New conditions on the role of color in perceptual organization and an extension to how color influences reading

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Color is one among many attributes that are involved in the similarity principle. Grouping by color is believed to be less effective when compared with other attributes such as shape and luminance. The main purpose of this work is to explore the role played by color in determining visual grouping and wholeness, not only in relation to further similarity attributes but also to other principles such as proximity, good continuation and past experience.

Conditions, different from those used by Gestalt psychologists, were chosen, and aimed to understand how color can influence visual organization and through it, other perceptual and complex processes such as reading and visual word recognition. In fact, involving cognitive and metacognitive domains, permits exploration of broader issues concerning perception, memory, knowledge, representation and learning, where color can express its biological advantages for humans more clearly. These processes can be assimilated to the Gestalt past experience considered as a principle of its own kind not fully explored in relation to the other principles. As a consequence, these conditions allow color to be pitted against past experience and against a number of principles at the same time. The results demonstrated that color can strongly influence grouping, shape and the process of segmentation of words involved in the reading task. Therefore, color not only is one among the many principles of grouping but an essential component for the foundation of the more complex organization aimed at creating wholeness, part-whole formation and fragmentation.

Keywords: Color vision; Perceptual organization; Perceptual grouping; Visual illusions; Text reading.

On the role of color in the similarity principle of perceptual organization

The problem of perceptual organization is traditionally related to the complexity of the following question, first suggested by Wertheimer (1912a, 1912b, 1923): Why do we perceive a world made of objects such as people, cities,
houses, words and trees, and not composed of scattered differences of luminances, colors, edges and bars? The answer to this question is based on the well-known ‘principles of grouping’ – proximity, similarity, good continuation, closure, convexity, exhaustiveness, symmetry, Prägnanz and past experience – resulted from Wertheimer’s (1922, 1923) studies, whereas other fundamental principles of figure-ground organization – surroundedness, size, orientation, contrast, symmetry, convexity, and parallelism – were discovered by Rubin (1921).

The inner local grouping of the small empty/filled squares of Fig. 1a, in rows (left) or columns (right), is due to the Gestalt principle of similarity stating that, all else being equal, the most similar elements (in color, brightness, size, empty/filled, shapes, etc.) are grouped together (empty/filled squares under our conditions). As illustrated in Fig. 1b, the opposite direction of the luminance contrast (black on gray or white on gray) is a perceptual attribute very effective in grouping elements by similarity. Moreover, all else being equal, the most similar elements in color are also grouped together as shown in Figs. 1c and 1d, where the blue and orange colors are equiluminant.

*Figure 1.* The local organization of the small squares is due to the Gestalt grouping principle of similarity. (Online in color.)
The role of color in Gestalt grouping is usually considered as one among the many attributes involved in triggering the similarity principle, although grouping by color is believed to be less effective when compared with other attributes such as shape, luminance or motion (Arnheim, 1997; Helson, 1947; Katz & Revesz, 1921; Koffka, 1935; Vicario, 1968). By comparing Figs. 1a-d, the luminance variations of Figs. 1a-b appear to elicit grouping effects within the elements stronger than the chromatic variations of Figs. 1c-d. The filled vs. empty squares and the squares with opposite luminance contrast emerge from the background more saliently both as single elements and as groupings of rows or columns.

This difference in strength is expected if we consider that shape is a phenomenal attribute different from color. Color is a visual attribute that appears to belong to an object and to its shape (the belongingness of the color). Phenomenally, the perception of an object is often considered identical to the perception of its shape but not to its color, which appears as a secondary attribute. As such it is believed that color has relatively little influence in the perception of shape although the perception of colors enhances the capacity of an organism to distinguish objects. The role of color can be considered secondary in perceptual grouping also with respect to attributes ascribable to shape, like luminance contrast, contours, size, orientation, etc.

Indeed, the previous statements derive from two results. Firstly, the perceptual grouping is phenomenally considered equal to shape formation, (i.e. rows or columns are equivalent to shapes oriented in space). Secondly, it is well known that stimulus features (color, brightness contrast, shape, movement), extracted by the retinal neurons, are kept segregated in separate “information channels” and processed in parallel by different cells at all levels of the visual system.

Nevertheless, phylogenetic and paleontological evidences demonstrate that the ability to perceive colors evolved independently several times and has existed for at least half a billion years implying a high evolutionary neural investment. This suggests that color vision has some fundamental and specialized functions providing biological advantages in using reflectance information to code the presence, the position and other figural properties. Moreover, color improves the biological ability to segregate, locate and organize the world into objects and parts (see Pinna, 2010a; Pinna & Reeves, 2013; Pinna, Uccula, & Tanca, 2010). This can be easily demonstrated in Figs. 2a-c, where different parts of the living organisms emerge mostly on the base of the chromatic colors rather than the luminance variations (cf. the chromatic pictures with the black and white controls).
These results suggest that there are visual meanings and organization properties, imparted by the chromatic variations, which are peculiar and unique with regard to the luminance ones. The main purpose of this work is to explore these phenomenal properties and the effectiveness of the reflectance information to group and segregate a figure from its background and to organize it in parts and wholes in both visual and cognitive domains.

General Methods

Subjects

Different groups of 15 undergraduate students of linguistics, literature, architecture and design participated to each experiment described in the Procedure section. Subjects had some elementary knowledge of Gestalt psychology and visual illusions, but they were naive both to the phenomena studied and to the purpose of the phenomenological experiments. They were both male and female undergraduates and all had normal or corrected-to-normal vision, and normal color vision on the Ishihara test plates and on the Farnsworth-Munsell 100 hue Color Vision Test.
Stimuli

Five different equiluminant colors (~72.27 cd m\(^{-2}\)) were used: brown (CIE chromaticity coordinates \(x, y = 0.49, 0.40\)), blue (0.17, 0.19), green (0.34, 0.51), purple (0.35, 0.24) and red (0.55, 0.37). For each observer, we determined the luminance match for the two contours with the luminance background to be tested using a variation of the minimally distinct border technique of Boynton and Kaiser (1968). The overall sizes of the figures were each ~5 deg. The luminance of the white background was ~122.3 cd m\(^{-2}\). Black contours had a luminance value of ~2.6 cd m\(^{-2}\). Stimuli were displayed on a 33 cm color CRT monitor (GDM-F520 1600x1200 pixels, refresh rate 100 Hz: Sony Corporation, Tokyo, Japan), driven by a MacBook Pro computer (Apple Ins., Cupertino, CA, USA) with a GeForce 8600M GT (Nvidia Corp. Santa Clare, CA, USA). The monitor was calibrated using a CS 100 Chroma Meter colorimeter (Konica Minolta, Tokyo, Japan) and procedures set out in Brainard, Pelli, & Robson, (2002).

The stimuli were presented in random order on a computer screen with ambient illumination from a Daylight fluorescent light (250 lux, 5600° K: Osram, Munich, Germany). All conditions were displayed in the frontoparallel plane at a distance of 50 cm from the observer. A chin rest stabilized the head position of the observers.

Procedure

*Phenomenological task*: A phenomenological free-report method was adopted (see section on the role of color in perceptual organization). For each stimulus, independent groups of 15 undergraduate students participated to the phenomenological descriptions. Different groups of 15 naive observers each, described only one stimulus. This was done to avoid interactions and contaminations among stimuli. The descriptions reported through the paper used similar phrases and words to those provided by the spontaneous descriptions of no less than 12 out of 15 subjects in each group, but edited for brevity and representativeness. To provide a fair representation of the descriptions given by the observers and to avoid contaminations with interpretations of the authors they were judged by three independent graduate students of linguistics, naive as to the hypotheses. The descriptions are incorporated within the text to aid the reader in the stream of argumentations. All the reports were quite spontaneous and the presentation stopped when the subject finished their report. Observation time was unlimited.

During the experiment, subjects were allowed: to make afterthoughts and to see in different ways. The subjects could also receive suggestions/questions of any kind, like for example: What is the shape or the organization of each element? What is the number of elements? All the possible variations occurring during the free exploration were noted down by the experimenter. This was necessary to define the best conditions for the occurrence of the emerging phenomena.

*Scaling task*. Each group of subjects (which was different for each of the experiments described in section concerning the role of color in cognitive organization) was instructed to scale the relative strength or salience (in percent) of the stimulus to the required perception in that specific experiment of section concerning the role of color in cognitive organization.

**On the role of color in perceptual organization**

Grouping and ungrouping the wholeness by color

The role of color in perceptual grouping can be understood, not only in the conditions as shown in Fig. 1, but also by studying the way color takes apart and groups together whole objects as demonstrated in Fig. 3. In Fig. 3a, a checkerboard is perceived. Phenomenally, it is a whole emergent object made up of a regular pattern of alternating black and white squares. The single squares
are the essential components of the checkerboard but, more importantly, it is the horizontal and vertical alternation of the black and white checks and their oblique grouping from left to right and from right to left to distinguish and define the main attributes of the checkerboard, i.e. the being of a checkerboard. This peculiarity can also be perceived when the white checks are replaced with gray ones, as shown in Fig. 3b.

However, when the gray checks of Fig. 3b are in their turn replaced with chromatic ones, as shown in Fig. 3c, the chromatic variation weakens or even destroys the perception of the whole checkerboard, although the luminance contrast is kept constant among the checks. This occurs despite the black checks continue to instill the perception of the rhythmic alternation to the homogeneous luminances. The property of being a checkerboard is further weakened when also the black checks are replaced with squares of different color but equal luminance, as illustrated in Fig. 3d (cf. the grayscale control of Fig. 3e). These results suggest that the color can strongly influence the perceptual organization of whole emerging objects, like a checkerboard, by ungrouping the periodic pattern and by confusing or reorganizing randomly a homogeneous luminance distribution of checks. Under the conditions shown in Fig. 3, color wins against luminance.

Figure 3. Color weakens or restores the Gestalt whole attribute of being a checkerboard. (Online in color.)
Moreover, the weak perception of a checkerboard in the black and gray condition of Fig. 3f is strongly improved or totally restored, all else being equal, by introducing a quasi homogeneous coloration (red) of the checks alternated to the black ones (see, Fig. 3g). Therefore, color can restore the attribute of being a checkerboard to a pattern of elements, which does not appear as a checkerboard or very weakly under grayscale conditions. This result is broadly confirmed by the clear perception of a checkerboard under equiluminant but chromatically different alternated checks, as shown in Fig. 3h, whose converted grayscale control is illustrated in Fig. 3i. To sum up, these results entail that color elicits a clear grouping of elements and whole effect within periodic patterns of checks.

Uncrowding shapes through color

Color can also induce the popping out and the figure-ground segregation of single colored shapes. In Fig. 4a, several stars are crowded and overlapped. Although, it can be relatively effortless to perceive the star shapes, their overlapping appears extremely confusing. The single shapes are not distinctly segregated and their number cannot be easily counted. Only after having accurately followed with the gaze the boundaries and after a deep attentional check, twelve regular eight-pointed stars of different size are revealed. By reversing the luminance contrast of several stars (white on gray vs. black on gray, see Fig. 4b), the segregation and salience of each star is enhanced and the sense of crowding and confusion is reduced. The stars can now be more easily separated and numbered.

However, by introducing equiluminant chromatic variations for each star, as shown in Fig. 4c, they segregate much more distinctively and reveal a further reduction of the apparent numerosness (illusion of numerosness), crowdedness and density. Due to the inner chromatic homogeneity of each star and, at the same time, due to its whole dissimilarity in relation to the others, each star emerges as a figure from the background and also groups with stars of similar color creating a group apart from the other groups. However, although it takes some time to count the stars, it is faster to count the colors. Moreover, the stars having the same color can be perceived as popping out from the others very easily. These new effects, shown here for the first time, can be responsible for the illusion of numerosness, where the number of colored stars is perceived as smaller than the ones of the control of fig. 4a. However, by mixing the colors within the same star (Fig. 4d), all the previous phenomenal attributes are reversed: numerosness, crowdedness and density of element (segments and shapes) appear enhanced.

The illusion of numerosness can be easily tested also in more simple conditions like those illustrated in Figs. 4e and 4f. By comparing these two figures, it clearly emerges that it is much easier to count the triangles of Fig. 4f
than those of Fig. 4e, where, though the stars are only four, they appear more numerous and grouped as a unity, i.e. as a unique emergent star rather than as a multiplicity of triangles. Within the star, the triangles are masked and almost camouflaged in spite of the good continuation of their sides. On the contrary, the triangles of Fig. 4f pop out as distinct elements, while the whole star is weak. It does not appear as a unity but as the grouping or the summation of four triangles.

![Figure 4. Multi-dimensional organization of stars and triangles uncrowded by chromatic variations. (Online in color.)](image)

These outcomes suggest that the chromatic variations induce a multi-dimensional organization of the elements making it richer than the organization induced by the luminance contrast only (Fig. 4a) or by the opposite direction of contrast (Fig. 4b). In other words, new organization options, to be added to the luminance domain, are originated by the multiplicity of colors introduced in a world crowded of juxtaposed, overlapped or intersected things. This is,
for example, the case of a forest, where different kinds of organisms, placed in different ecological niches and levels of the food chains, interact in many ways and at different planes of the biological existence at the same time.

**Object emergence through color and the bulging wholeness**

If in Fig. 4 color highlights the boundary contours, in Fig. 5a color segregates single surfaces that appear like islands and create altogether a quasi symmetrical whole object, reminiscent to one of the last chromatic cards of the Rorschach projective test, designed to reveal hidden emotions and internal conflicts when ambiguous stimuli are perceived. Such demonstration is often called “Mooney face.” Fig. 5a shows an unnoticed fact that the perception of Mooney face is disturbed when blobs are differently colored (Andrews & Schluppeck, 2004; Dolan et al., 1997).

![Figure 5](a) Color segregates single surfaces that appear like islands reminiscent to cards of the Rorschach projective test. (b-c) Male faces. (Online in color.)

Under these conditions, the surfaces, chromatically homogeneous, pop out as a whole and segregate from the groups of surfaces with different colors. Moreover, the quasi-symmetrical arrangement and coloration of patches create some kind of holistic abstract shape. When the chromatic components of Fig. 5a are converted to grayscale (see Fig. 5b), the single surfaces group more strongly...
as a holistic unknown shape and, when the visual attention is more contained in groups of surfaces smaller than the whole, three juxtaposed and radially arranged male faces emerge. They pop out more clearly if they are chromatically dissimilar as illustrated in Fig. 5c. It is worth noticing that, the faces, masked in Fig. 5a, now emerge very clearly.

Given these phenomenal results, in Figs. 5a-c it is not only the grouping of the chromatically similar elements to play a role, but also the past experience and the high sensitivity to see faces. To perceive a face the grouping of similar patches requires also that the white surface in between the patches becomes part of the face. The grouping of the patches is not sufficient to the bulging of a complex object like a face, composed of bright and dark or colored regions. Each face is, in fact, made up of both patches and white surrounding regions captured by the dark/colored regions.

Fig. 6 clarifies these further emerging properties of the perceptual organization that goes beyond grouping (see Pinna & Grossberg, 2006). In Fig. 6a, the electric plug-like shape segregates as a figure from the white background. However, when a further half-circular shape is placed near the plug (see Fig. 6b), an illusory E emerges and the whole pattern is now read as DED, although the first D is seen as vertically reflected of $90^\circ$. While the two Ds are perceived on a white background, the E is seen on a black background. Going back to Fig. 6a, the plug-like shape is now perceived as ED more easily than at a first sight on the base of the past experience triggered by Fig. 6b. In Fig. 6c, the word ARTE (Italian for ART) is easily read. Indeed, single letters are perceived in alternated black and white backgrounds. Fig. 6d can be perceived in two ways: as a square matrix with a missing element near the right top vertex (the most immediate but less strong outcome) or as an incomplete square matrix with an illusory bright large square juxtaposed to the black elements of the matrix, thus not induced by the amodal completion of the surrounding elements. In other words, the second and strongest outcome is the emergence of an illusory white square larger than the black square and not occluding anything.

![Figure 6.](image)

*Figure 6.* (a) Electric plug-like shape or ED; (b) an illusory E emerges and the whole pattern is now read as DED; (c) ARTE; (d) an illusory bright square larger than the black squares of the grid.
The conditions illustrated in Fig. 6a-d show white illusory figures coming out as segregated figures from the black components. Although the faces of Fig. 5c (see also Fig. 7a) can be considered as related to illusory figures like Kanizsa’s triangle (Kanizsa, 1955, 1979), they demonstrate a new kind of organization of the black and white components that group and fuse into a unity creating a unique bulging wholeness. The two black and white regions become indistinguishable and necessary parts of the face. The strength of the integration and unification is much stronger than the triangles in a star of Fig. 4e.

This can be considered as a new phase of the organization process, a new way of putting together element components. A true phenomenal phase transition from one kind of organization to another can be phenomenally crossed by comparing the results of Fig. 1 with the one of Fig. 7a. As a matter of fact, in Fig. 1, single elements are grouped together, although they maintain their

Figure 7. The bulging wholeness of faces and volumetric objects parceled out by the chromatic dissimilarity. (Online in color.)
individuality and reciprocal separation, while the white or gray background is inactive, independent and complementary as a background (see also Kennedy & Bai, 2000). The organization phase of Fig. 7a demonstrates that the patches become single regions, not elements, of a larger whole where they lose their individuality and reciprocal separation. As a consequence, they capture and induce the bulging of the background of the previous phase, which is now active as a surface joined and unified to the patches. Dissimilar regions (bright and dark) group together and unify as a whole. We call this kind of visual organization “bulging wholeness”.

The bulging wholeness, although related, is different from the figure ground segregation. In fact, the single patches of the face are clearly segregated as figures from the white background, but, at the same time, they are also unified to the background that is not seen as such anymore.

Moreover, the white of the bulging wholeness does not correspond to an illusory figure usually segregated from the inducers as in Kanizsa’s triangle, but it is a necessary component of a whole shape made up of bright and dark sides. In summary, this new organization phase does not depend on the illusory figures formation, since, as shown in Fig. 7a, there is not incompleteness, amodal completion of the inducers or segregation between inducing elements and illusory surfaces.

Nevertheless, perceptual hypotheses, postulated to explain the unlikely gaps within stimulus patterns, can be invoked to relate the bulging wholeness to the illusory figures. Gregory (1972, 1987) proposed that visual objects are similar to perceptual hypotheses postulated to explain the unlikely gaps within the stimuli. Objects are like “unconscious inferences”, i.e. the results of inductive conclusions as used in the formation of scientific hypotheses. According to this approach, Kanizsa’s triangle is created by a top-down cognitive hypothesis useful to explain the gaps (missing sectors of the disks and missing parts of the outline triangle) within the stimulus (see also Pinna, 2012a, 2012b, 2012c, 2012d; Pinna, Ehrenstein, & Spillmann, 2004). Similarly, the male face is created by a top-down cognitive hypothesis to explain the scattering patches that are like the cast shadows of a volumetric face in bright light.

Gregory’s object hypothesis, based on Helmholtz’s likelihood and related to the Bayesian statistical decision theory, become popular in more recent years, which formalizes the idea of perception as inference (Feldman, 2000; Landy, Maloney, Johnston, & Young, 1995; Mamassian & Landy, 1998; Nakayama & Shimojo, 1992; Weiss & Adelson, 1998). Briefly, the Bayesian approach aims to calculate the posterior probability distribution over the hypotheses and to select the most likely hypothesis with the highest posterior probability under the prior and conditional probabilities. The prior denotes how good an interpretation is independently of the proximal stimulus, and the conditional denotes how good the proximal stimulus is if the interpretation were true.

In spite of these theoretical arguments apparently convincing and based on the role of past experience, this principle does not represent the necessary condition to create the bulging wholeness. In Fig. 7b, not only does the face clearly emerge, but also the surrounding components pop out as unknown
bulging wholenesses. They appear like volumetric objects and, sometimes, as distorted faces made up of bright and dark components (see also Fig. 7c, where the volumetric effect and the bulging wholeness of “unknown objects” persists although the central face is totally broken). The black surfaces do not segregate from the empty background and are not flat but seem to bulge volumetrically in the three-dimension like a high relief. The chromatic dissimilarity among the patches (see Fig. 7d) weakens and parcels out the bulging wholeness. This is further weakened when the highlighting of the boundary contours enhances the singularity and the segregation effect of each patch as shown in Figs. 7e and 7f.

**Implicit shapes made explicit through colors**

If the previous results demonstrate that color can influence the grouping and the bulging wholeness, Fig. 8 shows how the shape of a visual object can be determined by its color. In Fig. 1, the chromatic similarity groups separated squares and determines the shape of the grouping, i.e. rows or columns. Under these conditions, the similarity is the only factor playing all else being equal. In Fig. 8, the chromatic similarity is instead pitted against good continuation, closure, symmetry and *Prägnanz* principles.

![Figure 8](image_url)

*Figure 8.* On the basis of the principle of chromatic similarity/dissimilarity the same pattern of stimuli can be grouped, ungrouped and reshaped in different ways. (Online in color.)

In Fig. 8a, eight-pointed stars and crosses can be alternately and reversibly seen. If the stars are perceived the crosses are invisible and *vice versa*, due to the unilateral belongingness of the boundaries (Rubin, 1921). A further possible result is the tessellation of stars and crosses although this result is much weaker than the
alternation of stars or crosses. In Figs. 8b-c, due to the chromatic similarity, only the stars (Fig. 8b) or the crosses (Fig. 8c) pop out while, respectively, the crosses and stars become invisible. In Figs. 8d-e, new shapes, given only by their boundary contours and reciprocally intersecting, are now created. In Fig. 8f, by regrouping the same pattern of segments on the basis of the chromatic similarity, blue squares are perceived overlapping an orange lattice of oblique parallel and orthogonal lines amodally completing behind the white squares. To sum up, by using the same principle of chromatic similarity/dissimilarity the grouping of segments and shape formation can be ungrouped and reshaped.

*Figure 9.* The chromatic similarity elicits new shapes and plays the main grouping role winning against other principles like good continuation, symmetry and *Prägnanz.* (Online in color.)

The results of Fig. 8 demonstrate that many possible shapes within one stimulus pattern can be triggered and made phenomenal through chromatic variations. The results of Fig. 9 corroborate this statement. Fig. 9a shows the control condition, where two eight-pointed stars, one inset into the other are mostly or uniquely perceived, although this pattern contains a very high number of potential implicit shapes. This outcome is strengthened in Fig. 9b, through the chromatic dissimilarity of the two stars that makes impossible other implicit shapes. In Fig. 9c, by changing the distribution of equiluminant colors, the stars become implicit and a chain or two kinds of rotated and intersected square-like shapes, made up of four closed quadrangular shapes on their vertices, clearly emerge. In Fig. 9d, two intertwined and spiraled star-like shapes, not one inset within the other as in Fig. 4a, but having equal size, are now segmented from colors. Moreover, by further changing the colors within the same pattern of segments, the two stars of Fig. 9a disappear and what emerges are respectively two wavy quadrangular shapes overlapped (Fig. 9e), two different symmetrical
novel shapes (Fig. 9f) and two overlapped irregular objects (Fig. 9g). Finally, irregular shapes can also be created by playing with the equiluminant colors of the overlapped stars of Fig. 9h, as illustrated in Fig. 9i. Under the conditions of Fig. 9, the chromatic similarity elicits new shapes and plays the main grouping role winning against other principles like good continuation, symmetry and Prägnanz.

These results suggest that different shapes within the same pattern of segments can be elicited from colors according to the following general statement: the emergence of one shape makes invisible or visible only partially the perception of other possible shapes within the same pattern of stimuli. A corollary to this statement asserts that the notion of shape can be phenomenally represented like a whole visual “holder” that contains sets of phenomenal possible shapes placed along a visual gradient of perceptibility. According to this, what is invisible at a first sight can become visible through a phenomenological exploration, through the action of new principles or through the psychophysical action of pushing and pulling one principle against another. Therefore, the set of possible ‘things’, located within the gradient of perceptibility, can become more and more visible or invisible.

The push-pull phenomenal action within the gradient of perceptibility is what a living organism uses evolutionally to adapt its appearance (both shape and color attributes) according to the selective pressure. Indeed, all complex living organisms (animals or plants) play with visual attributes (diematic and chromatic patterns). Some of the chromatic patterns which here mostly deserve attention, are referred to as diematic patterns. The presence of diematic patterns are above all typical of butterflies and moths and, in their design they simulate the eyes of monkeys and raptors. These diematic patterns, whose presence is located along the wings of the insects, are essential strategic defensive markings especially useful to help better guarantee the survival of certain species. More in detail, the diematic defense is a biological/natural device which makes use of ocelli taking the form of a pair of false-eye markings able to frighten away a predator or at least to startle it long enough for insect to make its escape. Furthermore, not only do ocelli function as an effective deterrent for starling and frightening potential predators but also they seem especially important to make implicit some vital parts of the body of an insect. For example, as in butterflies, the presence of a decoy target such as a false eye is quite common, toward their wings borders, it is not rare to observe diematic patterns with chunks, pecked out by birds. In fact, in this case, the ocelli work as an attraction diverting the predator’s attack to a non-vital area, the wings, which are not so crucial components in the body of a butterfly to determine the death of the insect in a predator’s assault.

Shape from color

If the shape is like a holder, the inner possible shapes, placed along the gradient of visibility, are triggered by making explicit/implicit different shape attributes. Among them, the horizontal/vertical axes, the gravitational orientation, the configural orientation and the large reference frame elicit many different well-known phenomena like the square/diamond illusion (Mach, 1914, 1959; Schumann, 1900), the configural orientation effect studied by Attneave
Within the hypothesis of the shape like a holder, colors can change a shape by accentuating one or another shape attribute. In Fig. 10a, a regular octagon is seen with the vertices oriented along the main directions (vertical and horizontal) of space. When chromatic discontinuities are introduced on the vertices placed along the vertical axes of the polygon, as shown in Fig. 10b, the same regular octagon of Fig. 10a is seen. However, by placing the same chromatic discontinuities in the middle of the two opposite sides placed along the oblique axes, as shown in Fig. 10c, the polygon appears now similar to the octagon of Fig. 10d with the sides oriented along the main directions of space.

Figure 10. The chromatic discontinuities within the polygons are like accents on shape attributes, like angles and sides, that induce the emergence of two different polygons, one pointed and the other flatter. (Online in color.)

The wholeness of the polygons of Figs. 10b-c is not broken down or disrupted. This is mainly due to the role played by the good continuation principle oriented only along the boundaries of the octagon that keeps the whole shape grouped and unique. Phenomenally, the chromatic discontinuities of Figs. 10b and 10c, placed on the vertices (angles) and sides, highlight and accentuate both geometrically and phenomenally different locations within the direction of space and different components (points/angles and sides) of the shapes that correspond to object attributes, respectively called pointedness and sidedness (Pinna, 2010b; Pinna & Sirigu, 2011). Therefore, the chromatic dashes within the polygons are like accents inducing the popping out of one or another geometrical basic attribute: angles and sides. This change in the inner object organization of geometrical attributes change in its turn the whole shape,
namely, the accentuated pointedness and sidedness create respectively two different polygons, one pointed and the other flatter.

As a consequence some other effects emerge. For example, Figs. 10a-d and 10b-c manifest the illusion of numerosness: at a first sight, the octagons of Figs. 10a-b appear as having a higher number of points than the octagons of Figs. 10c-d. The opposite is true about the numerosness of sides. Moreover, the vertical/horizontal orientation of the polygon of Fig. 10c appears illusory tilted in the opposite direction of the oblique orientation of the chromatic discontinuities. In other words, the orientation of the polygon, geometrically equal to the one of Figs. 10a-b, is perceived illusorily tilted more clockwise and beyond the main directions of space (vertical and horizontal). This result can be better appreciated by comparing the orientation of Fig. 10c with the ones of Figs. 10a and 10b.

The notion of shape from color is even clearer in the conditions illustrated in Fig. 11, where the chromatic dissimilarities break the oneness and the unitariness of the eight-pointed star of Fig. 11a. As can be noticed, those chromatic dissimilarities even change the figure’s shape, making it appear respectively like a concave polygonal shape rather than a star in Fig. 11b, like two rotated and perpendicular square shapes in Fig. 11c, like more and more regular and asymmetrical shapes different from star in the next conditions (Figs. 11d-f).
On the basis of these results color is involved not only in perceptual grouping as the other Gestalt principles but also in shape formation and, more specifically, in the segmentation, partition and accentuation of its figural attributes. The understanding of the role of color in perceptual organization can cast light on the perceptual complexity of the notion of shape that we suggested to be like a holder full of figural attributes defining the perceptual meaning of shape (see Pinna, 2012a, 2012d).

On the role of color in cognitive organization

Making the visible invisible and the invisible visible from color

The evolutionary use of color by living organisms supports our results. In fact, since color imparts segmentation, partition and accentuation of figural attributes, a new scientific attention can be directed to the different forms of camouflages where color plays some role.

Cryptic camouflage (Beddard, 1895; Cott, 1940; Edmunds, 1974; Endler, 1978, 1991) is a form of concealment that involves both shape and color, which allows an organism to avoid detection and predation by blending into the environment and by becoming effectively imperceptible. Cryptic camouflage is mostly based on chromatic variations on the animal body for concealment by making the organism or parts of its body hard to see (crypsis). Peacock Flounder demonstrates its cryptic ability to change its pattern and colors to match its surrounding environment. Through color the visible is made invisible.

Disruptive camouflage (Cott, 1940; Cuthill et al., 2005; Merilaita, 1998), by seeking to confuse the individual organism, is apparently the antithesis of the cryptic camouflage, that with its high contrasted and bright eye-catching colorations and markings, disguise the whole shape. This camouflage seems paradoxical, since disrupting outlines depend on using regions of color in reciprocal strong contrast. Therefore, while the colored patches are themselves conspicuous, the whole shape is disrupted, quod erat demonstrandum. Zebra, leopards and even giraffes are good examples of disruptive camouflage. Under these conditions, what is visible becomes invisible and what is usually invisible becomes visible through contrast, boundaries and colors.

Differently from the disruptive camouflage, in Fig. 2 there are some examples of purely chromatic camouflage (Harlequin camouflage, see Pinna, 2010a, Pinna & Reeves, 2013) as shown in the black and white version of the pictures. This kind of camouflage differs from the disruptive one by breaking up or parceling out the chromatic oneness and uniqueness of the whole organism, i.e. by imparting a clear chromatic rhythm.

The phenomenal notion of Rhythm agrees with the one derived from Greek ρυθμός – rhythms, meaning any recurring and not necessarily regular kind of motion and repetition. In music, rhythm is the pattern of either regular or irregular pulses determined by the occurrence of strong and weak beats both melodic and harmonic (see Pinna & Sirigu, 2011). According to this notion, all the previous figures demonstrated that the rhythm imparted by color can be
different from the one imposed by the shape and its boundary contours. This is also the case of disrupting colors observable in the male of the mandarin duck (*Aix galericulata*, see Figs. 12a-b). The chromatic rhythm breaks the continuation of edges and parcels out the wholeness of the duck body. In fact, by the pictures shown, the bird in Fig. 12b is something hardly recognizable as a bird. This entails that the chromatic parceling out, induced both by the rhythm and the chromatic variations, is aimed to hide. The male and female plumages of the Mandarin Duck are so unalike (compare Figs. 12a and 12c) to reveal the meaning of color for this species, i.e. to be and not to be perceived. This is the “to be or not to be perceived” dilemma that emerges with a large variety of organisms, mostly animals, where the sexual dimorphism (a phenotypic difference between male and female within a species) is strong. Therefore, the most multicolored mate needs to be and not to be perceived at the same time. This is the case of the mandarin duck, whose male “wants” to be perceived by the female of the same species but not by animals of other species, which can be potential predators.

![Mandarin Duck](image)

*Figure 12. Color imparts segmentation, partition and accentuation of figural attributes eliciting equilibrium between oneness and multiplicity. (Online in color.)*

Next to this, there is also the part vs. whole dilemma, related for example to the sexual attraction. When parts of the body of an organism assume sexual functions, they are highlighted, for example, through brilliant and saturated
colors or pop out by means of special colored shapes (horns, crest, etc.). The part vs. whole dilemma depends on the chromatic emergence of parts that weaken or parcel out the wholeness. The dilemma can be solved through a part-whole organization, according to which, the whole emerges mostly for a conspecific as a consequence of the multi-coloration of the parts. For the two dilemmas, the equilibrium between oneness and multiplicity represents the best way to adapt to the environment and to elicit the highest adaptive fitness. They are complementary, biologically related and reciprocally supporting each other.

What is important for color vision is that colors likely represent the best way to find a solution to the two dilemmas. In fact, because color belongs to a shape, it is syntactically subjected to shape. The color is the shape adjective. As a matter of fact, we use to say “a red square” and not “a square red”. The last sentence sounds odd and wrong (see Pinna, 2012e, 2012f). As a consequence, if color is subjected, it qualifies a shape by giving to it a multiplicity of possible attributes without destroying, hiding or making totally invisible the shape (like in the crypsis). This implies that color, differently from the shape or from other properties, is the figural attribute best candidate to find the best equilibrium and compromise between the poles of oneness and multiplicity.

This can be observed through the spontaneous way of using colors, as for example when highlighting different countries within the map of Europe (see Fig. 12d) without losing the wholeness emerging from the multiplicity of countries. By introducing boundary contours among the countries, the perception of the multiplicity is strengthened to the detriment of the oneness, similarly to the results of Fig. 7e.

These results suggest that chromatic rhythm phenomenally induces some kind of spatial movement or sets of changes marked by some kind of regulated succession of more or less strong regions or beats (see also Pinna & Sirigu, 2011). Therefore, chromatic rhythm segments, groups or parcels out in subsets regions of space otherwise invisible or visible in different ways and meanings on the basis of the action of an alternative rhythm determined, for example, by the shape. The complementation between similarity and dissimilarity of color is the requisite to reorganize the visual world and, thus, to create the camouflage or implicitness of several sequences of elements or phrases and, at the same time, to accentuate or make visible and explicit other phrases. This is very simply what everybody spontaneously does by using highlighters of different vivid and translucent colors to draw attention to sections of text that in this way pop out immediately as relevant concepts and thoughts. The use of color in biological evolution can be compared with a process similar to the one of the highlighter. In fact, in the case of fruits and flowers, as with a highlighter, color is used to show and to highlight exactly a portion or a part within a whole (part-whole segregation). Given that the process of chromatic highlighting is very effective, very common in nature and with a very high adaptive fitness, it is reasonable to hypothesize that the role of color in perceptual organization is more effective than the one of other Gestalt principles.
In the next section, the metaphor of the highlighter is taken to a further step in the understanding of the role of color in imparting a rhythm in perceptual organization by investigating the way color influences the reading process when pitted against other Gestalt principles of grouping.

Reading by color

In this section, the role played by color in determining visual grouping and wholeness is explored, not only in relation to further similarity attributes, but mostly in relation to other principles such as proximity and past experience. The last phenomenological remarks, according to which the role of color in biology can be more powerful than other principles of perceptual grouping, can be tested in Fig. 13. In Fig. 13a, a long set of equidistant letters makes the reading hard. By introducing blank spaces in between words (Fig. 13b), the reading is easier due to the proximity principle of grouping that imparts a visual rhythm. In Fig. 13c, the long sequence of letters of Fig. 13a is now segmented and marked with a new rhythm by the chromatic similarity, making the reading easy and even easier than the words of Fig. 13b. The words of Fig. 13d, due to the synergistic action of the proximity and the chromatic similarity, become now the easiest text condition to be read. However, by pitting one principle against the other (Fig. 13e), the segmentation and rhythm, due to the chromatic similarity, makes the text unreadable or very hard to be read. The reading becomes even worst in Fig. 13f, where the chromatic similarity favors the popping out of non-words, therefore, making visible non-words and invisible or camouflaged the words that are physically there. Three controls are illustrated in Figs. 13g-i, where the chromatic dissimilarity among adjacent letters fragments each word making the reading of Figs. 13g and 13i more difficult than the one of Fig. 13a and the reading of Fig. 13h more difficult that the one of Fig. 13b.

a) PARCELLINGOUTDUETOCOLORS
b) PARCELLING OUT DUE TO COLORS
c) PARCELLINGOUTDUETOCOLORS
d) PARCELLING OUT DUE TO COLORS
e) PARCELLING OUT DUE TO COLORS
f) PARCELLINGOUTDUETOCOLORS
g) PARCELLINGOUTDUETOCOLORS
h) PARCELLING OUT DUE TO COLORS
i) PARCELLINGOUTDUETOCOLORS

Figure 13. Some examples showing the role played by the chromatic similarity principle in reading process. (Online in color.)
The role of the perceptual organization involved in the reading process is more systematically explored in the text conditions described in the next sections. This is a new way to test the effectiveness of the Gestalt principles and, more specifically, to understand how color can influence visual organization and, through it, other perceptual and complex processes such as reading and visual word recognition. In fact, involving cognitive and metacognitive domains permits the exploration of broader issues concerning perception, memory, knowledge, representation and learning, where color can more clearly express its biological advantages for human species. These processes can be assimilated to the Gestalt past experience considered as a principle of its own kind not fully explored in relation to the other principles. As a consequence, these conditions allow color to be pitted against past experience and against a number of other principles at the same time.

If color induces wholeness, it can also induce fragmentation, when it is applied contrariwise. This is related to the fact that reading is a perceptual task and a process of segmentation of the words. Wilkins (2002) and Wilkins and Lewis (1999) demonstrated that colored overlays improve reading speed. In our experiments, we studied the role of different colors among words, and letters of the same word. Moreover, to understand the role played by color we used color, both as a whole and as a fragmentation tool, thus operating synergistically or against some grouping principles and similarity attributes. On these bases, color is expected to influence grouping and other visual processes related to reading and word recognition.

The text used as a stimulus was the following, the well known “The war of ghosts” (in Italian) by Bartlett (1932).

One night two young men from Egulac went down to the river to hunt seals and while they were there it became foggy and calm. Then they heard war-cries, and they thought: “Maybe this is a war-party”. They escaped to the shore, and hid behind a log. Now canoes came up, and they heard the noise of paddles, and saw one canoe coming up to them. There were five men in the canoe, and they said: “What do you think? We wish to take you along. We are going up the river to make war on the people.” One of the young men said, “I have no arrows.” “Arrows are in the canoe,” they said. “I will not go along. I might be killed. My relatives do not know where I have gone. But you,” he said, turning to the other, “may go with them.” So one of the young men went, but the other returned home. And the warriors went on up the river to a town on the other side of Kalama. The people came down to the water and they began to fight, and many were killed. But presently the young man heard one of the warriors say, “Quick, let us go home: that Indian has been hit.” Now he thought: “Oh, they are ghosts.” He did not feel sick, but they said he had been shot. So the canoes went back to Egulac and the young man went ashore to his house and made a fire. And he told everybody and said: “Behold I accompanied the ghosts, and we
went to fight. Many of our fellows were killed, and many of those who attacked us were killed. They said I was hit, and I did not feel sick.” He told it all, and then he became quiet. When the sun rose he fell down. Something black came out of his mouth. His face became contorted. The people jumped up and cried. He was dead.

The five different equiluminant colors (see section section on stimuli) were varied to pit the similarity in color (i) in favor or against the grouping principles of proximity (distance between two adjacent words, breaking off each word by adding a blank space), element connectedness (Palmer, 1999; underline typeface) and past experience, and (ii) against similarity attributes like orientation (italic typeface) and width (bold typeface).

Four chromatic conditions were used (see Fig. 14): (i) monochromatic – the entire text could be of only one of the 5 colors; (ii) word – each word was of a different color; (iii) half word – half word was of a different color from the second half; (iv) letter – each letter was of a different color. Fig. 14 shows one example of the stimuli used for the four chromatic conditions.

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Baingio Pinna and Katia Deiana

Figure 14. Four chromatic conditions of the stimuli: (a) monochromatic; (b) each word of a different color; (c) half word of a different color from the second half; (d) each letter of a different color. To save space, the text of “the war of ghosts” is here reported only partially and in both Italian and English languages. (Online in color.)
The subjects’ task was (i) to read the text as clearly as possible in a loud voice (reading task), (ii) to scale (in percent) the reading easiness of the stimuli used in each experiment (scaling task), and (iii) to answer a multiple-choice reading comprehension test related to the text (comprehension task).

Different groups of 15 subjects participated in only one condition each. In the scaling task, for three times, subjects could compare freely the reading easiness of all the stimuli of each experiment by switching them on a computer screen and by going back and forth until they were satisfied with their judgment. Subjects were invited to read the text more carefully, accurately and as fast as possible. The results of the three tasks will be reported only as for the first experiment, while about the others only the results of the scaling task will be reported.

**Color and Past Experience**

The aim of this experiment was to test the effect of the color organization of the four chromatic conditions on stimulus texts made up of joined words (without any separation by a blank space, Fig. 14). This is the simplest condition where color is synergistic or pitted against word recognition during reading (chromatic similarity and past experience principles of grouping).

![Figure 15. Chromatic similarity and past experience – Results of reading time, reading easiness and comprehension test.](image-url)
Fig. 15 illustrates the results of the reading time, the reading easiness in percent and the comprehension score plotted as a function of the four color conditions. These results can be phenomenally tested by reading the text in English illustrated in Fig. 14.

The results showed that the chromatic similarity strongly influences the three tasks. The wholeness and the segmentation among words, induced by color, speed up the reading time, improve the reading easiness and enhance the comprehension score when compared with the monochromatic, half word and letter conditions. The opposite results were obtained when each word was fragmented as in the half word condition or by using a different color in each letter. Briefly, the results of the half word condition showed the worst ratings in the three tasks. They improve in the letter condition, then in the monochromatic and finally in the word condition, which obtained the best scores. A one-way ANOVA, for each task, showed significant variations in the four conditions (respectively, reading time: $F_{4,42} = 15.9$, $p < 0.001$; reading easiness: $F_{4,42} = 13.2$, $p < 0.001$, and comprehension score: $F_{4,42} = 16.6$, $p < 0.001$). All the Fisher PLSD post hoc analyses of the possible pairs were significant ($p < 0.05$).

**Color and Proximity**

The purpose of this experiment was to study the reading easiness of the four chromatic conditions with stimuli where the inter-word separation ranged from 0 to 3 blank spaces (color and proximity principles of grouping). Fig. 16 shows examples of the stimuli with one blank inter-word separation. Fig. 17 illustrates the results of the reading easiness for the four inter-word separations plotted as a function of the chromatic conditions.

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**Figure 16.** Chromatic similarity and proximity – Examples of the stimuli with one blank inter-word separation. (Online in color.)
The results support the previous ones by showing for each of the four blank spaces the same order among the four conditions, namely, half word, letter, monochromatic and word. A two-way ANOVA showed significant variations in the four conditions for the four inter-words separations ($F_{3,42} = 19.9, p < 0.001$ and $F_{3,42} = 18.1, p < 0.001$). The interaction between the two factors was not significant. The Fisher PLSD post hoc analyses of all the possible pairs were significant ($p < 0.05$).

It is worthwhile noticing that the color organization in the chromatic conditions influences also the apparent interspace extent between two contiguous words, as well as the letter and word density, the chromatic saturation and, finally, the size and the numerosness of letters and words of Fig. 16, when they are perceived at a glance. The strength of these illusory effects would require specific and accurate psychophysical measurements that are beyond the main purposes of this work.

Color and Proximity

The four chromatic conditions were also tested with stimuli where each word was broken off in the middle by a blank space (color and proximity principles of grouping).

In Fig. 18, two examples of the stimuli and the results of the reading easiness are plotted as a function of the four color conditions.

These results, similar to the one of the previous experiments, demonstrate once more the basic role played by chromatic similarity in reading process both synergistically and against other Gestalt principles. As shown in the graph, the absolute percentages of the reading easiness are lower than those of the previous experiments. This is related to the fact that the broken words make the reading very difficult, as the flow is usually marked by blank space. What emerges very clearly is that the words are phenomenally “glued” and restored through the chromatic similarity.
A one-way ANOVA showed significant variations in the four conditions (F3,42 = 14.7, p < 0.001). All the Fisher PLSD post hoc analyses of the possible pairs were significant (p < 0.05).

**Color and Element Connectedness**

The color organization of the four chromatic conditions can also be pitted in favor or against underlined typeface (color and element connectedness principles of grouping). Fig. 19 shows two examples of the stimuli with the whole word underlined or half word underlined and the mean ratings of the easiness reading.

The outcomes follow the previous ones in the same order and in similar strength. A two-way ANOVA showed significant variations in the two word/half word conditions for the four chromatic similarities (respectively F1,14 = 19.9, p < 0.001 and F3,42 = 18.1, p < 0.001). The interaction between the two factors was not significant. All the Fisher PLSD post hoc analyses of the possible pairs were significant (p < 0.05).
Color and Orientation/Width

In Fig. 20, two examples of the stimuli with the whole word or with half word only in italic and bold typefaces and the results of the color organization in favor or against italic and bold typefaces (color and similarity by orientation/width) are illustrated.

The results corroborate the previous ones, demonstrating the basic role of colors in typesetting to improve the reading. Two two-way ANOVAs showed significant variations in the two word/half word conditions for the four chromatic similarities respectively for the italic typeface (F1,14 = 19.9, p <0.001 and F3,42 = 18.1, p <0.001 with not significant interaction) and for the bold typeface (F1,14 = 17.3, p <0.001 and F3,42 = 20.2, p <0.001 with not significant interaction). All the Fisher PLSD post hoc analyses of the possible pairs were significant (p <0.05).

Color and all the other Typeface Attributes

In the last experiment we tested underline, italic and bold typefaces taken together in the whole or half word pitted in favor or against the color organization of the four chromatic conditions (color and all the other typeface attributes).

In Fig. 21, two examples and the results of the reading easiness are plotted as a function of the four color conditions.
Una sera due giovani di Egulac discesero il fiume per cacciare foche e mentre stavano li si fece nebbioso e calmo. Udirono grida di guerra, e pensarono: "Forse è una spedizione guerresca". Fuggirono sulla spiaggia.

**Figure 20.** Stimuli and results of color and similarity by orientation/width. (Online in color.)

Una sera due giovani di Egulac discesero il fiume per cacciare foche e mentre stavano li si fece nebbioso e calmo. Udirono grida di guerra, e pensarono: "Forse è una spedizione guerresca". Fuggirono sulla spiaggia.

Una sera due giovani di Egulac discesero il fiume per cacciare foche e mentre stavano li si fece nebbioso e calmo. Udirono grida di guerra, e pensarono: "Forse è una spedizione guerresca". Fuggirono sulla spiaggia.

**Figure 21.** Stimuli and results of color and all the other typeface attributes. (Online in color.)
The outcomes replicate the previous ones and demonstrate that chromatic similarity wins against all the other typesetting similarities playing together. A two-way ANOVA showed significant variations in the two word/half word conditions for the four chromatic similarities (respectively $F_{1,14} = 21.5, p < 0.001$ and $F_{3,42} = 19.3, p < 0.001$). The interaction between the two factors was not significant. All the Fisher PLSD post hoc analyses of the possible pairs were significant ($p < 0.05$).

**Conclusions**

Phenomenally, a general principle of ‘unilateral belongingness of color to shape’ is implicitly assumed. It states that color is a visual attribute that belongs to an object and to its shape and not vice versa (Pinna, 2012e, 2012f). The perception of an object is usually equated to the perception of its shape but not to its color, which appears like a ‘secondary’ syntactic property, i.e. the adjective of the shape, the noun. As a consequence, it is believed that color has relatively little influence in both shape formation and perception. In the previous sections, the effectiveness of color similarity to group and segregate a figure from its background and to organize it in parts and whole as a shape in both visual and cognitive domains was phenomenologically studied through new phenomena and new conditions.

The results demonstrated peculiar and unique visual meanings and organization properties imparted by the chromatic variations. More particularly, the role of color is crucial in visual organization and segmentation, in imparting spatial rhythm and unification, in grouping and ungrouping wholenesses, in uncrowding shapes and making implicit shapes explicit, in shaping and reshaping the same pattern of stimuli in different ways. These outcomes were extended and strengthened by studying the way color influences the reading process (reading time, reading easiness and reading comprehension) when chromatic similarity is pitted in favor or against other Gestalt principles of Gestalt grouping. These principles are proximity (distance between two adjacent words and breaking off each word by adding a blank space), element connectedness (underline typeface) and past experience, and against further similarity attributes like orientation (italic typeface) and width (bold typeface). The results demonstrated that the chromatic similarity can influence the process of segmentation of words and, therefore, the phenomenal grouping and shape formation. Moreover, color wins against all the known typesetting similarities (underline, italic and bold typefaces) playing together. This entails that color is not only one among the many factors of grouping but an essential component for the foundation of the more complex organization aimed at creating wholeness, part-whole formation and fragmentation.

This statement is not antinomic with the principle of ‘unilateral belongingness of color to shape’. As a matter of fact, by qualifying a shape like an adjective does with a noun, color imparts to the shape a multiplicity of possible attributes without destroying, hiding or annulling the shape that
represents the visual oneness and the basic most invariant visual attribute. Color complements shape. This is the case of the fruits that through color variations change their visual and cognitive meanings.

At the same time, the shape can be reshaped (shape from color), camouflages ("Harlequin camouflage"), made totally (or only in some parts) invisible through colors. This suggests that color, differently from the shape and from other visual properties, is the best candidate to find the optimum equilibrium and compromise between the poles of oneness and multiplicity that are the two opposite poles belonging to every object that is, at the same time, one thing made of many parts.

This was demonstrated by showing that chromatic rhythm segments, groups, unifies or parcels out in subsets regions of space otherwise invisible or visible in different ways. The chromatic similarity/dissimilarity is the requisite to organize and reorganize the visual world and, also, to induce the camouflage or implicitness of several sequences of elements or wholes and, at the same time, to accentuate or make visible and explicit other elements or wholes.

Finally, we suggest that the phenomenological study of the role of color in perceptual organization casts light on the understanding of the high evolutionary neural investment for color system and on the fundamental and specialized functions of color in providing biological advantages and high adaptive fitness. More generally, it can be useful to answer the following basic biological questions: What is the purpose of color for living beings? Why are animals so colorful? What are the adaptive and perceptual meanings of monochromatism and polychromatism?

On the basis of our results, the answers to the previous questions are based on the tripartition roles of chromatic similarity to the visual organization. (i) To unify each chromatic component within an object, determining the emergence of the wholeness. (ii) To elicit a part-whole organization, where both components are not pitted one against the other but complemented and reciprocally reinforced within the whole. (iii) To accentuate fragments and to hide the whole by favoring the emergence of single components.

To conclude, we suggest that the general purpose of color for living beings is to elicit wholeness, part-whole organization and phenomenal fragmentation.

References

Arnheim, R. (1997). *Art and Visual Percepion. A psychology of the creative eye*. Berkley and Los Angeles: University of California Press.

Arnheim, R. (1997). *Art and Visual Percepion. A psychology of the creative eye*. University of California Press.

Attneave, F. (1968). Triangles as ambiguous figures. *American Journal of Psychology, 81*, 447–453.

Bartlett, F. C. (1932). *Remembering: An Experimental and Social Study*. Cambridge: Cambridge University Press.

Beddard, F. E. (1895). *Animal coloration: an account of the principal facts and theories relating to the colours and markings of animals*. 2nd ed. London, UK: Swan Sonnenschein.
Brainard, D. H., Pelli, D. G., & Robson, T. (2002). Encyclopedia of imaging science and technology. *Display characterization*, 172-188.

Cott, H. B. (1940). *Adaptive coloration in animals*. London, UK: Methuen and Co. Ltd.

Cuthill, I. C., Stevens, M., Sheppard, J., Maddocks, T., Párraga, C. A. & Truscianko, T. S. (2005). Disruptive coloration and background pattern matching. *Nature*, 434, 72–74.

Dolan, R. J., Fink, G., R., Rools, E., Booth, M., Holmes, A., Frackowiak, R., S., J., & Friston, K., J. (1997). How the brain learns to see objects and faces in an impoverished context. *Nature*, 389, 596–599.

Edmunds, M. (1974). *Defence in animals*. Longman Group Ltd: Harlow, UK.

Endler, J. A. (1978). A predator’s view of animal color patterns. *Evolutionary Biology*, 11, 319–364.

Endler, J. A. (1991). Interactions between predators and prey. *Behavioural ecology: an evolutionary approach*, 3, 169-196.

Feldman, J. (2000). Bias toward regular form in mental shape spaces. *Journal of Experimental Psychology: Human Perception and Performance*, 26(1), 1–14.

Gregory, R. L. (1972). Cognitive contours. *Nature*, 238, 51–52.

Gregory, R. L. (1987). Illusory contours and occluding surfaces. In *The perception of illusory contours* (pp. 81-89). New York: Springer.

Helson, H. (1947). Adaptation-Level as Frame of Reference for Prediction of Psychophysical Data. *The American Journal of Psychology*, LX, 1–29.

Kanizsa, G. (1955). Margini quasi-percettivi in campi con stimolazione omogenea. *Rivista di Psicologia*, 49, 7–30.

Kanizsa, G. (1979). *Organization in Vision*. New York: Praeger.

Katz, D., & Revesz, G. (1921). Experimentelle studien zur vergleichenden Psychologie, Versuche mit Hühnern. *Z. angew. Psychol.*, 18, 307–320.

Kennedy, J. M., & Bai, J. (2000). Cavanagh and Leclerc Shape-from Shadow Pictures: Do Line Versions fail because of the Polarity of the regions or the contour? *Perception*, 29, 399–407.

Koffka, K. (1935). *Principles of Gestalt Psychology*. London: Lund Humphries.

Kopfermann, H. (1930). Psychologische Untersuchungen über die Wirkung zweidimensionaler Darstellungen körperlicher Gebilde. *Psychologische Forschung*, 13, 293–364.

Landy, M. S., Maloney, L. T., Johnston, E. B., & Young, M. (1995). Measurement and modeling of depth cue combination: in defense of weak fusion. *Vision Research*, 35, 389–412.

Mach, E. (1914/1959). *The analysis of sensation*. Chicago: Open Court.

Mamassian, P., & Landy, M. S. (1998). Observer biases in the 3d interpretation of line drawings. *Vision Research*, 38, 2817–2832.

Merilaita, S. (1998). Crypsis through disruptive coloration in an isopod. *Proceedings of the Royal Society of London B*, 265, 1059–1064.

Nakayama, K., & Shimojo, S. (1992). Experiencing and perceiving visual surfaces. *Science*, 257, 1357–1363.

Palmer, S. E. (1980). What makes triangles point: Local and global effects in configurations of ambiguous triangles. *Cognitive Psychology*, 12, 285–305.

Palmer, S. E. (1989). Reference frames in the perception of shape and orientation. In B. E. Shepp & S. Ballesteros (Eds.), *Object perception: Structure and process* (pp. 121–163). Hillsdale, NJ: Erlbaum.

Palmer, S. E. (1999). *Vision Science: photons to phenomenology*, Cambridge, Massachusetts, London, England: The MIT press.

Palmer, S., & Bucher, N.M. (1981). Textural effect in perceiving pointing of ambiguous triangle. *Journal of Experimental Psychology: Human Perception & Performance*, 8(5), 693–708.

Pinna, B. (2010a). What color is it? Modal and Amodal Completion of Color in Art, Vision Science and Biology. *International Journal on Arts & Technology*, 3, 195–220.
Pinna, B. (2010b). New Gestalt principles of perceptual organization: An extension from grouping to shape and meaning. *Gestalt Theory, 32*, 1–67.

Pinna, B. (2012a). The Place of Meaning in Perception – Introduction. *Gestalt Theory, 33*, 221–244.

Pinna, B. (2012b). The role of amodal completion in shape formation: Some new shape phenomena. *Perception, 41*, 1336–1354.

Pinna, B. (2012c). What is the meaning of shape? *Gestalt Theory, 33*, 383–422.

Pinna, B. (2012d). Perceptual organization of shape, color, shade and lighting in visual and pictorial objects. *i-Perception, 3*, 257–2.

Pinna, B. (2012e). The organization of shape and color in vision and art. *Frontiers in Human Neuroscience, 5*, article 104. doi: 10.3389/fnhum.2011.00104

Pinna, B. (2012f). The place of meaning in perception. *Gestalt Theory, 33*, 221–244.

Pinna, B., & Grossberg, S. (2006). Logic and phenomenology of incompleteness in illusory figures: New cases and hypotheses. *Psychofenia, 9*, 93–135.

Pinna, B., & Sirigu, L. (2011). The Accentuation Principle of Visual Organization and the Illusion of Musical Suspension. *Seeing and Perceiving, 12*, 1–27.

Pinna, B., & Reeves A. (2013). What is the purpose of color for living beings? Toward a theory of color organization. *Psychological Research. DOI:10.1007/s004426-013-0536-2*

Pinna, B., Ehrenstein, W., & Spillmann, L. (2004). Illusory contours and surfaces without perceptual completion and depth segregation. *Vision Research, 44*, 1851–1855.

Pinna, B., Uccula, A., & Tanca, M. (2010). How does the color influence figure and shape formation, grouping, numerosness and reading? The role of chromatic wholeness and fragmentation. *Ophthalmic and Physiological Optics, 30*, 582–592.

Rubin, E. (1921). *Visuell wahrgenommene Figuren*. Kobenhavn: Gyldendalske Boghandel.

Schumann, F. (1900). *Beiträge zur Analyse der Gesichtswahrnehmungen. Zur Schätzung räumlicher Grössen. Zeitschrift für Psychologie und Physiologie der Sinnesorgane, 24*, 1–33.

Vicario, G. (1968). “Il metodo dello smistamento nello studio della preferenza forma colore”. In Kanizsa, G, & Vicario, G. (Eds.), *Ricerche sperimentali sulla percezione* (pp. 243–277). Trieste: Edizioni Università degli Studi.

Weiss, Y., & Adelson, E. H. (1998). Slow and smooth: a Bayesian theory for the combination of local motion signals in human vision (A.I. Memo No. 1624). Massachusetts Institute of Technology Intelligence Laboratory.

Wertheimer, M. (1912a). Über das Denken der Naturvölker. *Zeitschrift für Psychologie, 60*, 321–378.

Wertheimer, M. (1912b). Untersuchungen über das Sehen von Bewegung. *Zeitschrift für Psychologie, 61*, 161–265.

Wertheimer, M. (1922). Untersuchungen zur Lehre von der Gestalt. I. *Psychologische Forschung, 1*, 47–58.

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt. II. *Psychologische Forschung, 4*, 301–350.

Wilkins, A. (2002). Coloured overlays and their effects on reading speed: a review. *Opthal Physiological Optics, 22*, 448–454.

Wilkins, A., & Lewis, E. (1999). Coloured overlays, text, and texture. *Perception, 28*, 641–650.