Neon Color Spreading. (**a**) green-orange spreading; (**b**) black-pink spreading.

The phenomenology of the coloration effect in both illusions of Figures 6 and 7 manifests the following properties: (i) the color appears as a diffusion of a small amount of pigment of the embedded chromatic contours; (ii) the coloration is transparent like a light, a shadow, or a fog; (iii) the appearance of the color is diaphanous, and it appears similar to a veil that glows like a light upon the background, like a transparent layer, or like a dirty, shadowy, foggy, or muddy filmy sheet.

While the watercolor illusion occurs through the juxtaposition of parallel lines with different color, the neon color spreading is elicited by the continuation of one segment with another of a different color (continuation vs. juxtaposition). Pinna & Grossberg [10] showed that both illusions can be reduced to a common two-dots limiting case, based on nearby color transitions.

The chromatic illusion and illusoriness were fully and immediately perceived in Figure 8. Differently from the previous conditions, the answer to the question "what is it?" promptly revealed the chromatic illusoriness. The centers of the radial arrangement of lines were perceived of as a vivid and saturated green self-luminous, and as flashing with eye or stimulus movement. The green flashing effect disappears when the center of the radial lines is perceived directly (foveally). Under these conditions, the inner disk appeared gray. At the same time, all the other disks (extrafoveally) were perceived like flashing greens floating out of their confines, pulsing or oscillating. This is the flashing anomalous color contrast [17] fully perceived as an illusion with illusoriness.

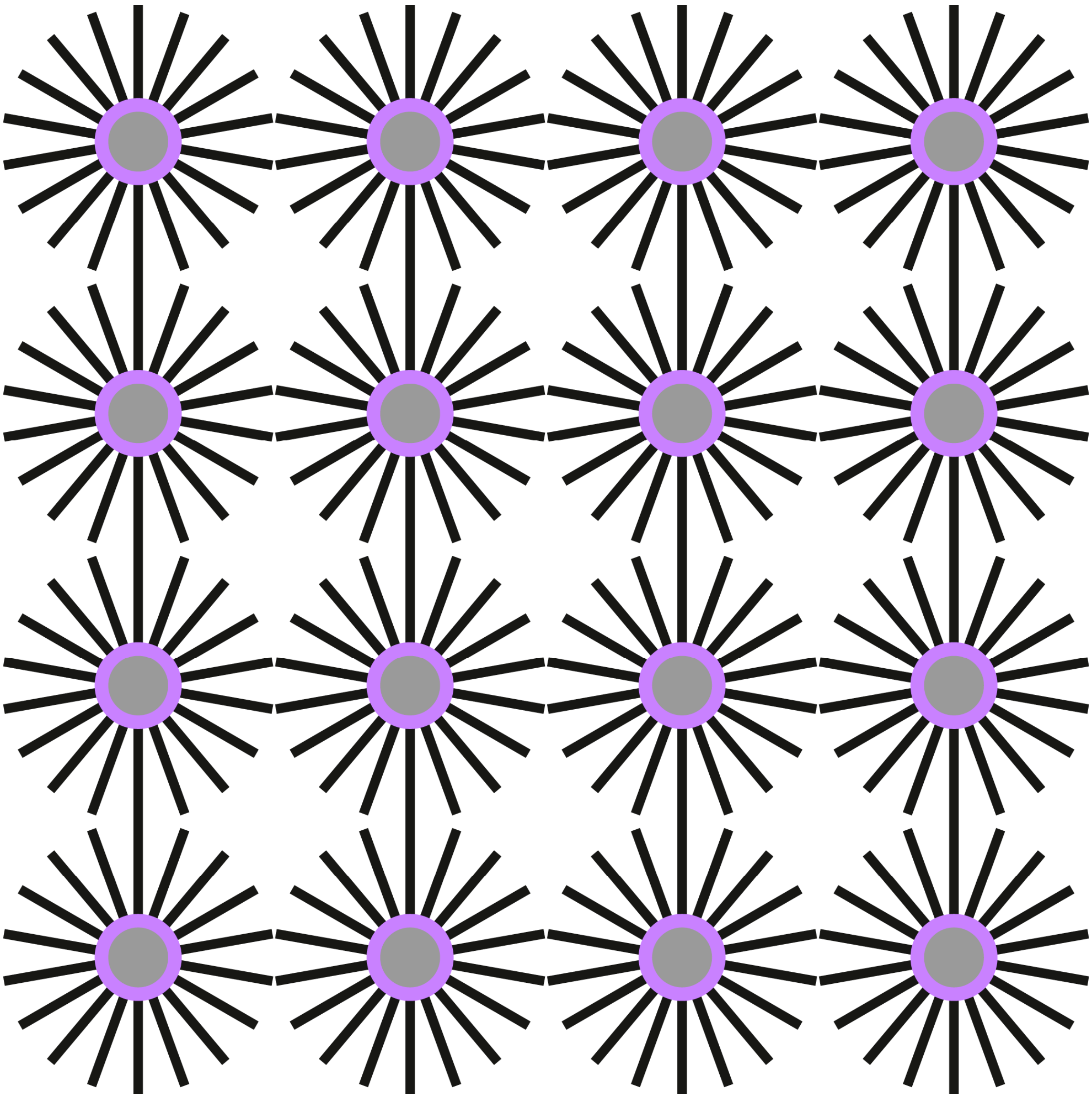


Figure 8. The flashing anomalous color contrast.

3.2. Chromatic and Achromatic Whites

In the previous section, not only the chromatic components of the stimuli but also the whites of the objects and the background were considered. The illusoriness was shown to be related to these whites. More particularly, one of the illusions without illusoriness, not mentioned in the previous section, is the phenomenal difference between these whites as, for example, it happens in Figure 1a. This illusion was not mentioned as such and likely it was not even noticed by the reader accurately, as it does not manifest any illusoriness. This occurs in spite of the fact that it was a basic problem for the Gestalt psychologist. According to Rubin [18,19], the white of the undulated object is perceived of as full like an opaque surface and denser than the same physical white of the surrounding background that is perceived instead as empty and totally transparent. While the former manifests a surface color property with a chromatic paste seen as solid, impenetrable, and epiphanous like an opaque surface, the white of the background is, on the other hand, perceived as empty, penetrable, and diaphanous, like a void [20]. As soon as subjects were made aware of this difference they perceived the illusoriness, but they did so very weakly and took it for granted.

The distinction between the two Rubin's whites can be appreciated in Figure 9, although it is much stronger than the one illustrated in Figure 1a,b. Now, the word ARTE (Art in English) can be promptly read [21]. The R and the E letters manifest a strong surface and epiphanous white in contraposition to the diaphanous void of the background. The illusoriness of this condition is quite clear, and it is related to the illusion/mismatch that does not need to be revealed to be perceived as such. In spite of this clear effect, the illusoriness was considered by our subjects as derived from the readiness and past experience of the black letters. This naïve explanation weakens the illusoriness. This is not the case of the next condition.

Figure 9. The illusory word ARTE.

A white with a more salient illusoriness is illustrated in Figure 10. Now, the inside edges of the circular arrangement of letters are perceived as white surfaces and the effect here is much stronger that those described in Rubin's figures. The emerging illusory shape is promptly perceived as illusory and with a clear illusoriness. The white is seen much more prominently, like an independent surface, and is whiter than the white of the background that is perceived as empty and diaphanous. These illusory figures emerge in spite of the absence of any amodal completion and the incompleteness of the inducing elements [22,23].

The perceived illusoriness is about as strong as or slightly weaker than the condition in which these occlusion cues are introduced as shown in Figure 11. Here, the radial lines are perceived as amodally completed behind the illusory disks [24], whose white is similar to the one illustrated in Figure 10.

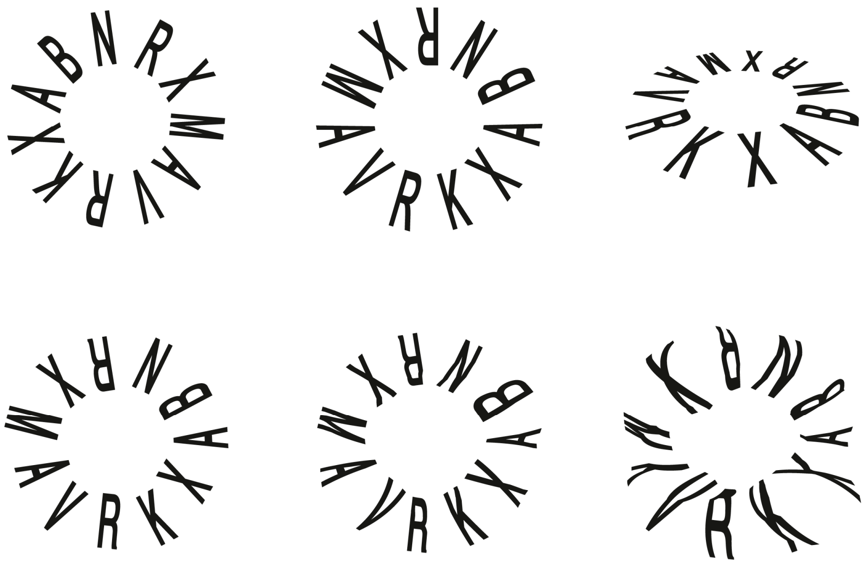


Figure 10. Circular arrangements of letters inducing inner illusory figures.

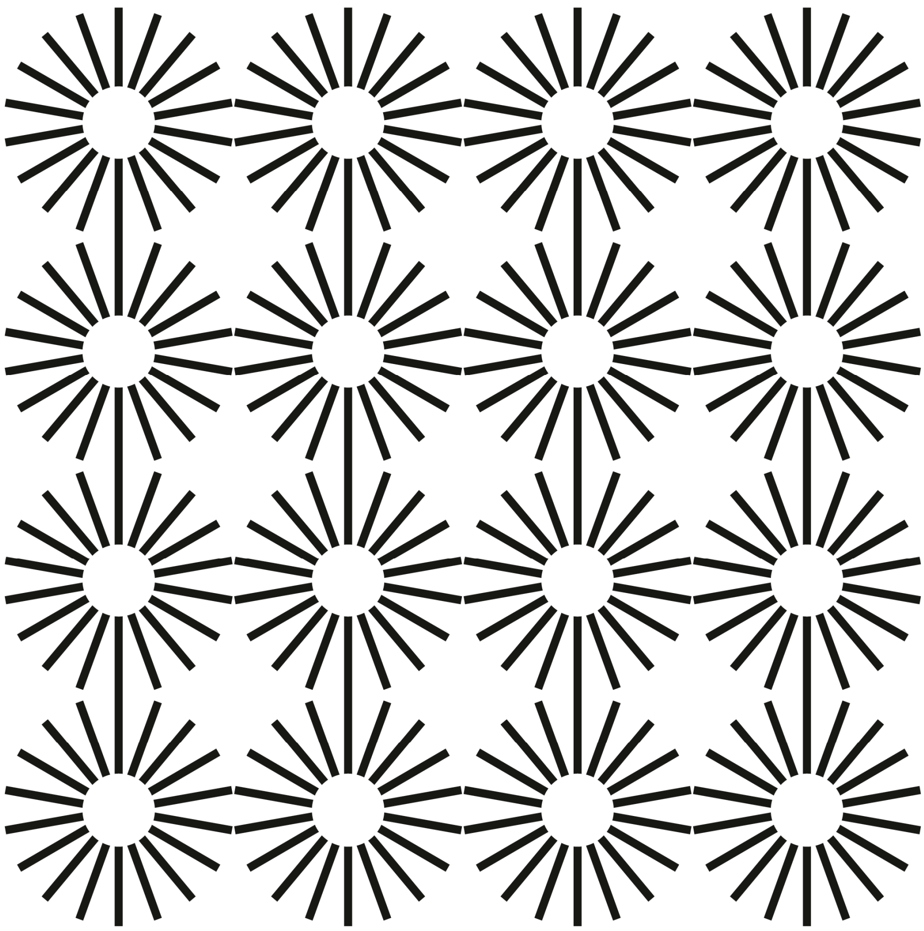


Figure 11. Radial lines inducing inner illusory disks.

The salience of the illusions and of the illusoriness of the whites illustrated in Figures 10 and 11 is strongly reduced by replacing the illusory contours of each disk of Figure 11 with black rings (see Figure 12). Now, although Rubin's whites are weaker than the previous ones, they are very similar for at least two important properties: they are all achromatic and opaque whites.

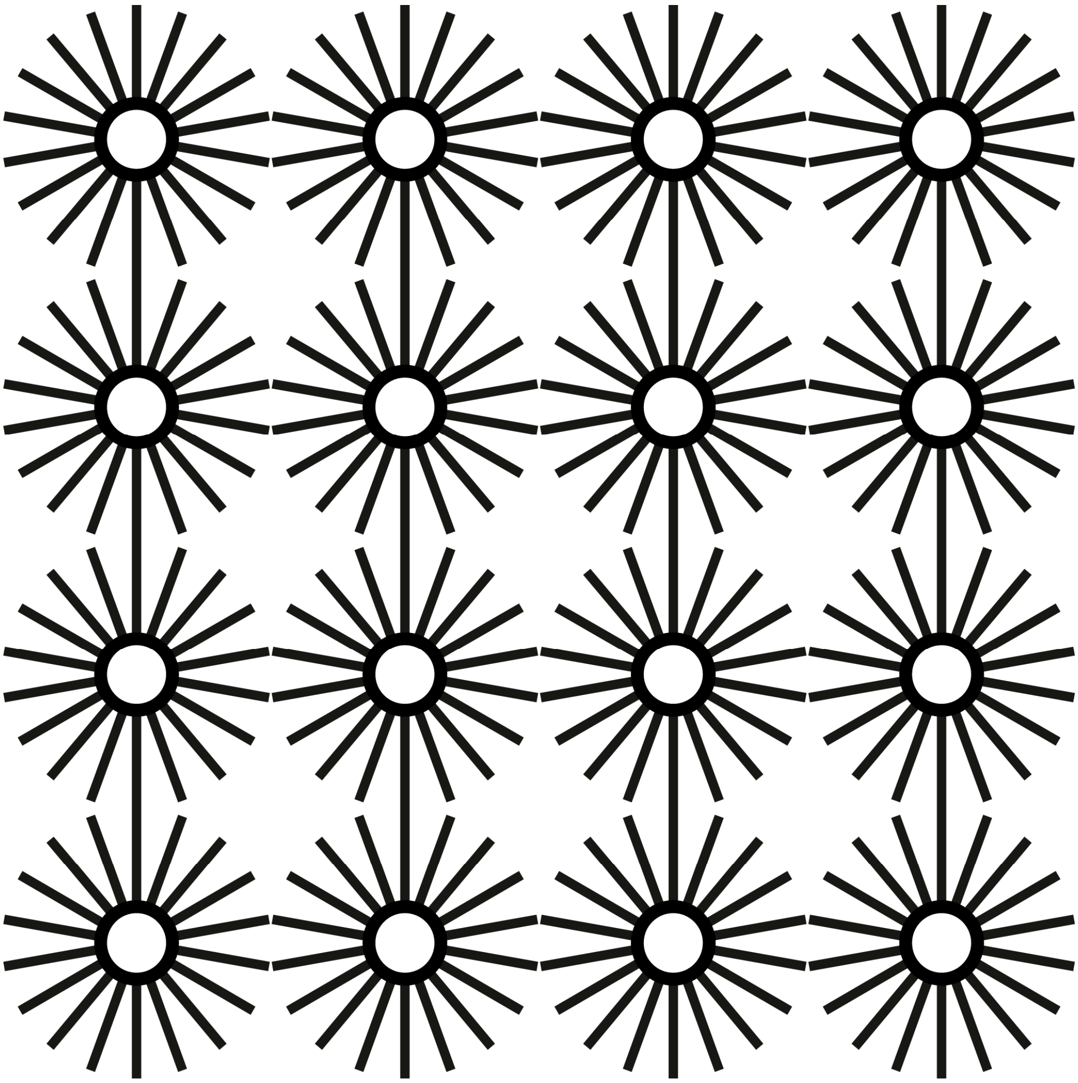


Figure 12. Radial lines and black rings showing achromatic whites.

By replacing each black ring with a purple one (Figure 13), the inner white becomes clearly chromatic. The resulting effect [23] is much brighter than in the Ehrenstein's illusion, and it appears like a surface colored with a dense paste of bright and quasi-luminous white color. The expression "chromatic white" is related to the fact that the white appears as if belonging not to the gray continuum but to the chromatic saturated colors. The phenomenon is clearly perceived as an illusion, and it manifests strong illusoriness attributes. All colors can produce these chromatic whites.

A control without radial lines is illustrated in Figure 14. Now the chromatic whites are absent and only Rubin's achromatic whites are perceived without any illusion and illusoriness.

The chromatic illusory whites can be enhanced as illustrated in Figure 15, in which the whites, although opaque and sharp in their contours, appear to be emanating their own light and self-luminous in a unique way that differs from a glare effect as shown in Figure 16a, in which each inner ring appears to shine with a dazzling apparent luminosity not necessarily brighter than the one of the background.

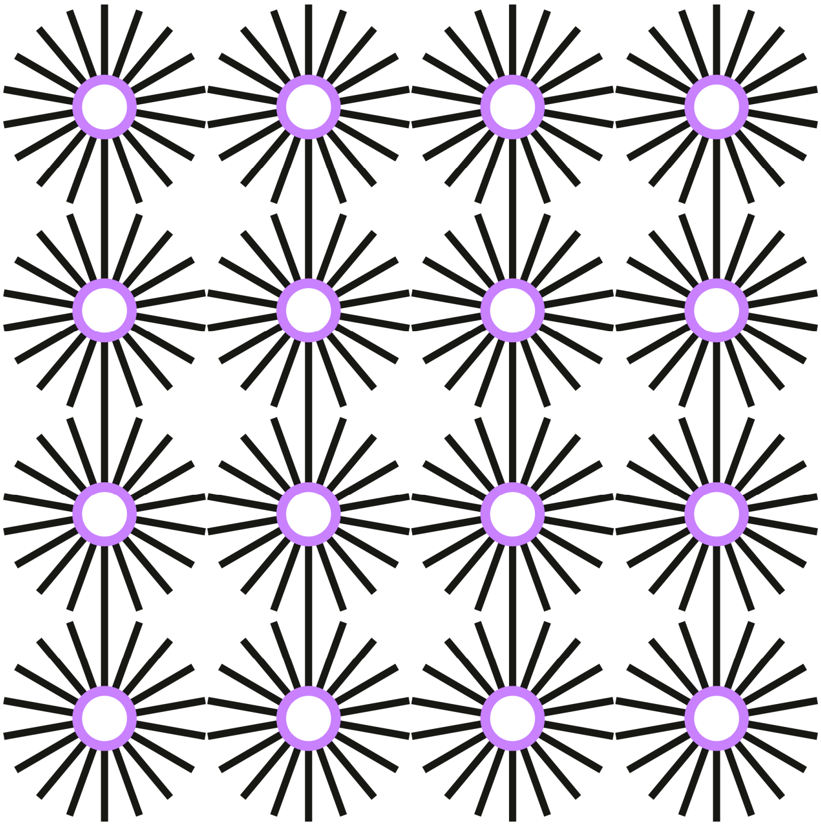


Figure 13. Radial lines and purple rings inducing chromatic whites.

Figure 14. By removing the radial lines the chromatic whites are absent.

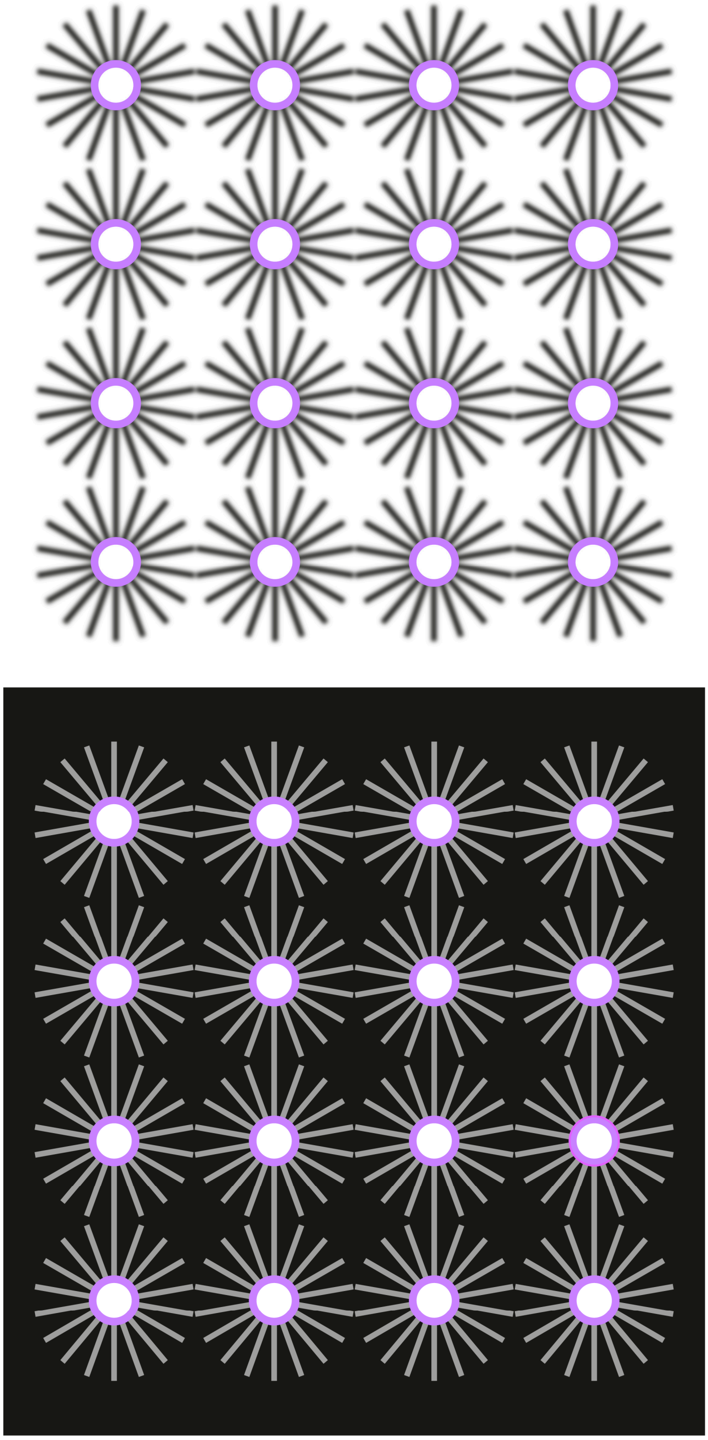
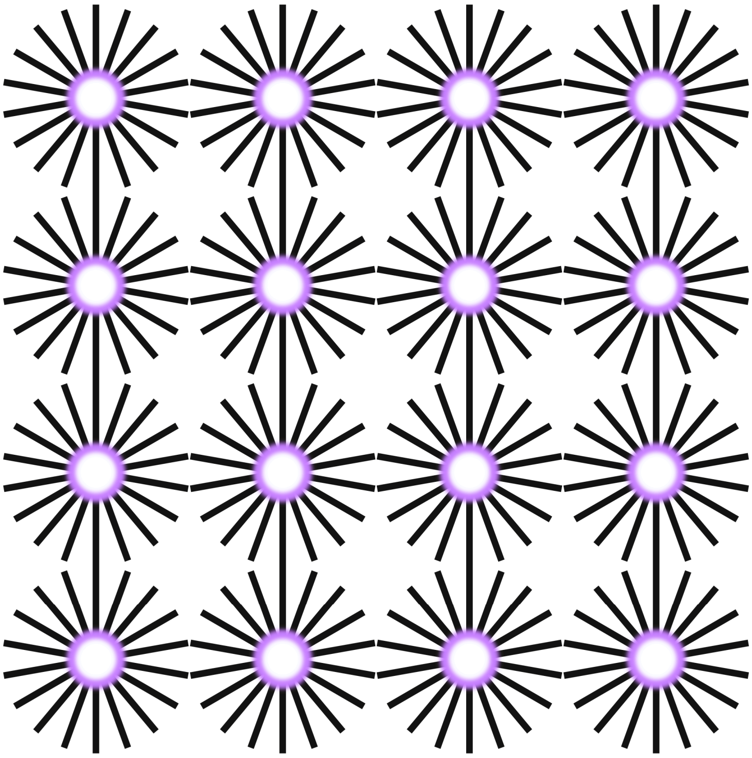
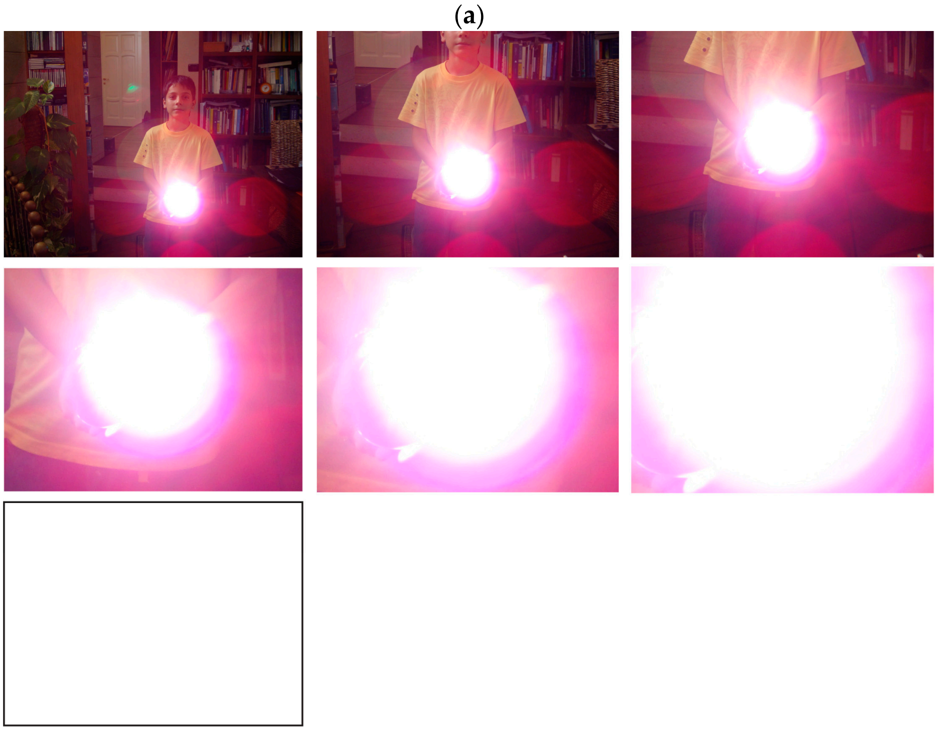


Figure 15. Two conditions showing chromatic whites enhanced and self-luminous.

It is worth noting, for our purposes, that the glare phenomenon, common in everyday life and not showing any illusoriness, as it appears, for example in Figure 16b, becomes illusory when the critical region is gradually zoomed as observable in the sequence of pictures of Figure 16b. In greater detail, the self-luminous white of Figure 16b, which is much brighter than the white of the background, gradually disappears when the picture zooms more and more inside that white. The sequence of photograms can annul or enhance the illusoriness depending on the starting point of the sequence, namely, from the beginning to the end or vice versa. This suggests that the perception of the illusoriness can change, not only by means of the awareness of the illusion but also through different ways of watching the stimulus.



(a)



(b)

Figure 16. A glare effect of chromatic whites. (**a**) Dazzling apparent luminosity; (**b**) illusory glare due to the gradual zooming of the sequence of pictures.

This last point is important, since the visual world is full of illusory objects and elements that, at a first sight, appear strange, deceiving, *sui generis*, mendacious, and odd. Only after observation from a different point of view, in a different way, from a different angle, or with a simple prolonged sight, these objects decrease or increase their illusoriness. This is the case of the fish illustrated in Figure 17. By watching this figure, subjects were deceived for a short time by the two "eyes", although some of them (4 out of 12) needed a prolonged time (about 10 s) to discover the trick of the fish that the eyes are false. Therefore, in the beginning the illusoriness was absent and only after a relatively longer observation the illusoriness emerged.

Figure 17. A fish playing with illusions and illusoriness.

Other fishes, using colors to play with illusions and illusoriness, are illustrated in Figure 18. Again, spots, stripes, and false eyes create illusions that do not show, at first sight, any illusoriness. However, it emerges after a short time by revealing the trick.

Figure 18. Different fishes playing with illusions and illusoriness.

The illusoriness perceived by our subjects is not necessarily perceived by the peculiar preys and predators of these fishes. More generally, if a prey perceives the illusoriness then it survives; conversely, if a predator perceives the illusoriness, its hunting can succeed. In nature, animals have to deal with the play of illusion and illusoriness, according to which the perception of illusoriness is related to the adaptive fitness of an organism. In the Discussion section, these biological implications of the illusoriness will be explored in more detail.

4. Discussion

In contemporary vision science, illusions, which are becoming more and more popular, subsume two important issues that challenge scientists and deserve to be further investigated. The first issue is related to the mismatch between the geometrical/physical domain and the phenomenal one. The necessary condition to see an illusion is usually considered to be related to the perception of this mismatch. The second issue follows from the first, and it is related to at least two different visual levels that emerge from each illusion: the perception of the illusion and the perception of the illusoriness.

If in recent neuroscience all visual percepts are considered equally illusory, in this work we demonstrated that the phenomenology of the illusions and illusoriness is placed along a visual gradient of visibility with complex and useful interactions. More particularly, we demonstrated that (i) the mismatch between physical and phenomenal domains does not necessarily involve the perception of an illusion; (ii) besides the illusion is useful to study the illusoriness that is an independent visual attribute related to a sense of strangeness or oddity; (iii) the illusoriness emerges spontaneously or after a deeper observation and acknowledgment of mismatches; and, finally, (iv) the perception of an illusion does not necessarily require the perception of the illusoriness.

We also suggested that these issues are very useful to demonstrate new biological meanings and implications useful to understanding the complexity of the organization of the visual world and the interactions between visual and cognitive domains. As a matter of fact, the complex interactions and changes, studied in the previous sections, between explicitness and implicitness reflect the necessity to organize the visual world into a gradient of visibility, in which the most significant information in terms of adaptive fitness emerges in the foreground, to the detriment of the less important visual information placed in the background. This entails that, although all visual percepts can be considered equally illusory, it is not biologically useful to perceive everything as being illusory. In other terms, the perception of illusions and of illusoriness is not advantageous to the animal behavior that is required to act promptly without doubts and hesitations induced by illusions. Only under special conditions of illusoriness it is useful to stop, rearrange, and reorganize unexpected conditions.

Since illusoriness is related to a sense of strangeness, deception, singularity, mendacity, and oddity, its visual meaning plays a basic biological role. In fact, it is not a mere companion of illusions but a signal of a hidden structure invisible at a first sight, a structure that is related to the gradient of visibility and that can pop out thanks to a deeper investigation or cognitive discovery. More importantly, illusoriness plays a basic biological role by alerting and warning an organism about something wrong, unclear, ambiguous, tricky, or potentially dangerous within the visual world. As a matter of fact, all living organisms, from plants to animals, use visual strategies to deceive prey or predators, to attract, fascinate, or seduce conspecifics, or to reject, dissuade, or repulse them. In detail, each organism plays with illusions to change and manipulate their appearance and to deceive and influence other organisms to its will and purposes. This enhances the adaptive fitness. At the same time, organisms need to reduce the illusoriness that the represented illusion might manifest; otherwise, the illusory trick is uncovered and, immediately, discovered. Thus, to be effective, all the biological illusory strategies should elude the sense of illusoriness that could signal the deceiving behavior, structure, or coloration.

It is not coincident that colors and colorations are so commonly used to play with the illusory biological signals and identities. Color attributes are the best candidate to play with deceiving and illusory effects. Animal and plant colors play a basic role for their survival [25]. Color is used as a cue for species identification; it emphasizes and determines sexual dimorphism within the same species, and it also advertises the presence of animals and signals its dangerousness or poisonousness. Colors are also useful for identifying contenders, strength, and age. In addition, colors are used for cryptic camouflage and are seen as a defense against predation. In fact, cryptic camouflage [26–29] is a deceiving tool that is used to become imperceptible based on coloration. The opposite is the disruptive camouflage [26,30,31], whose purpose is to confuse by means of highly contrasted colorations and markings [32].

False eyes, dots (Figures 17 and 18), and a variety of patterns present in several animals' bodies are aimed to confuse by showing a disruptive masking and deceiving shape, and by hiding the most vital and important part of their body. The same defensive markings (diematic patterns) can also have the effect of startling or frightening potential predators. In butterflies, the presence of a decoy target, such as a false eye or other patterns, diverts the attack of possible predators away from the butterfly's body, towards the wings' borders.

To conclude, further studies of illusoriness could help to understand more deeply how adaptive fitness depends on the play of illusions and illusoriness, and how the biological meaning of the intense feedbacks and interconnections between organisms and between real and illusory visual conditions are essential to their survival.

Supplementary Materials: The following are available online at http://www.mdpi.com/2313-433X/4/2/30/s1, Video S1: By slowly reversing the contrast of adjacent contours, complementary peninsulas with inner illusory coloration emerge.

Aknowledgments: This work is supported by Fondazione Banco di Sardegna (finanziato a valere sulle risorse del bando Fondazione di Sardegna—Annualità 2015).

Author Contributions: Baingio Pinna and Daniele Porcheddu conceived and designed the experiments; Katia Deiana performed the experiments; Daniele Porcheddu and Katia Deiana analyzed the data; Baingio Pinna wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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