Vision Research 143 (2018) 9–25

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

A new principle of figure-ground segregation: The accentuation

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ARTICLE INFO

No of reviewers = 2

Keywords:
Figure-ground segregation
Shape perception
Gestalt psychology
Perceptual organization
Visual illusions

ABSTRACT

The problem of perceptual organization was studied by Gestalt psychologists in terms of figure-ground segregation. In this paper we explore a new principle of figure-ground segregation: accentuation. We demonstrate the effectiveness of accentuation relative to other Gestalt principles, and also consider it autonomous as it can agree with or oppose them. We consider three dynamic aspects of the principle, namely: attraction, accentuation and assignment. Each creature needs to attract, fascinate, seduce, draw attention (e.g., a mate or a prey animal) or distract, refuse, dissuade, discourage, repulse (e.g., a predator). Similarly, each organism needs to accentuate, highlight, stress, underline, emphasize or distract from another. Thus, accentuation assigns meaning to a visual pattern such as a coat, a plumage or a flower. False eyes (ocelli) and dots (diematic patterns) demonstrate "deceiving camouflage by accentuation" that confuses predators/preys and hides or highlights vital body parts (butterflies/flowers). They also display the deceiving appearance and exhibition of biological fitness. The same accents may serve different or even opposite goals. We conclude that accentuation improves the adaptive fitness of organisms in multifarious ways.

1. Introduction

1.1. On Rubin's principles of figure-ground segregation

The first question in a phenomenological investigation of seeing has to be "What is a visual object? Rubin (1915, 1921) suggested that figure-ground segregation is essential to the existence of phenomenal visual objects. In important phenomenological researches Rubin discovered and studied the basic principles of surroundedness, size, orientation, contrast, closure, symmetry, proximity, convexity, and parallelism, all of which contribute to objectness.

Fig. 1a, shows a variant of the well-known vase/cup-face profiles. The answer to the question "what is this?" is usually "a black cup". However, after protracted observation two close white face profiles, which face each other, suddenly pop out. When this occurs the cup "disappears"; it becomes invisible, simply background, i.e., nothing, not a figure. Once perceived, these two possible outcomes can be easily alternated in favor of the cup or of the face profiles by switching visual attention to one or on the other (Peterson & Gibson, 1993, 1994; Peterson, Harvey, & Weidenbacher, 1991). Other ways to change the relative salience and weight are to reverse the contrast or apply the closure principle, as illustrated in Fig. 1b. The profiles now pop out more strongly and spontaneously, while the cup is invisible or barely perceptible. In Fig. 1c, the figural salience of the two possible results is closely balanced. The result is highly reversible, although the human bias to see faces (pareidolia) perhaps puts the cup at a disadvantage. Indeed, once perceived, the profiles cannot be easily switched off, while the suppression of the cup is easier.

The previous outcomes are also perceived in pure line drawings, using external bounding contours or silhouettes as shown in Fig. 1d.

Similar results emerge when the effects due to pareidolia are removed (Fig. 1e–g). The large convex figures of the square frame alternate with small concave regions (Fig. 1e–f). In Fig. 1g, the convex component is mostly perceived as defined by convexity and proximity.

This is tied up with "figure-ground segregation", the unilateral belongingness of boundaries Rubin (1921) (often called "border-ownership", see Nakayama & Shimojo, 1990; Pinna, 2010a; Spillmann & Ehrenstein, 2004), according to which the shape of a figure derives from its contour (see Hoffman & Singh, 1997; Peterson, 1994; Peterson & Skow, 2008; Pomerantz & Kubovy, 1986). When one segment of an image emerges as "figure", the complement is ignored as "(shapeless) background" (Rubin, 1921) This illustrates the "winner-takes-all" notion (e.g., Grossberg, 1997; Grossberg, Mingolla, & Viswanathan, 2001; Oster, Douglas, & Liu, 2009). It often captures the crux of figure-ground

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https://doi.org/10.1016/j.visres.2017.08.009
Received 31 May 2016; Received in revised form 29 August 2017; Accepted 30 August 2017
Available online 21 December 2017
0042-6989/

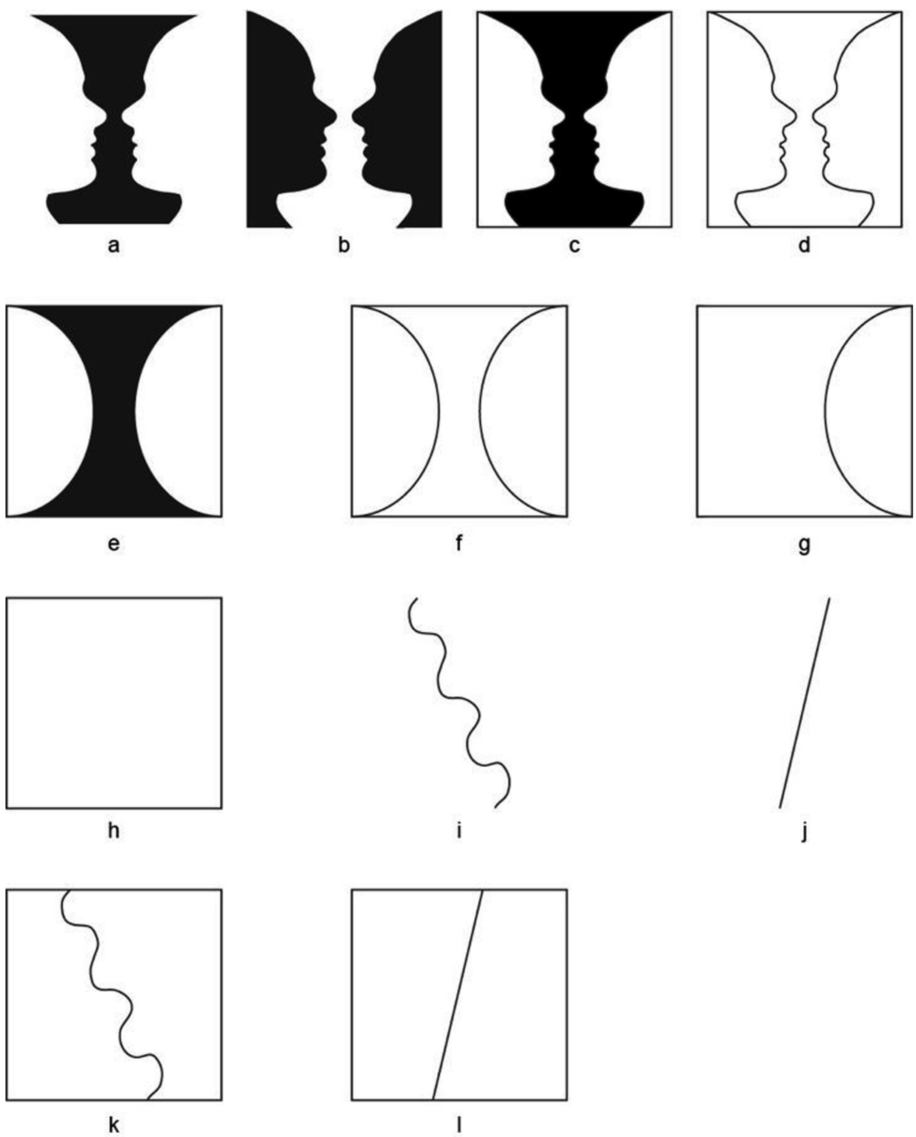


Fig. 1(a–l). Rubin's vase/cup-face profiles with variations and figure-ground segregation induced by simple contours.

segregation. This meta-principle is essential in resolving ambiguity.

Segmentation in biology virtually always implies a choice. One segment is chosen, the other ignored. This makes biological sense when the organism needs to act and does not have the resources to analyze the entire scene in parallel. Thus, any partition should be one-sided. Seeing something necessarily implies not seeing something else at the same time and in the same place. This involves the very definition of "shape" (see Pinna, 2012a, 2012b; Pinna & Deiana, 2014; Pinna & Ehrenstein, 2013). For any organism it is crucial to identify possible preys, predators or mates. Notice that it is equally crucial to hide or deceive, that is to camouflage. We return to these biological issues in the Conclusions section.

A second basic property is the color/brightness of the figure as opposed to its background. It varies from being similar, posing an obvious contrast, or appearing transparent. The figure manifests a unique surface quality (*Erscheinungweise*, Katz, 1930). It may appear as solid and impenetrable or as flimsy as a gauze drapery. In contradistinction, the background appears void, penetrable, and diaphanous, as apparent in Fig. 1d and f–g. More examples will be discussed below.

Yet another property related to the figure-ground segregation is the solidity and volumetric quality of the figure as opposed to the background which appears as a void. This visually explains the unilateral belongingness of the contours and the chromatic/brightness differentiation between figure and ground. All our examples so far show this effect.

These three main attributes of the visual objects can be imparted synergistically by a simple contour, as shown in Fig. 1g. The key point is the asymmetric nature of the visual segmentation in figure and ground. This explains how Fig. 1h displays the full set of figure-ground properties. It might have supposed to be a "square shaped" outer edge, which indeed describes its form, but the outer edge that presumably would have been perceived cannot have any shape, in the sense of the shape of an object.

The phenomenal power of a single line to be like a figure-ground divide pertains to limiting conditions like the simple lines of Fig. 1i–j, either straight or undulated. Both induce a phenomenal figure-ground asymmetry, which is more clearly perceived when they are included within a frame that confines the figure-ground differentiation on both sides of each line segment (see Fig. 1k–l). These limiting conditions demonstrate the strength and, more importantly, the priority of the figure-ground organization over the perception of mere lines. Lines are two-sided, whereas divides or contours are one-sided. Perceived as contours between figure and background, lines represent the visual evolution of a contour into a surface (see Grossberg, 1994; Grossberg & Swaminathan, 2004). Contours spontaneously organize themselves into surfaces delimited by them and present over the background. This

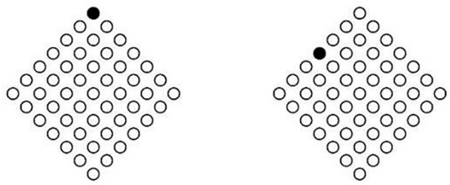


Fig. 1(m-n). The accentuation as a grouping principle.

tendency to self-organization is implicit in Rubin's principles and enforced by our *accentuation principle*.

The accentuation principle (Pinna, 2010a) was demonstrated to dominate grouping when pitted both against or in favor of the classical Gestalt principles (Pinna & Sirigu, 2011). The accent (a filled black circle) emphasizes and polarizes the grouping of elements in the direction pointed by the accent (Fig. 1m–n).

Accentuation is involved not only in eliciting grouping but also in defining many shape attributes such as orientation (Pinna, 2010a, 2010b, 2012a, 2012b, 2012c; Pinna & Sirigu, 2011, 2016), spatial position (Pinna, 2012a, 2012b), inner dynamics and apparent movement (Pinna & Sirigu, 2016).

It turned essential in eliciting organic segmentation (Pinna, 2012a, 2012b) and in inducing musical illusions of suspension (Pinna & Sirigu, 2011) and downbeat (Pinna & Sirigu, 2016).

The following sections demonstrate the accentuation as a new and independent principle. It can work with or against the conventional Gestalt principles. We analyze accentuation in detail and demonstrate various novel conditions. Finally, we extended these into the domain of biology and discuss if the accentuation imparted by a disk can be interpreted as a special case of visual attention.

2. General methods

2.1. Subjects

Different groups of 12 undergraduate students of linguistics, art, music and literature participated in the experiments. For each experiment, two methods were adopted as described in the Procedure section. About 10% of the subjects had some basic knowledge of visual illusions and Gestalt psychology, the others were totally naive both to the stimuli here presented and to the purpose of the experiments. Subjects were both male and female (about 50% each) and all had normal or corrected-to-normal vision.

2.2. Stimuli

The stimuli were the figures illustrated or described in the next sections. They were displayed on a 33 cm color CRT monitor (Sony GDM-F520 1600 × 1200 pixels, refresh rate 100 Hz), driven by a MacBook computer with an NVIDIA GeForce 8600 M GT, in ambient illumination provided by a Osram Daylight fluorescent light (250 l×, 5600° K). All conditions were shown in the fronto-parallel plane at a distance of 50 cm from the observer.

2.3. Procedure

The ultimate purpose of this work is to reveal the degree to which accentuation plays with or against the conventional Gestalt principles. Given the complexity of the possible interactions, this may well seem impossible (see also Palmer, 1999; Todorovic, 2008), and our work can hardly be the final word on the matter. We present it as a novel and possibly fruitful perspective on the phenomenology, rather than as definitive.

The procedure involves two methods similar to the classical Gestalt methods of experimental phenomenology (see Kanizsa, 1979, 1980, 1991; Koffka, 1935; Metzger, 1963, 1975; Spillmann & Ehrenstein, 2004).

2.3.1. Phenomenological task

In this task subjects were first introduced to the phenomenon of figure-ground segregation, then they reported spontaneously on what they perceived. These descriptions of the stimulus were judged by three graduate students of linguistics, totally naive as to the hypotheses, in order to get a fair representation of the responses of the subjects. All reports were spontaneous. Observation time was unlimited: the observers looked at the stimuli during their report, and presentation was ended only when they finished.

Participants could make free comparisons, compare things, add comments as afterthought, and view the displays in different ways and from different distances. They could also match the stimulus with every other one they considered appropriate. All variations and possible comparisons arising during the free exploration were written down by the experimenter. This large degree of freedom aimed at more stable outcomes. The selection of stimuli involved opposite conditions and controls and possible comparisons between stimuli. The selection was strategically structured to minimize the problems of biases or experience.

2.3.2. Scaling task

With this task subjects were expected to rate (as percentage) the main descriptions resulting from the previous phenomenological task. At this stage, new groups of 12 subjects were asked to scale the relative strength or salience (in percent) of these main descriptions. Their task was literally: "please rate whether this statement (e.g. "I see two face profiles" or "this region is filled like a figure if compared with this other part that is empty and transparent" or "I see the right side filled and solid, while the left side is like an empty space") is an accurate reflection of your perception of the stimulus, on a scale from 100 (perfect agreement) to 0 (complete disagreement)". We report descriptions whose mean ratings were greater than 80 across all experiments. For these procedures see Pinna (2010a, 2010b), Pinna and Albertazzi (2011), Pinna and Sirigu (2011, 2016), Pinna and Reeves (2006). Critically, the statements being rated were based on a careful analysis of previously-obtained spontaneous descriptions, so the subjects were not being forced to rate appearances that no-one had reported before.

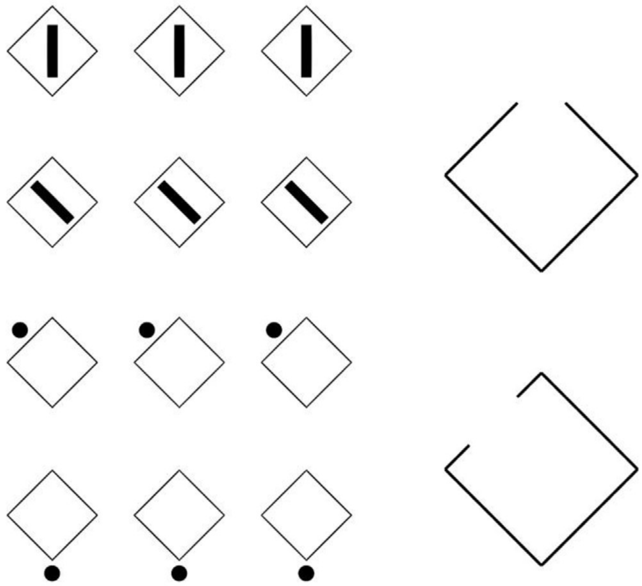
3. Results

3.1. Figure-ground organization accentuated

We studied the role of accentuation in figure-ground segregation under the limiting conditions shown in Fig. 1. As a matter of fact, by increasing the number of accents or by changing the kind of accent or improving its salience (see Fig. 1p–r) the final figure-ground effect imparted by the accentuation is expected to be strengthened. In short, if the resulting effect is clearly perceived under the simple and limiting conditions studied here, it can be easily improved. This plays in favor of the principle of accentuation.

Subjects' spontaneous descriptions report the contour of Fig. 1i to appear as "a wiggly line". They also spontaneously appeared as the boundary contours of an undulated surface reminiscent to the profile of solid hills in one (left) or in the other (right) side. There is a vivid filled and empty figure-ground alternation, clearly related to what is perceived convex or concave. The convex filled area is perceived more dense and material, whereas the concave area is mostly seen as sparse and void.

Of course, the perception of concave/convex geometrical curvatures depends on the choice of the system of reference. Therefore, by attending to the left or on the right side of the wiggly contours, the convex or concave outcome may switch concave-convex sides. This entails a switch of the system of reference. It involves the apparently



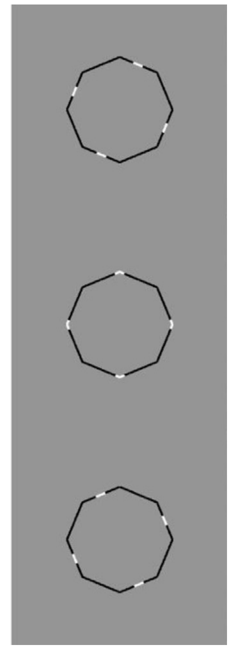


Fig. 1(p–r). The accentuation and different kinds of accents defines the shape: diamonds or rotated squares, flattened or pointed polygons, and rotations clockwise and anticlockwise.

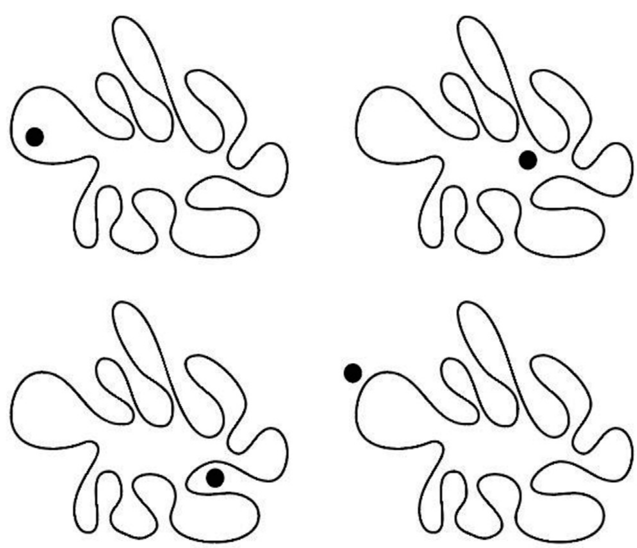


Fig. 1(s–v). Examples of organic segmentation with different headedness-bodiness and different inner dynamics and apparent movement due to the accentuation principle.

higher “density” or “solidity” of the convex region. This neatly aligns with Rubin’s principle of convexity, according to which, all else being equal, convex rather than concave regions tend to be perceived as figures.

The convexity/concavity effect can also be switched by simply moving the gaze from the left to the right side of the wiggly contour. This spontaneously occurs during observation of the stimulus and makes the figure-ground outcome (filled hills-empty spaces) highly unstable and reversible. Adding an accent on one of the two sides of the wiggly line may be expected to make the figure-ground outcome less ambiguous. This is indeed what has been reported (see Fig. 2a–b). It is evidently related to the role played by the dot in defining the apparent reference frame. Here we have taken a decisive step forward, because it enables us to control the appearance to a larger extent.

Apparently, the particular location of the black dot defines what will be taken as figure. Perhaps this suggests that the accentuation effect, due to the dot, is ancillary to the Gestalt principles. However, we demonstrate below that the accentuation can do much more than just highlighting a specific part or aspect of the stimulus.

Accentuation behaves as indicating the figure side of a contour, irrespective of its curvature. This phenomenal result comes forth also when the dots are placed nearby the concave components of the wiggly line instead of the convex ones (see Fig. 2c–d). However, outcomes from Fig. 2c–d are weaker than the ones of Fig. 2a–b, no doubt due to the convexity principle. Apparently, the role of accentuation is not restricted to aiding the Gestalt principles. It may play an autonomous role, in this case against convexity.

Results suggest that more dissimilar and thus stronger accentuation, leads stronger effects. For example, red dots are more effective than black ones (see Fig. 2e). The accentuation imparted by the dot persists when only one dot is used as accent for the entire wiggly line (Fig. 2f–g). The effect generated by the dot spreads as if it were along the entire line. Similar results are obtained by moving the dot away from the contour (Fig. 2h–i). Placing the wiggly line within a square frame (Fig. 2j–k) increases the effect of the accent. In addition, the same effects occur for a straight line (Fig. 2l–m). We may summarize this as follows: a single dot can be sufficient to attract attention and even the gaze, to accentuate a specific attribute, like figurality, and to assign the accentuated attribute to the nearby boundary contours and, then, to the whole object.

To fully appreciate the conclusions from this and the following sections it is recommended to observe and judge each stimulus separately. They are here grouped and presented together for editorial reasons. As a consequence, their proximity but also the fact that they are indicated with letters below (see also Pinna & Sirigu, 2011) distorts the final result in various ways. This is again due to the accentuation principle!

The term “figurality” (see also Pinna & Reeves, 2006) refers to all three Rubin’s main properties together as described in the Introduction section. All of them can be clearly perceived in the conditions illustrated in Fig. 2. However, they can be better appreciated when accents are placed within the cup/faces conditions, as shown in Fig. 2n–q. As expected, the dots accentuate and change the figure-ground effect in favor of the accentuated region that appears now less reversible than before. This involves not only “figure or background” but also the apparent color and depth of the two regions. This is clear when comparing the perceived white of the two profiles in Fig. 2n–o when they are both perceived as profiles. The asymmetric and reversed figural strength imparted by the red dots makes the white of the profiles accentuated

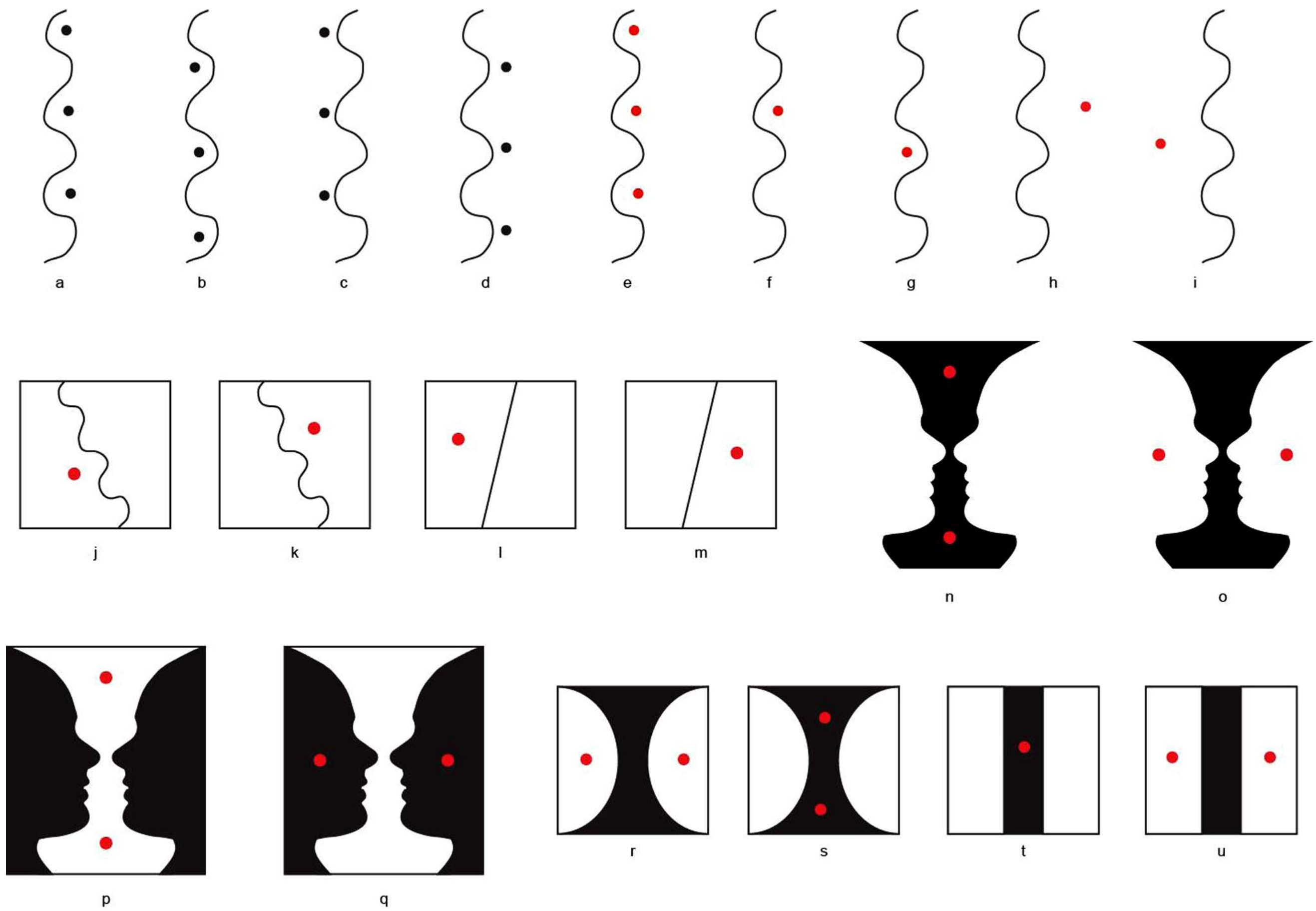


Fig. 2. On the accentuations of the stimuli of Fig. 1.

and enhanced to appear “more white”, wider in their white, brighter and filled of white like a smoothed surface reflecting light. In other terms, the whiteness is perceived differently both in the quality and in the quantity. The previous descriptions were spontaneously used by our subjects and they emerge also when it was asked to switch the perception in favor of the profiles. Of course, the profiles were perceived at a different intensity, i.e., stronger when the profiles were accentuated. Therefore, given that the profiles were perceived in both conditions, it means that the accentuated figure-ground attributes (shape, color and depth) manifest a reciprocal asymmetry. This entails that their ratio is not constant, but proportional to the twice the increase of strength on the accentuated side, and, thus, they are not linearly dependent (about this point reader may refer to previous papers, Pinna & Reeves, 2006; Pinna & Sirigu, 2011). The same results related to the whites-whiteness and to the blacks-blackness can be clearly perceived by comparing Fig. 2p–u.

Not only whiteness and blackness, but also depth and volumetric effects can be clearly accentuated by dots. This occurs in the conditions illustrated in Fig. 3. In Fig. 3a–b, some kind of map with lands and sea are perceived. The depth appearance of the single regions is reversed and complementary, filled like a land or background like a sea, but more importantly it is reversible and can be easily alternated by changing the location of the sight and the focus of attention. Indeed, the unilateral belongingness of the boundaries is fragile and switchable and the perceived sea coast and borders of the lands are not volumetrically delimited and differentiated. The segregation is not deep and elevated in 3-D as it is perceived in Fig. 3c–d, where the dots increase the depth and enhance the salience of the boundary contours. It is worthwhile highlighting that by reducing the number of red dots within the closed inner region when it is perceived like land, the boundary contours increase their depth and volumetric attributes, bulging in 3D (see Fig. 3e–f).

These results were to be expected on the basis of the foregoing observations. The phenomenal meaning of an accent is apparently that of a noticeable and localized foreground feature. Hence it imparts a clear and distinct visual emphasis to one or more visual attributes. This suggests that the optimal or ideal accent should be distinct and noticeable, i.e., something different, distinguishable, notable and possible unique. Therefore, single dots serve to induce salient depth articulations (Fig. 3g–h). Its strength is heightened when the dots are chromatically alternated (e.g., red and green) from one land to another (Figs. i–j). The surprising power of a single dot accent is explored in detail below.

Before introducing new patterns, it is worthwhile notifying that the conditions studied in the next Sections were designed as limiting cases, i.e., the simplest figures where the accentuation could have a clear effect. These conditions are based on line drawings and on a minimum number of accents. They are useful to demonstrate the strength of our effect in limiting conditions similar to those studied by Gestalt psychologist. Moreover, a further argument is the following: if the accentuation is effective under the following poor conditions, all the more reason it is expected to be effective, for example, by adding more accents or by replacing the line drawings with surfaces. Demonstrations based on enriched conditions (filled surfaces rather than line drawings) clearly reveal enhanced effects, as illustrated in Fig. 3k–m. The effect related to the number of accents is shown in Fig. 3c–h. Finally, Fig. 3n–o demonstrate the effective role of accents of different color within the same enclosed region. In spite of the break of the assumption of homogeneity belonging to a figure, the accentuation imparts a clear figure-ground effect. This control is also useful to null a possible role of chromatic assimilation of the accents, although the assimilation is reduced to a minimum when only one accent is used.

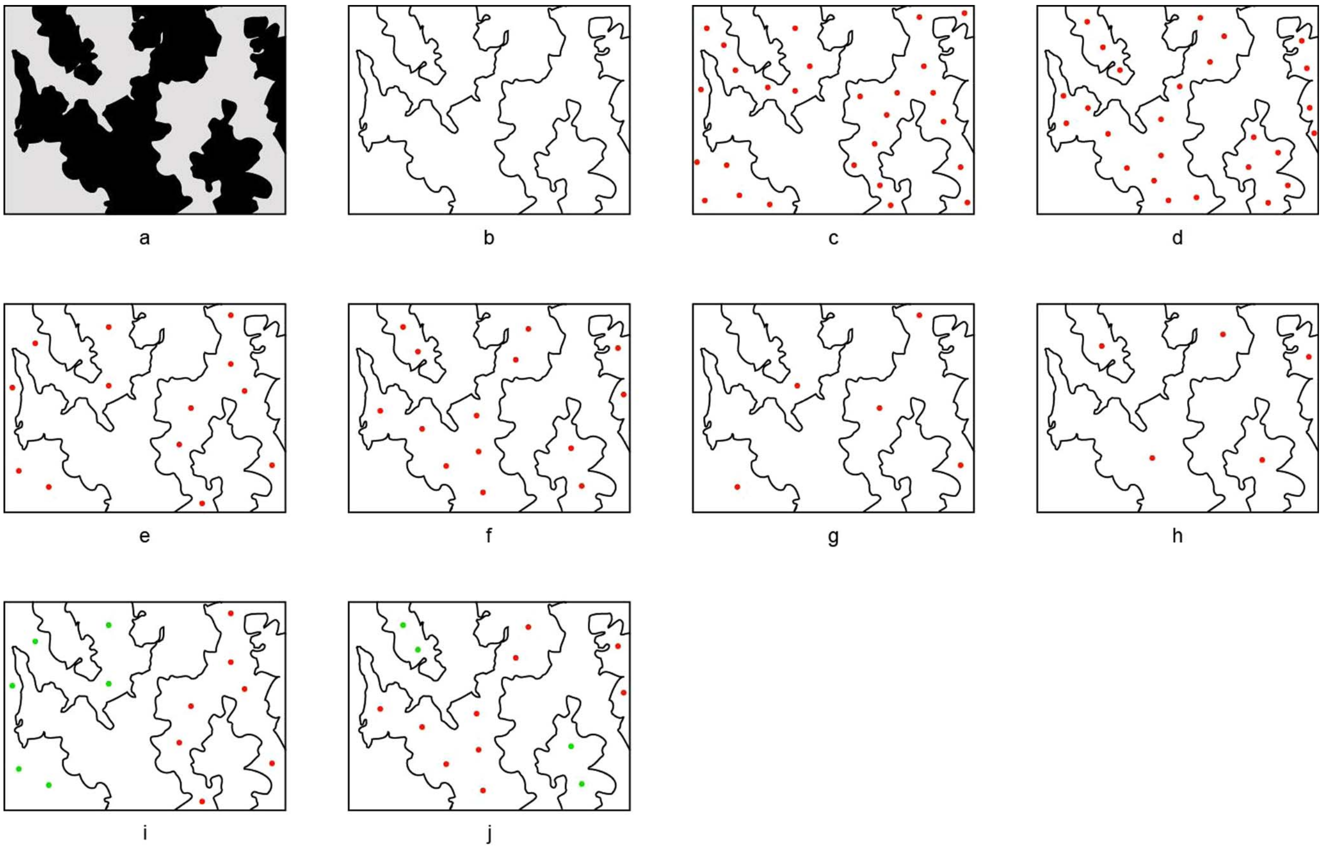


Fig. 3(a–j). Accentuating the depth and the volumetric effects of the figure-ground segregation.

3.2. Accentuation vs. Gestalt figure-ground principles

Here we explore accentuation as a novel principle of figure-ground segregation. We investigate the strength of the accentuation in relation to the classical Gestalt principles. We attempt to demonstrate that accentuation is an independent and autonomous principle, rather than psychophysically quantifying its absolute strength in specific cases.

3.3. Proximity/smaller size vs. accentuation

Gestalt psychologists demonstrated that proximity and size are principles that, all else being equal, rule the perception of a figure. The first row of Fig. 4 demonstrates reversible figure-ground segregation between two mutually equivalent regions. Reducing the size of one region stresses the figural dominance of the smaller area, the larger, being predominantly, is seen as background (see the second row of Fig. 4). This figure-ground effect is inverted in the third row, where a red dot is placed on the larger regions of each stimulus. Here, the accentuation due to the red dot plays against the proximity and smaller size, evidently overriding the classical tendencies. When the accentuation principle is synergistic with the Gestalt ones, the results lead to an enhanced effect (fourth row of Fig. 4).

These outcomes also appear indirectly in Fig. 3, where larger regions were accentuated with dots. Similar results emerge in the fifth row of Fig. 4, where the inner rhombic wiggly contours can be perceived like a rhombic hole or like a solid object with a rhombic shape.

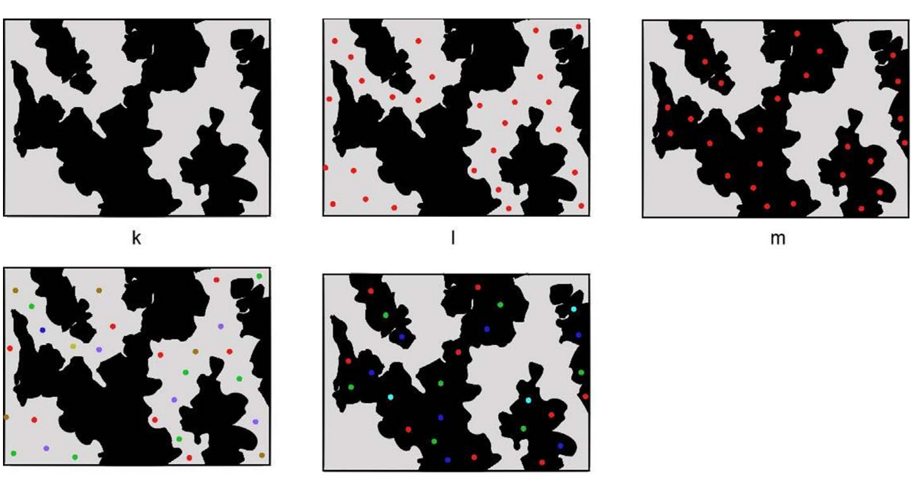


Fig. 3(k–o). Accentuating filled surfaces, rather than line drawings, elicits a stronger figure-ground effect.

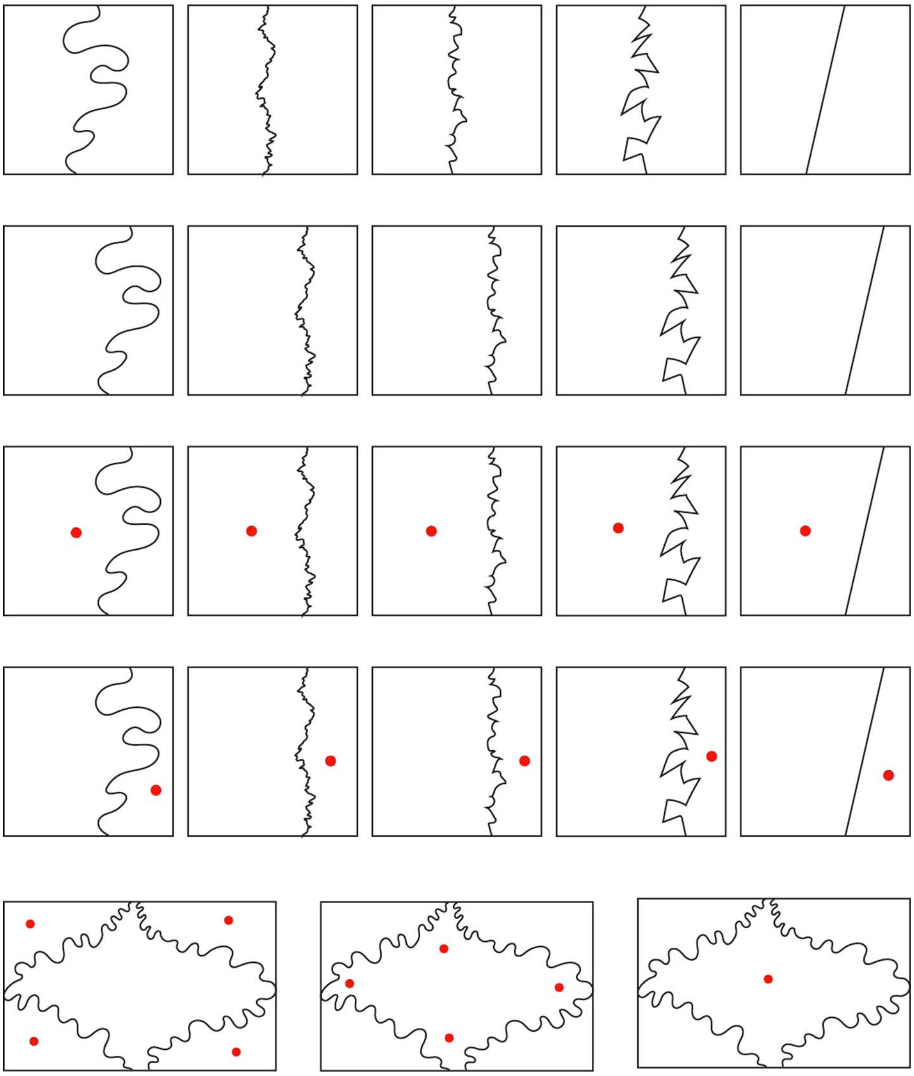


Fig. 4. Accentuation and proximity/smaller size principles.

3.4. Surroundedness vs. accentuation

A special implication of proximity and smaller size is the surroundedness principle, according to which an inset smaller region is, all else being equal, perceived as a figure (Fig. 5a). Under these conditions it is not impossible to switch the figural effect in favor of the surrounding region and elicit the perception of a picture frame. However, this switch becomes much easier when the accent plays against surroundedness, as shown in Fig. 5b. A control with a synergistic condition can be seen in Fig. 5c.

The smaller size of the surrounded area depends on proximity (see Fig. 5d). Now, although the inner square is still surrounded by the larger one, the sides of both squares are closer, their distance being smaller than half the diameter of the inner square. Under these conditions, proximity and surroundedness are not synergistic but compete. Increasing the proximity decreases the effect of the surroundedness. As expected, in Fig. 5d proximity wins against surroundedness. The perception is that of an empty picture frame.

These results can be inverted through an accentuation that rules figure-ground against or in favor of proximity (the opposite for surroundedness), like a swing vote (Fig. 5e–f). The results do not change when the red dot is placed in different positions in the pattern (Fig. 5g–i). The previous effects appear even stronger when two combined accents are included within the frame or the inner square (Figs. j–m).

However, this is not the full story within these simple figures. There is another hidden principle that should be taken into account, namely the effect of parallelism, which is discussed below.

3.5. Parallelism vs. accentuation

According to the principle of parallelism, parallel contours tend to be perceived as the boundaries of the elicited figure (Morinaga, 1942). To appreciate this, it is sufficient to tilt the inner surrounded square of Fig. 5a, as it reverses the previous results. The picture frame influence becomes very weak and the tilted square (Fig. 6a) is more salient. Accentuation can significantly act in favor or against (Fig. 6b–e) this principle. The reversed outcome is demonstrated in Fig. 6b–c.

Another way to test the role of parallelism is by distorting the straight contours of the inner square as in Fig. 6f. With these wriggly contours the perception of the frame becomes very difficult. However, since a weak parallelism between the boundaries of the squares remains and since the surroundedness remains as well, the best compromise among the inner figure-ground dynamics is the perception of a hole. This hole may be understood as a figure and as a background at the same time (see Bertamini, 2006; Bertamini & Hulleman, 2006; Bertamini & Mosca, 2004; Hulleman & Humphreys, 2005; Casati & Varzi, 1994; Feldman & Singh, 2005; Palmer, 1999; Peterson, 2003; Pinna & Tanca, 2008; Subirana-Vilanova & Richards, 1996). In other words, the inner void of the picture frame is enhanced due to a partial

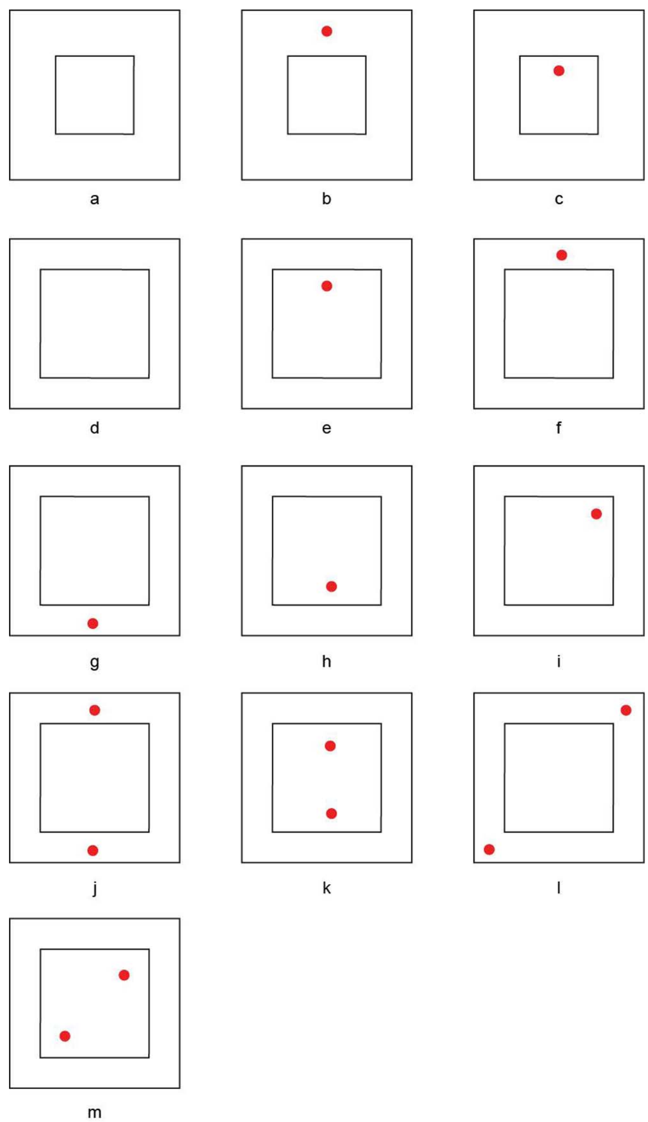


Fig. 5. Accentuation and surroundedness.

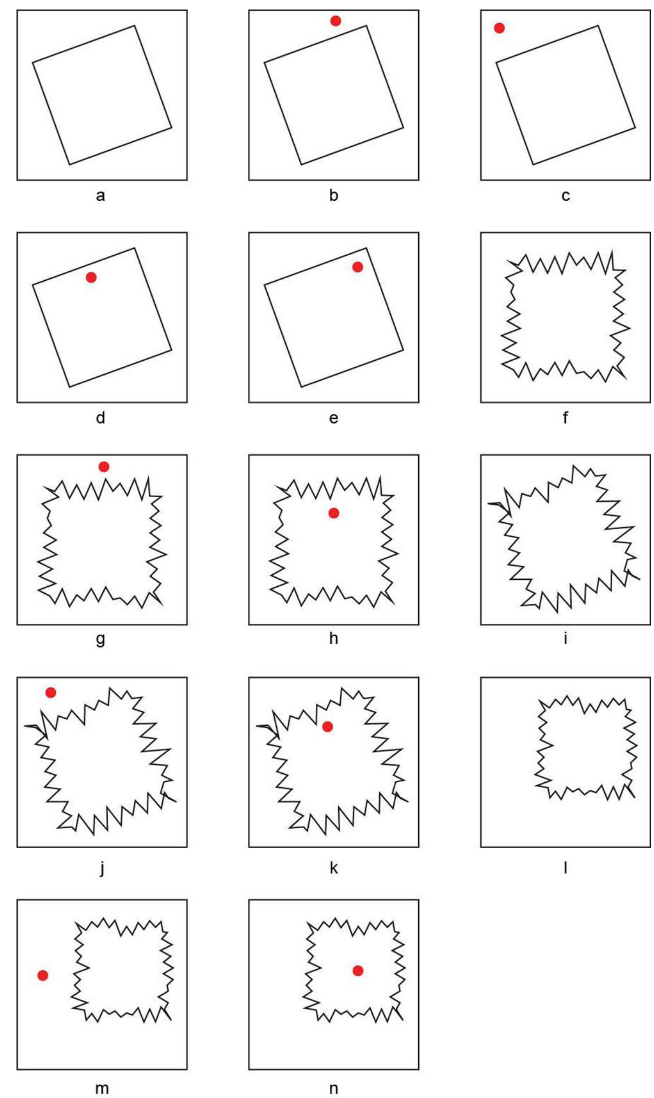


Fig. 6. Accentuation and relative orientation and the loss of parallelism.

loss of parallelism and greater strength of surroundedness. This perhaps surprising result (i.e., the emergence of a hole) can be easily weakened or enhanced through the addition of accents (Fig. 6g–h). Analogous results occur when the inner distorted square is tilted (Fig. 6i–k). A further way to weaken the parallelism is to place the central square eccentrically in the frame (Fig. 6l). This promotes perception of a hole, which can again be aided or impeded by accents (Fig. 6m–n).

Actually, parallelism was first demonstrated (Morinaga, 1942) under conditions different from these. A simple way to show its effectiveness is demonstrated in Fig. 7a–b. Here, the figural effect of the parallel contours of Fig. 7a is much stronger than the one of the non-parallel ones of Fig. 7b. The effect of parallelism is also perceived in Fig. 7c, where the regions delimited by wavy parallel lines more easily appear as figures.

Accentuation can either reverse or strengthen these results (Fig. 7d–e). The effect of accentuation is further heightened when dots of different colors are included in alternated regions (Fig. 7f). The strength of accentuation persists when wiggly lines are combined with straight ones (Fig. 7g–h). This case involves not only parallelism but also the similarity of pairs of lines. Apparently parallelism can be considered as a special case of similarity. This will be the main topic of the next section. More generally, all principles can be understood as special instances of a general principle of maximal homogeneity as stated by Musatti (1931). Just as parallelism is one of the many special cases of similarity, similarity is in its turn a special case of maximal homogeneity. This makes it hard to relate the relative strength of the various factors. They are not independent principles but rather various instances of a single, more general principle. In our conclusion we will reconsider this notion in the light of accentuation, which appears as an independent factor.

3.6. Similarity vs. accentuation

The examples of Fig. 7 already address the interplay of accentuation and similarity. There are countless possible similarities and these can all be combined with each other, both synergistically or antagonistically. We discuss merely the most common and strongest ones. In Fig. 8a–b, we consider the role of chromatic similarity, according to which, all else being equal, contours of the same color tend to be perceived as the boundaries of a figure, whereas regions delimited by contours of different colors tend to be perceived as background. In Fig. 8c–d, the accentuation is shown to play against or in favor of chromatic similarity. An even better test for the effectiveness of accentuation in changing the outcome of chromatic similarity and parallelism is presented in Fig. 8e–f. The synergy between the two similarities (Fig. 8e) enhances the induced figural effect. Accentuation (Fig. 8g–h) weakens or heightens the effects in the expected way. When parallelism plays

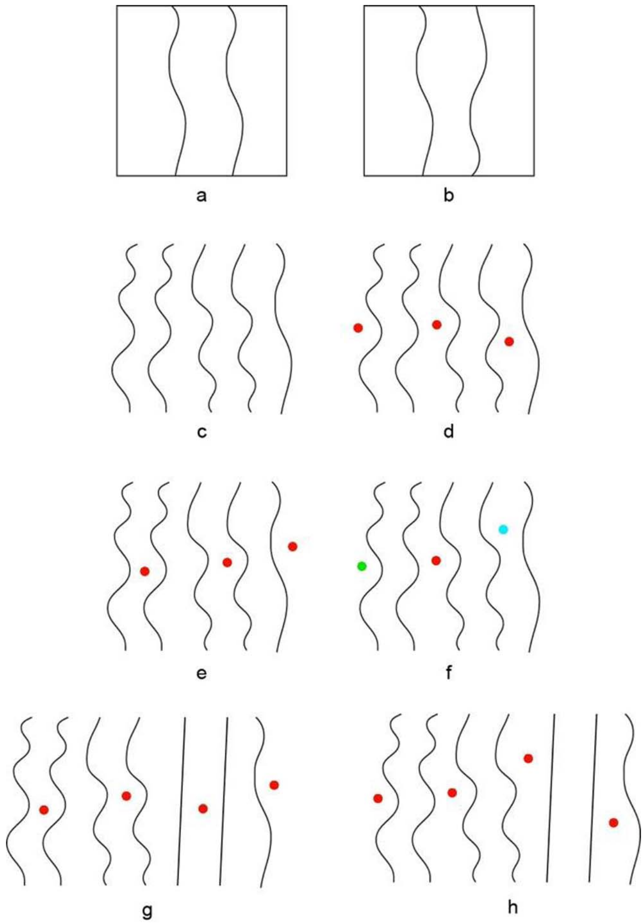


Fig. 7. Accentuation and Morinaga's parallelism.

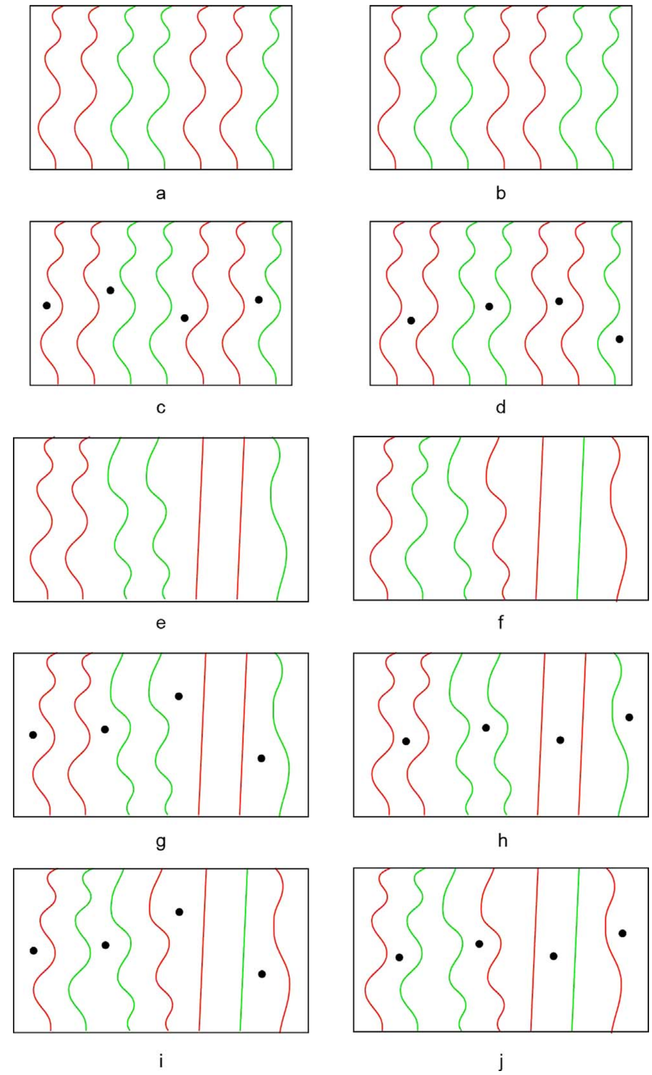


Fig. 8. Accentuation and chromatic similarity/parallelism.

against chromatic similarity, the role of accentuation is stronger in both directions, either weakening or enhancing (Fig. 8i–j). The reason is that accentuation plays against only one of the two similarities.

The effect of accentuation can also be tested with the combination of chromatic similarity and convexity (Fig. 9). The classical way to study convexity is illustrated in Fig. 9a. In spite of proximity, the convex region manifests the most intense figural effect, while the concave one tends to be perceived as background. Under these conditions, accentuation is evidently against or in favor of convexity (Fig. 9b–c). When chromatic similarity is included too (Fig. 9d–e), accentuation again acts as expected.

Accentuation also works when a further kind of similarity, related to the shape of contours, is added to chromatic similarity and convexity (Fig. 9f–i). Accentuation has an evident effect in the case of many principles being active simultaneously. Its main role is apparently that of implicitly connecting mutually separated elements, in our examples, with dots. [note: why 'intermediate'? intermediate or central ? Fig. 9 doesn't say.] The separation of the contours may be the reason of the accentuation here. This hypothesis can be tested as shown in Fig. 10. Now the basic element is a unique switchback zigzagging contour (Fig. 10a). One immediately perceives it as organized in two peninsulas going from left to right or, reversibly, as two different peninsulas going from right to left. In the first case the main area of land is perceived at the bottom, in the second at the top.

Accentuation effectively defines which of the regions are perceived as peninsulas (Fig. 10b–c). This occurs equally when other types of similarities are added and all together are pitted against accentuation (Fig. 10d–h). Perhaps contrary to the previous hypothesis of independent additive effects, this demonstrates that, when the components are connected, the role of accentuation can be even stronger.

The zigzagging contours of Fig. 10 can be considered as extended cases of the wiggly lines with alternated convex and concave curves of Fig. 2. Moreover, the zigzagging undulated contour of Fig. 10 partially enclose major regions, similarly to the convex figures where the figural effect is more persistent and dense. Thus, the role of the accent could be related to a tendency to further close up these regions. If this is the case, then accentuation and the closure principle cannot be put in competition. We consider this issue below.

3.7. Closure vs. accentuation

A simple and useful way to proceed from the previous convex conditions to stimuli related to the closure principle is illustrated in Fig. 11a, where the region in between the two horizontal sinusoids, although not actually closed, yet appears closed by virtue of its length. Accentuation can switch the figurality from the inside edges to the outside as shown in Fig. 11b–c. Of course, under these conditions, parallelism is also playing a role. Similar results are obtained by replacing the sinusoids with two parallel sequences of Greek frets (Fig. 11d–g).

A connection with the peninsulas of Fig. 10 is established in Fig. 11h–k. The observations are in agreement with the previous ones. Going further, the internal region of each sinusoid can be fully closed. Its figurality increases as in Fig. 11l, where the vertical orientation and its isolation render the closed undulated figure apparent as a solid

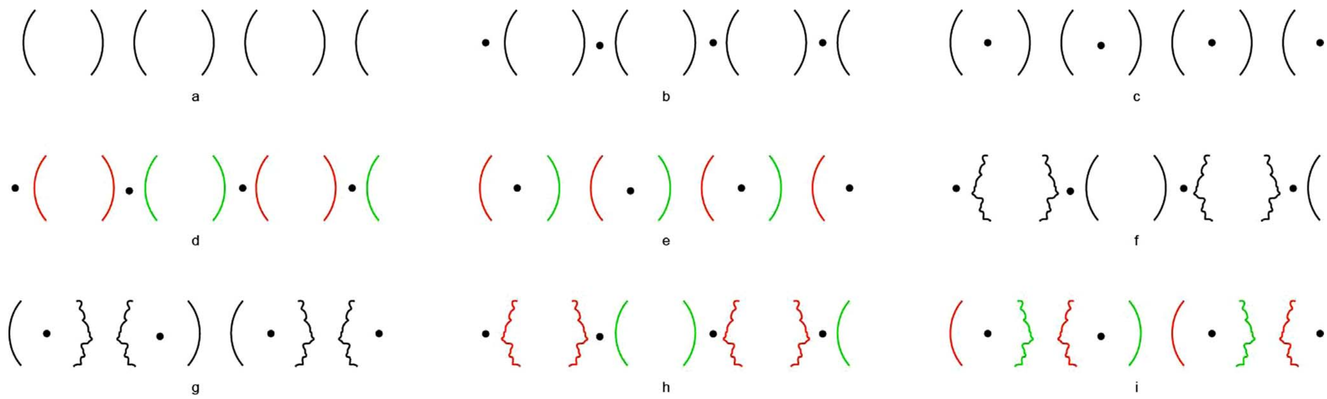


Fig. 9. Accentuation and similarity/convexity.

object similar to a column. However, despite the orientation and closure, accentuation of the outer large area reverses the figurality. The inside edge tends to appear as an empty space (Fig. 11m). Conversely, when the accents are placed on the inner region its figurality is strongly enhanced (Fig. 11n). Further conditions related to the cup/face profiles are shown (Fig. 11o–p).

3.8. Good continuation vs. accentuation

It is well known that closure can beat good continuation as in Fig. 12a. This pattern is obtained by juxtaposing two sinusoids. Due to the good continuation of the undulated contours, the closure is ineffective in inducing a figural effect. Therefore, the inner closed region is perceived as empty. This entails that the contours are perceived as such, i.e., like two overlapped waves whose continuation or curvature change is smoothed and minimized.

In Fig. 12b–c, the role of closure and good continuation are pitted against accentuation, showing either filled closed shapes (Fig. 12b), or two lines of rounded teeth in contact (Fig. 12c). When the sinusoids are overlapped (Fig. 12d), good continuation and the perception of two undulated waves prevails. However, this percept is weakened by placing the accents within different closed regions as shown in Fig. 12e–g. Similar effects were reported when two irregular waves are overlapped (Fig. 12h) and when a Greek fret is overlapped with a sinusoid (Fig. 12i). The accentuation is effective also under these conditions (Fig. 12j–k).

3.9. Vertical-horizontal orientation and proximity vs. Accentuation

Rubin discovered a principle of orientation, stating that, all else being equal, the regions oriented along the main directions of space (vertical and horizontal) tend to be perceived as figures. The role and effectiveness of this principle can be observed in Fig. 13a, showing a variant of the classical well-known Rubin's Maltese-cross. Here, the oblique cross is hardly perceived as a figure but mostly as an empty background without any shape. The four circular sectors oriented and aligned vertically and horizontally become the four arms of a Maltese-cross, while the complementary ones are seen as background or empty spaces. These results can be reversed with a significant visual effort, thereby eliciting the appearance of an oblique cross.

Fig. 13b shows that accentuation wins over orientation, thus revealing the oblique cross. A control with the two principles operating synergistically is illustrated in Fig. 13c. By combining orientation of the Maltese-cross and proximity against or in favor of accentuation

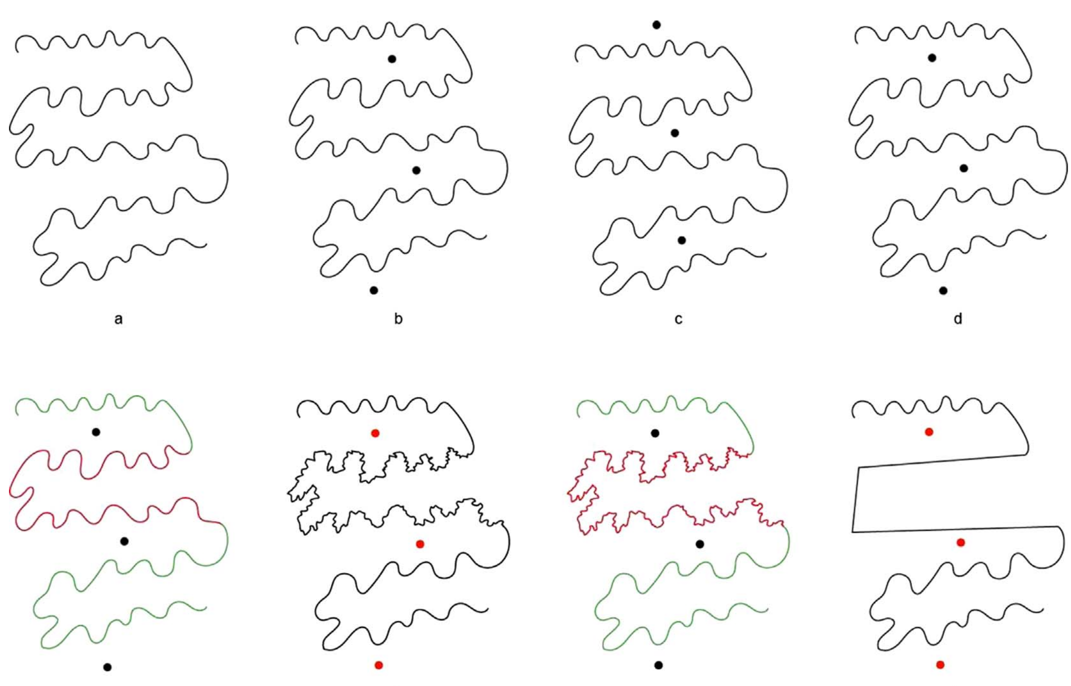


Fig. 10. Accentuation and similarity.

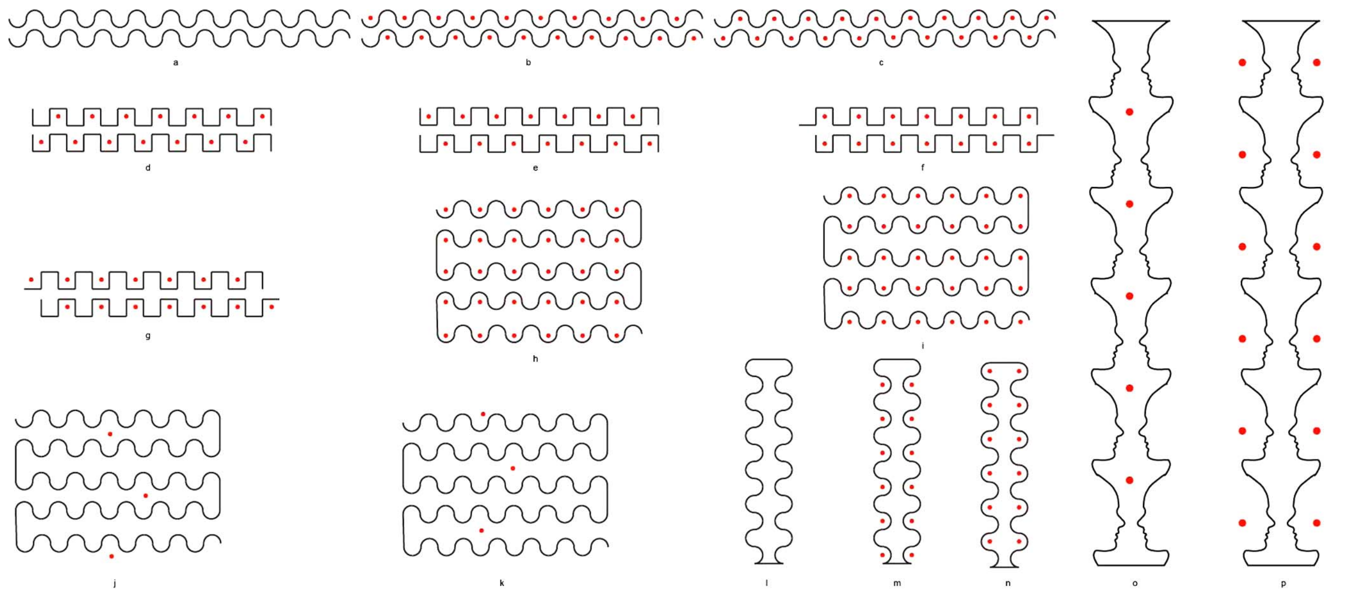


Fig. 11. Accentuation and closure principle.

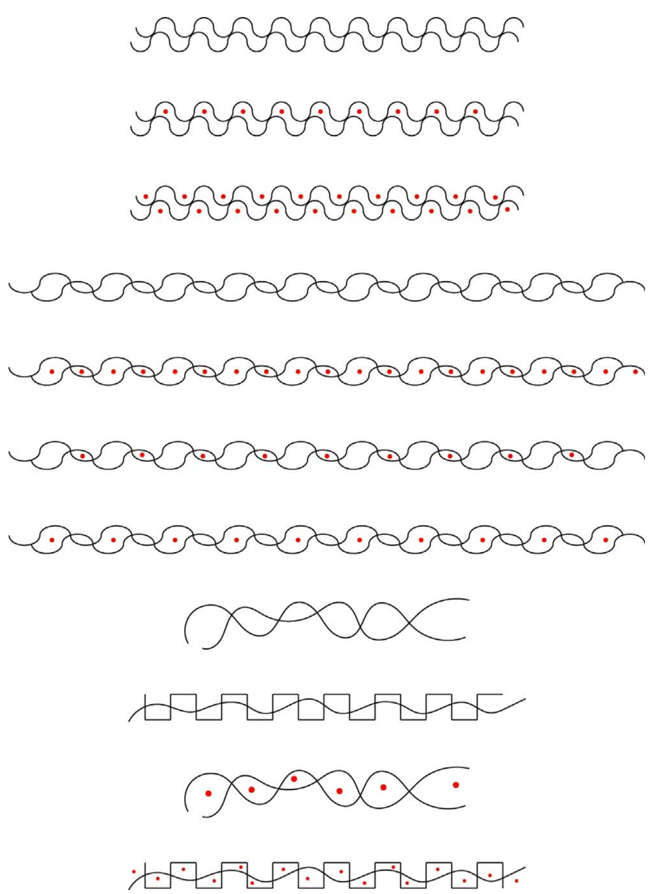


Fig. 12. Accentuation and good continuation.

(Fig. 13d–f, where Fig. 13d is a control), the results reveal the strength of the accentuation. It readily beats proximity and orientation taken together.

The same results emerge when the surrounding circumference is removed (Fig. 13g–i). Fig. 13j–k strongly corroborate the strength of accentuation according to which strange and irregular figures (some kind of cross with three arms) are elicited in opposition to the Maltese-cross. Moreover, Fig. 13l–m demonstrate that accentuation is effective also when the red inducing dots are placed outside the accentuated region. By increasing the distance of the dot from the figure, the resulting effect becomes weaker and weaker (not illustrated).

The Maltese-cross fails to discriminate between vertical and horizontal main directions which are the strongest determinants of figurality. In Fig. 13n, a configuration similar to the Maltese cross but with a reduced number of arms demonstrates the two directions to be of unequal importance. Under these conditions, the figural effect appears stronger on the vertical direction. However, as shown in Fig. 13o–p, the figurality is clearly changed according to the accent locations. These results also occurred in spite of the proximity principle involved against accentuation (Fig. 13q–s).

3.10. Tessellation vs. accentuation

The observations pertaining to the classical Maltese-cross are readily studied in the case of tessellations. The latter are juxtaposed tiles that, read in different ways, manifest different global patterns. Other examples of tessellations are illustrated in Figs. 1–3. We use the case of tessellations to demonstrate a general property of accentuation that has important implications, to be more thoroughly discussed in the conclusions.

In the first five rows of Fig. 14, the same pattern can be perceived in various, mutually complementary ways, depending on accentuation. Accentuation immediately reveals different hidden figures (Pinna, 2010a, 2012c, 2013; see also Pinna, Spillmann, & Werner, 2003). In the two further rows, the black stars can be partially hidden or concealed by the accents placed on the white complementary regions. A similar outcome although weaker can be also perceived when the stars are empty inside. This suggests that accents can disambiguate the otherwise fleeting, ambiguous illusory figures due to figure-ground alternation (see Pinna & Grossberg, 2006). This is clearly demonstrated in the last two rows of Fig. 14 (see Pinna, Ehrenstein, & Spillmann, 2004).

4. Discussion and conclusion

Starting from previous results (Pinna, 2010a, 2010b, 2012a; Pinna & Sirigu, 2011, 2016), we investigated accentuation as a novel and powerful principle of figure-ground segregation and object formation. The role of this principle has been investigated in the traditional, phenomenological approach of Gestalt psychology (Koffka, 1935; Metzger, 1963), through novel phenomena. We found that this novel

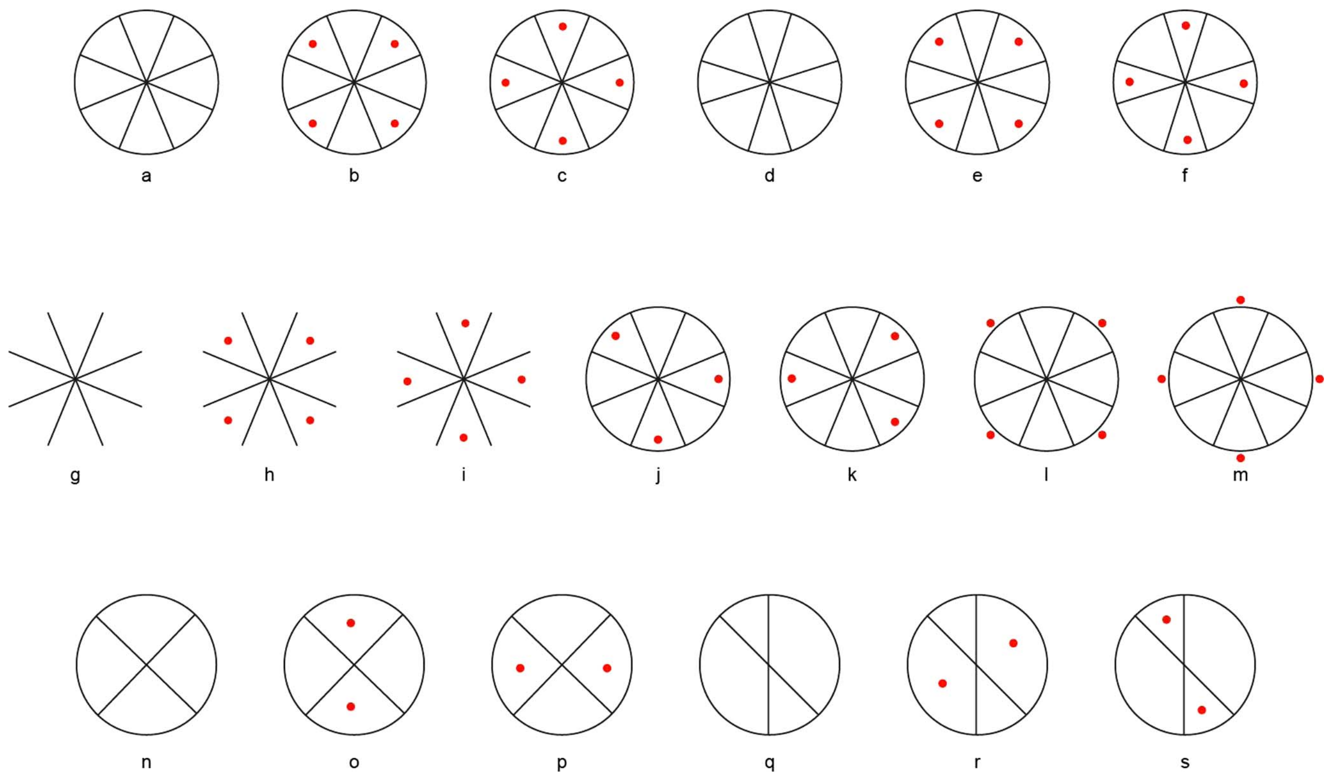


Fig. 13. Accentuation pitted against and in favor of vertical-horizontal orientation and proximity.

principle is an independent and autonomous one that can be pitted against or in favor of the conventional Gestalt principles of figure-ground segregation.

Accentuation is likely a distinct brain mechanism. Thus, it invites detailed descriptions similarly to every other kind of visual regularity and principle (a possible mechanism is suggested in Grossberg & Pinna, 2012). Although accentuation has been demonstrated to be one of many independent and autonomous principles, it manifests new and unexpected properties that make it a true *sui generis* one.

Granted that the classical principles can be subsumed or reduced to a general inclusive meta-rule stating that, all else being equal, the region enclosed within contours with the maximal homogeneity tends to be perceived as a figure (Musatti, 1931), accentuation seems to be an exception. It does not fall within the general meaning of homogeneity or regularity. It is not clear in which way the accentuated region perceived as a figure can obey a rule of maximal homogeneity, in fact, at a first sight the opposite seems to be true. The presence of a dot increases the inner entropy of the figure. This entails that the accentuation principle is in a class of its own.

Phenomenally, a figure should be more articulated and differentiated than the background, which by definition should be empty and totally homogeneous with our simple line drawings. Thus a figure differs in kind from a homogenous background. Yet, a figure is and should be homogeneous or, at least, should contain some kind of homogeneity, otherwise it could not be regarded as a figure given that it would not be a unique thing but a conglomerate. Uniqueness and homogeneity represent two mutually complementary aspects of "figure".

A figure is something homogeneous and unique and, simultaneously, is like a fracture placed on the background that is not "something" homogeneous, since it is not something but void and "nothing", hence, it cannot be homogeneous in the sense of a figure that is something filled and full. Uniqueness implies that a figure and a background are like the two sides of the same coin: one cannot be without the other and *vice versa.* One emerges if and only if the other disappears, one can manifest the attributes of having a shape, a color and a volume only if the other loses all of them or assumes complementary attributes.

Here the efficaciousness of accentuation presents an essential problem. It is quite unlike the classical Gestalt principles. Accentuation is something *sui generis*, which obeys a different logic although it can also be regarded as a kind of figure-ground segregation principle. The specificity of accentuation is perhaps best understood in the light of the many kinds of object properties that it can affect. It acts as a principle of grouping (Pinna & Sirigu, 2011), but also as a factor determining many shape attributes such as orientation, spatial position, inner dynamics and apparent movement which turned out to be essential in eliciting the organic segmentation (Pinna, 2012a, 2015) and figure-ground segregation (see also Pinna & Sirigu, 2016). Furthermore, through new musical illusions of suspension (Pinna & Sirigu, 2011) and downbeat (Pinna & Sirigu, 2016), it was also shown that accentuation rules perceptual organization in space and in time, i.e., in both visual and musical domains. None of the Gestalt figure-ground or grouping principle has a similar spectrum of effects and applications. Accentuation is evidently in a class by itself.

4.1. Visual attention and accentuation principle

The phenomenal nature of accentuation shown in the previous sections certainly suggested the following question: Can accentuation be interpreted as a special case of visual attention? The question is whether the cue for figure-ground segmentation is accentuation or, rather, attention. Previous studies have shown that visual attention, both voluntary (endogenous) attention (e.g., Baylis & Driver, 1995; Peterson & Gibson, 1994) and exogenous spatial attention (Vecera, Flevaris, & Filapek, 2004) can influence figure-ground perception. Vecera et al. further demonstrated that exogenous spatial attention can influence the operation of image-based (bottom-up) Gestalt cues for figure-ground assignment. However, other studies (Kimchi & Peterson, 2008; Kimchi & Razpurker-Apfeld, 2004; Mazza, Turatto, & Umiltà, 2005; Peterson & Kim, 2001; Peterson & Skow, 2008; Razpurker-Apfeld

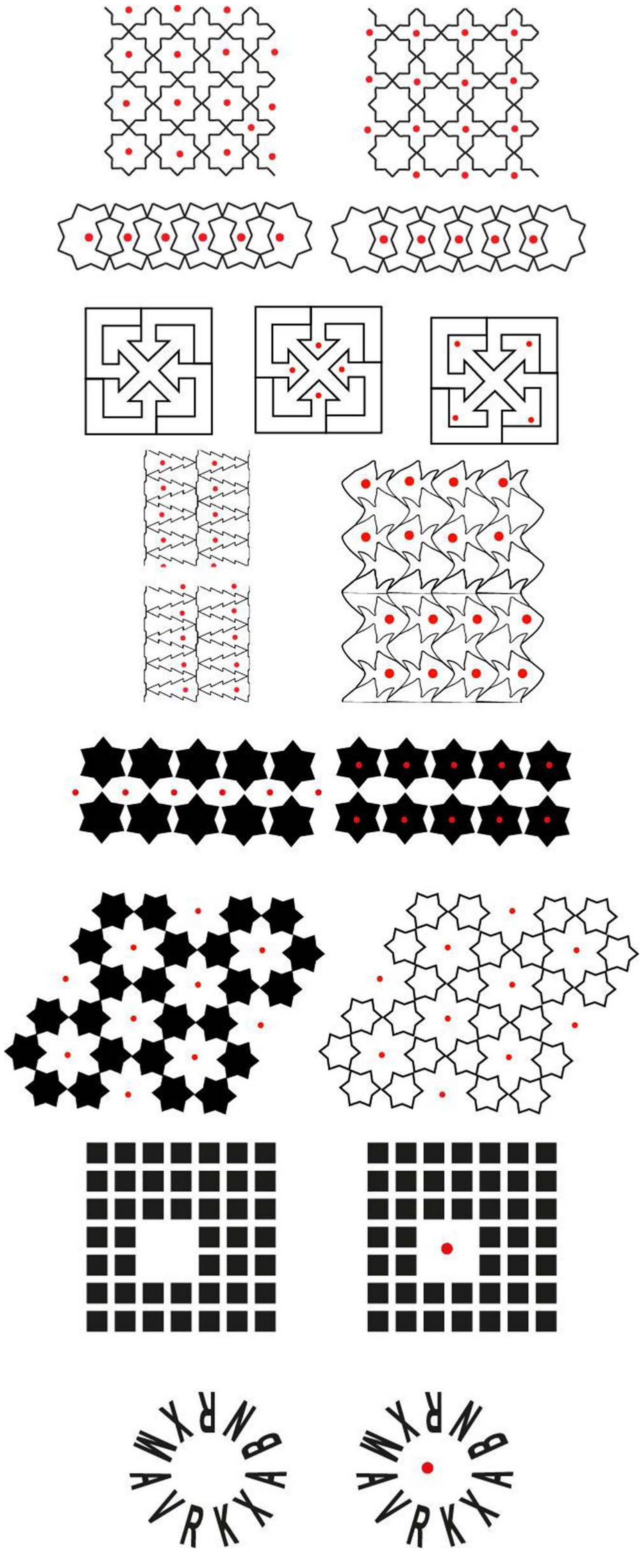


Fig. 14. Accentuation reversing tessellations and enhancing the salience of illusory figures.

& Kimchi, 2007) showed results clearly demonstrating that figure-ground segmentation can occur without focal attention. The question of whether or not figure-ground is pre-attentive is still unresolved.

It is not our purpose to discuss in depth this problem, since our hypotheses pointed in a different direction. However, what is worth to be explored and deepened here is whether the small circle used as an accent can be considered as a special case of visual attention. Like in the previous sections, this doubt is argued and possibly solved in phenomenal terms.

First of all, by seeing, for example, Fig. 1k or l, by switching the focal attention, the figure-ground segregation switches accordingly. Again, in Fig. 3a–b, the figure-ground organization can be easily reversed through attention bringing to the same conclusion: visual attention plays a clear and strong role. Nevertheless, the role of visual attention is much less effective when it is pitted against the accentuated figure-ground organization, as illustrated in the further conditions of Fig. 3. Although, some amount of reversibility can still be obtained, the accentuated figure is more salient than the complementary region that, due to the role played by attention, should appear as a figure. If accent and attention are the same thing, then they cannot be pitted one against the other. It follows that accentuation and attention belong to different and possibly independent processes.

The same deduction can be obtained also through the following argument: although ocelli and diematic patterns deceive predators (cfr. the next section), they are not always deceived, otherwise they would become extinct. This means that some other cognitive process occurs to prevent deception, so the deception due to the ocelli belongs to a process different from the one used to prevent it, perhaps visual attention.

In spite of these logical arguments, the previous doubt is not solved at all due to the phenomenal nature of the small circle that appears strongly related to focal attention. Several other arguments are needed to differentiate or highlight the independence of accentuation from attention.

Fig. 1m–n show the accentuation of the filled circle in polarizing and grouping the empty circles in the direction pointed by the accent. Under these conditions, the accent reveals vectorial attributes (see Pinna & Sirigu, 2011, 2016) not present in the focal attention. More importantly, if Fig. 1m–n are considered as part of a sequence (see Fig. 16a–d; the letters within the figure have been omitted since they act as accents in their turn), then it can be concluded that the accentuation, under the conditions shown in Fig. 1m–n, is imparted by similarity/dissimilarity. In other terms, the accentuation becomes here a limiting case of the similarity/dissimilarity Gestalt principle and, as a consequence, a process of perceptual organization different from attention.

However, accentuation cannot be considered only as a limiting case of the similarity principle. The simplest example of this independence is shown in Fig. 16e–f, where the separated filled circle polarizes and groups the empty elements in the direction pointed by the filled circle and, at the same time, switches the whole shape of the empty circles from diamond to rotated square, similarly to Fig. 1p. By replacing the filled circle with a small square these results are even stronger (Fig. 16g–h). This is due to the dissimilarity attribute required to an accent, different from the similarity principle. A stronger demonstration of this difference comes from the fact that accentuation can be pitted against grouping by similarity, as shown in Figs. 8, 9 and 10 (see also Pinna, 2013).

Therefore, the similarity of elements can operate accentuating, for example, a specific direction (Fig. 16a–d), although it cannot be assimilated to the accentuation principle as shown in Fig. 16e–h. However, under these conditions, both accentuation and similarity deliver the same results suggesting that they are two principles of perceptual organization, but, since they are principles of perceptual organization, they cannot be totally assimilated to “attention”. Critically, ‘accentuation’ and ‘attention’ operate at different levels of explanation. One can attend to a stimulus (i.e.,‘select it for further processing’) because it is close, or similar, or colored, or accented, or expected, or useful, or any other of many properties. Thus ‘attention’ and assimilation are not on the same level.

This is also demonstrated in Fig. 17. In Fig. 17a, diamonds are grouped in a large diamond. In Fig. 17b, squares are grouped in a large diamond. By introducing the similarity principle that accentuates the

Fig. 15. Accentuations in biology.

inner elements as illustrated in Fig. 17c–d, diamonds are now perceived as rotated squares, while squares are perceived as diamonds. A similar, effect is also imparted when the accentuation is reduced to only one element or when the accent is placed outside the whole diamond of elements (see also Pinna, 2010a, 2010b, 2012a).

As a grouping principle similarity groups the elements, the accentuation polarizes a spatial direction with its vectorial attributes and, thus, imparts a shape (diamond or rotated square) to each element of the pattern (for a deeper discussion on the distinction between similarity and accentuation see Pinna, 2010a, 2012a). These phenomenal organization dynamics cannot be found cannot be deduced from any known properties of visual attention. This entails that accentuation cannot be considered as a special instance of attention.

To further differentiate the accentuation from the focal attention, it is worth to note that the accentuation can be induced by many kinds of accents as shown in Fig. 1q–r. Also the organic segmentation (Fig. 1s–v) can be imparted by accents different from filled circles. More generally, every kind of shape, instead of the small circle, behaves like an accent and as such it imparts the same effects.

In Fig. 18, letters and numbers elicit a figural effect to the frame (Fig. 18b) or to the inner square (Fig. 18c) when compared with the control (Fig. 18a). Similar but less effective results emerge with empty figures (line drawings) as shown in the second row of Fig. 18. These results bring to the next argument.

Just as the accent can switch the shape of a diamond in a square (rotated), the shape of a diamond can switch in its turn the shape of the accent in a diamond or in a square (Fig. 19; see also Pinna, Porcheddu, & Deiana, 2016). In other words, there is a mutual effect according to which the accent influences the accentuated shape and the accentuated shape influences the shape of the accent. More in detail, in Fig. 19), the larger diamond switches the shape of the accent from diamond to rotated square (see also Fig. 16g–h). Since, these kinds of mutual effects cannot be found within the attention domain, accentuation cannot be considered as a special case of attention.

The last argument in favor of the independence of accentuation from attention is related to the musical accents (Pinna & Sirigu, 2011, 2016) that very strongly demonstrate the illusory switch between downbeat and upbeat totally uncorrelated with attention, since attempts to distract from accentuation are in vain.

In conclusion, despite these arguments, the role of visual attention

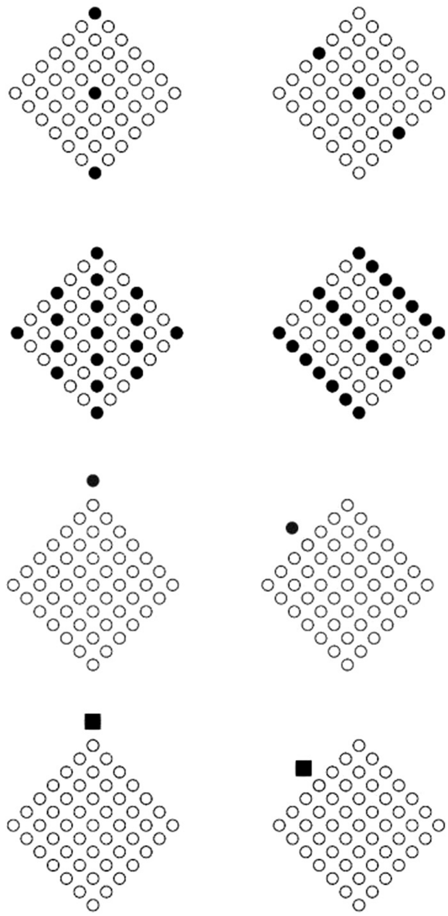


Fig. 16. Similarity and accentuation principles.

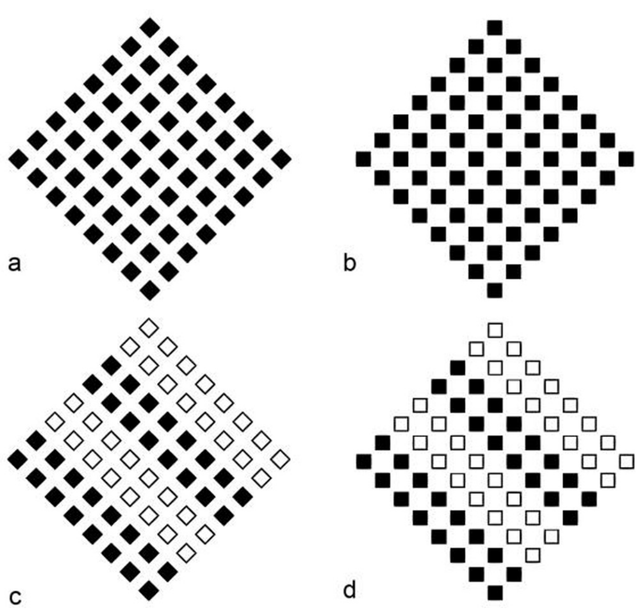


Fig. 17. Diamonds perceived as rotated squares and squares perceived as diamonds.

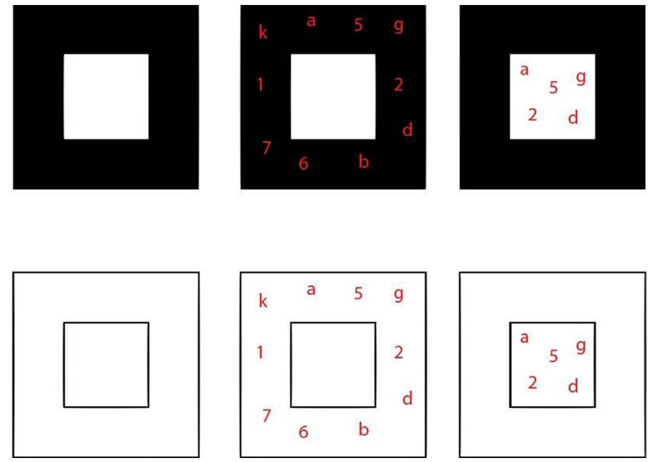


Fig. 18. Every kind of element (number and letter) behaves like an accent in imparting figure-ground segregation.

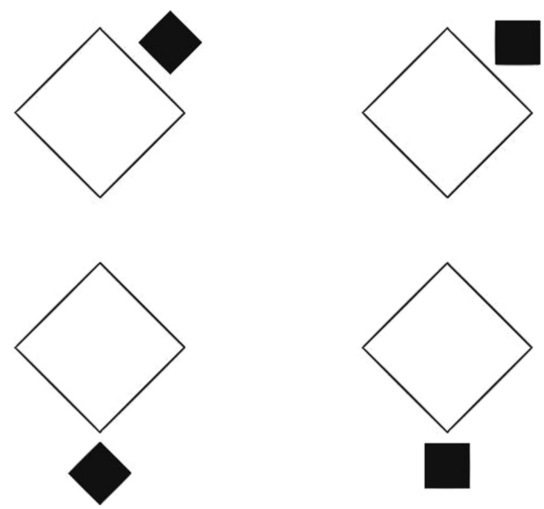


Fig. 19. Mutual effect between accent and shape.

cannot be denied in these kinds of effects (see Grossberg, 1997; Grossberg & Pinna, 2012; Grossberg et al., 2001). As a matter of fact, the three dynamics, attraction, accentuation and assignment, require attention. Under most of our conditions, accentuation and attention play together synergistically. However, accentuation does not necessarily require attention. More generally, it is the accent that attracts and creates a displacement of the attention and not the attention that creates the accent. The reciprocal independence between accent and attention is required for the perceptual and biological purposes previously described.

Finally, deepening the previous arguments and the phenomenology accentuation can cast a new light on the understanding of relations between attention and perceptual organization.

4.2. Biological implications of the accentuation principle

The specificity and uniqueness of the accentuation can be better understood if we consider its biological implications. We suggest that at least three phenomenal dynamics for this principle should be considered: namely *attraction*, *accentuation* and *assignment*.

The red dot used in our demonstrations attracts attention, perhaps by capturing gaze, and promotes focusing vision on a detail and on a location. Thus, restricted and isolated, the assignment of an attribute takes place. Within the biological domain, attraction, accentuation and assignment are three basic dynamics and needs for each organism, animal or plant. Each creature needs to attract, fascinate, seduce, draw attention (e.g., a mate or a prey) or distract, refuse, dissuade, discourage, repulse (e.g., a predator). Similarly, each organism needs to accentuate, highlight, stress, underline, emphasize somebody or something and divert or distract from somebody else. To perceive something, it is necessary not to perceive something else. To perceive is to make a choice, a choice that may literally be of vital importance.

Within the biological and evolutionary domains, this rule is basic to the survival of the species. Indeed, all organisms use this rule, focus visual attention and assign a meaning. Indeed, accentuation within a coat, on a plumage or on a flower is finalized by *assigning a meaning*. The accent communicates something to a target (mate, pray or predator). What is communicated should be precise and very focused, because life, or even the species is at stake. Accentuation assigns a biological message. To be effective the accent should be simple and immediate. This is where the accentuation principle differs from the Gestalt principles. Briefly, this is what makes the accentuation a *sui generis* rule. Examples of these dynamics can be easily found as shown in Fig. 15, where the accents are used by different organisms and in different contexts for many different purposes, some of which can be the result of a compromise, e.g., of the need to attract one's attention (a female) and at the same time to distract another's (a predator). The solution to these compromises are the result of different kinds of evolutionary and selective pressure that forge and shape the accents as illustrated in Fig. 15 (see also Pinna & Reeves, 2013).

False eyes (ocelli) and dots (diematic patterns) demonstrate the "deceiving camouflage by accentuation" aimed at least at confusing the predators/preys (Merilaita & Lind, 2006) and at hiding/highlighting the most vital and important parts (butterflies/flowers) of the body (Stevens, 2007; Stevens, Cuthill, Párraga, & Troscianko, 2007; Stevens & Merilaita, 2009; Stevens & Ruxton, 2012; Troscianko, Benton, LovellP, Tolhurst, & Pizlo, 2009). They also demonstrate the deceiving appearance and exhibition of strength, being healthy, ready to mate. This implies that the same accents may serve different and also opposite purposes as stated by a min-max principle: maximum result with minimum effort. This is related to the fact that attracting means also distracting, accentuating implies hiding and assigning-imparting means also camouflaging. The three dynamics are used in these opposite acceptations by organisms to better interact with conspecifics, preys and predators and improve their adaptive fitness.

Acknowledgments

This work was supported by *Fondazione Banco di Sardegna (finanziato a valere sulle risorse del bando Fondazione di Sardegna – Annualità 2015)* and by the Visiting Scientist Program (2014) of the University of Sassari, Italy (to JK).

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