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Experimental phenomenology on the role of chromatic accentuation in reading tasks

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Abstract

According to Gestalt psychologists, color is considered a secondary attribute and a less effective tool if compared to shape, luminance and motion. In this work novel and meaningful visual properties given by chromatic variations in the reading process in normal and dyslexic readers have been studied. It was shown that color highlights wholeness, parts-whole organization and phenomenal fragmentation during reading and comprehension tasks in reading texts made of words and non-words modified through several color conditions: monochromatic (the whole text colored with only one color); word (each word colored in different color); half word (half word colored in a color different from the one of the second half); syllable (every syllable in a different color); letter (each letter in a different color). The aleatory variables here considered were: the reading time, the reading errors and the incorrect answers given in a comprehension test. The outcomes demonstrated that these variables are all directly related and strongly affected by the five chromatic conditions. These findings illustrate similar trends in the four groups of readers: children and adults, normal and dyslexic readers. Further possible researches and eventually some clinical applications are also discussed along with some questions related to color vision. They suggest the main purposes of color for living beings which is that to generate wholeness, parts-whole organization and perceptual fragmentation.

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on the role of chromatic accentuation
in reading tasks"**

Tesi di dottorato in culture, letterature
e lingue dell'età moderna e
contemporanea

Chapter 1

Seeing the world in color

How would it look like a world without color? Surely, a world deprived of color would be missing of some of the very crucial elements in life. According to Werner et al. (2007), not only do colors make us see the world more precisely, but also they enhance emergent qualities that would not exist in a world without them. For example, if we look at the picture in color in Fig.1.1 below, it shows autumnal leaves lying in the calm water of a fountain. In this picture, it is possible to appreciate the reflections of trees and that of a dark-blue afternoon sky behind them. On the contrary, in the black-and-white picture Fig. 1.2 representing the same scene, the leaves are perceived less distinctively, the dark-blue sky is absent, the reflections of the light are also very weak, the water itself can hardly be visible, and the difference concerning the apparent depth among the sky, trees and that of the floating leaves is completely absent (Pinna, 2006).

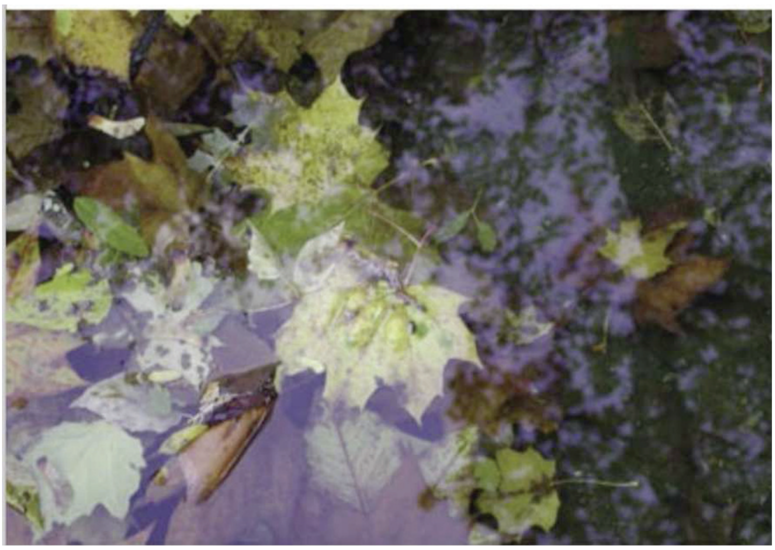


Figure 1.1. Autumn leaves and reflexions in a fountain in color.

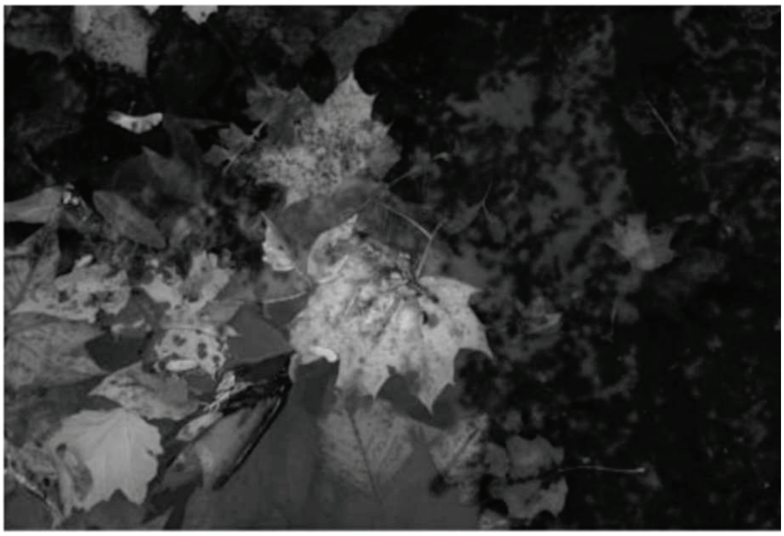


Figure 1.2. Autumn leaves and reflexions in a fountain in black and white.

However, the role for color, and even its true nature is not well recognized. Most people consider color as a defining and essential property of objects, depending completely on the specific wavelengths of light reflected from them. In reality, this belief is not correct. In fact, color is a sensation created in our brain. If colors we perceive depend only on the wavelength of reflected light, an object's color would appear to change drastically with variations in illumination throughout the day and in shadows. On the contrary, patterns of activity in our brain make an object's color quite stable in spite of the changes in its environment.

The majority of researchers who study vision are convinced that color helps us discriminate objects when differences in brightness are insufficient to do that. Some also claim that color is a luxury which is not really needed, in fact, they state, that totally color-blind people and many other species of animals have demonstrated to do well even without the degree of color perception that most humans possess (Pinna, 2006). Besides, the pathway in our brain that serves navigation and movement, is essentially color-blind. In addition, people who become color-blind after a stroke reveal to have normal visual perception as well. These observations have been brought as a support for the insular nature of color processing, which suggests that it has no role in processing depth and form. Indeed they stress the fact that color is only about hue, saturation and brightness.

The studies of illusory colors, (those colors that the brain is tricked into seeing) have proved that color processing in our brain occurs together with the processing of other properties, such as shape and boundary. As a matter of fact, illusions have helped researchers understand more precisely how the neural processing of color results in some ways bound to other properties such as shape and boundary (Pinna, 2006). At this stage, if seeing in color is a psychological experience, two important questions come accordingly. First of all, how does it come that we can see color? And, how does the human visual system process it? Before deepening into more technical details a few general information will be reported below for less experts readers.

Color Vision

The view of color is surely one of the most intriguing and fascinating experience. Perceiving color is, in fact, an exclusive experience which, among the sensory modalities is the most spectacular as well if compared to other object's propriety. Physical objects and lights sources have this peculiarity of appearing colored. People normally think that objects are colored because they are perceived as such, but in reality they are not. The idea that the grass is green because it appears as green and that the sky is blu because it looks blue is highly mistaken. Although all this may seem very odd, objects and lights are not colored. As a matter of fact, color is a psychological property related to our visual experience which occurs when we look at objects and lights. In other words, colors are the results of a complex interaction between the physical lights present in the environment and the correct functionality of our nervous system. In brief, the perception of color is possible thanks to the physics of light which reacts with our retinal receptors and responds to it. The experience of color is also an exclusive event as being both a cultural and personal experience. Different cultures in fact, name the colors of surfaces differently, as well as different people may perceive colors differently in shades or they may not perceive them correctly in part or at all (Palmer, 1999).

Computational experience of color perception

To explain color perception Marr (1982) gives a simplified computational description. In order to perceive color, the input is given by the light reflected into the eye by the surface, while the output is the color experience that occurs when the observer looks at those surfaces. The mapping is the psychophysical correspondence between these two aspects.

The physical description of light

The first great explanation of color vision came after the discovery of the English physicist Isaac Newton in1666. He discovered that the white light coming from the sun is not at all uncolored but it is made by different elements, each producing a different color experience. He created a hole in his laboratory shade and placed a prism behind it, so when the beam of light passed through the hole and

hit the prism, many different colors appeared as can be seen in the picture below (Fig. 1.3).

Figure 1.3. The refraction of light as discover by Isaac Newton (1666).

Following this first experiment, Newton turned the rainbow of colors into a white beam again by placing additional prisms to recompose and observe the white beam of light (Fig. 1.4).

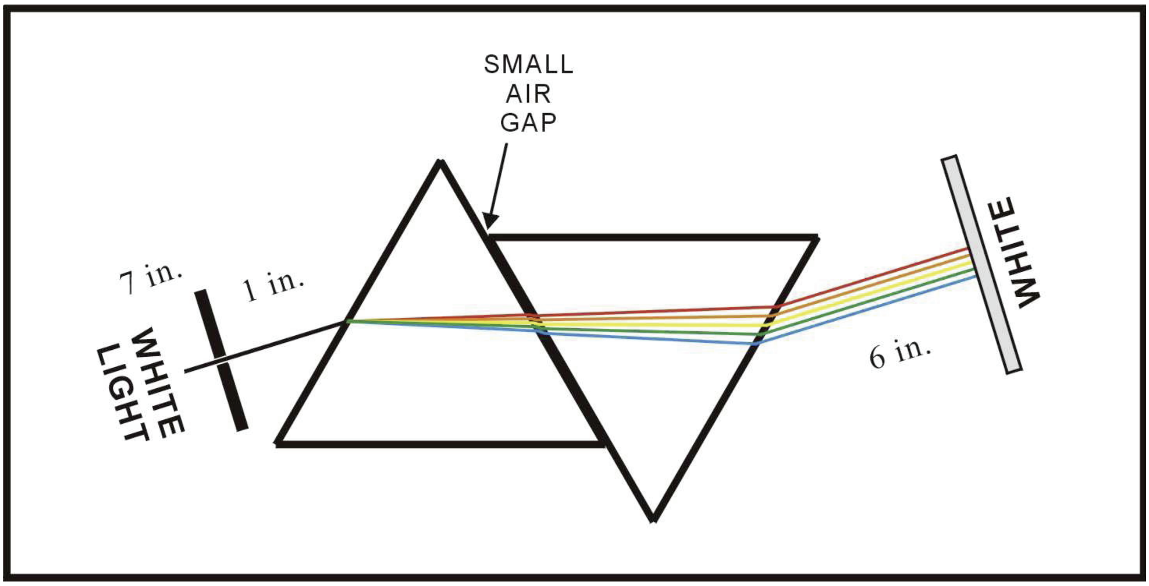


Figure 1.4. The recombining of the white beam of light by means of more prisms.

After these experiments Newton claimed that the sunlight was made up of many different colors and not just one. Then, he also stated that colors were not in the beam of light itself but that they were produced by the effect of the light on our visual system (Palmer, 1999).

The photons

Another fundamental discovery in the physical properties of light is given by the discovery of some extremely small invisible units called photons. In particular, it is the wave behavior of photons which is crucial for the understanding of color vision.

A photon is a very tiny unit of vibrating electromagnetic energy. What is really important in a photon is the wavelength of its vibration. The wavelength of photons is measured in units of distance and they can be very small or extremely large, in fact, they can reach thousands of kilometers. In the figure 1.5, it is shown the electromagnetic spectrum. More precisely, it is shown the portion where photons are perceived as visible light.

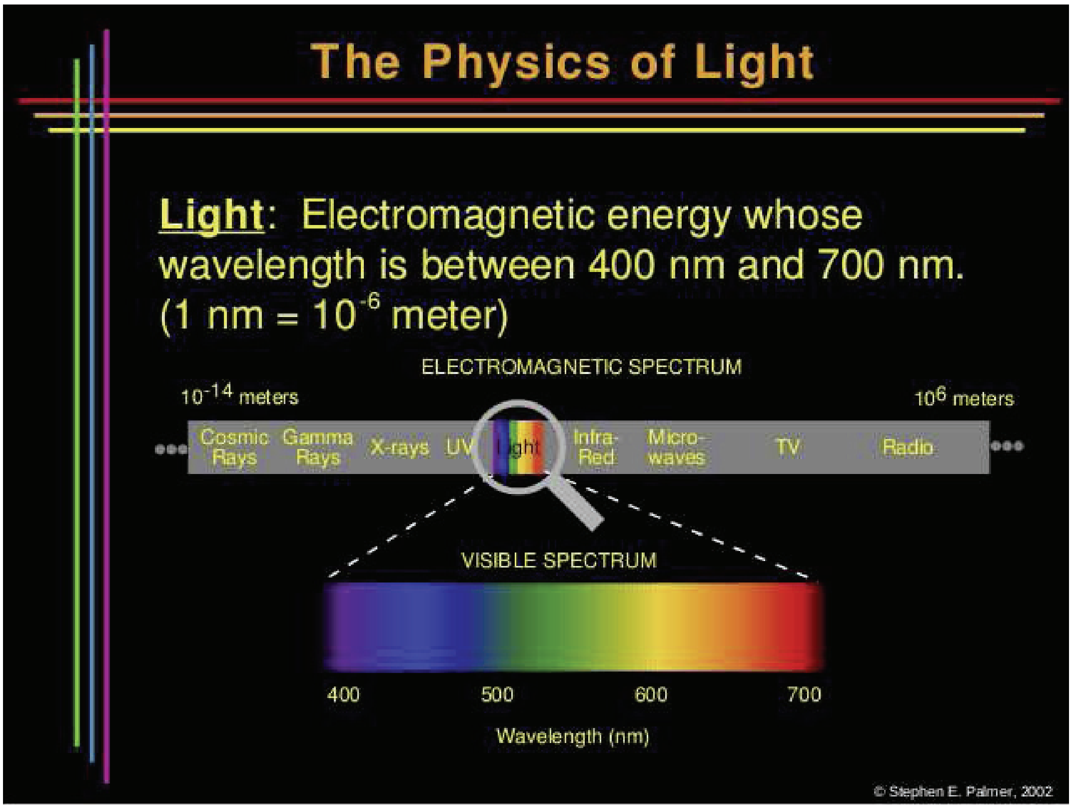


Figure 1.5. The electromagnetic spectrum.

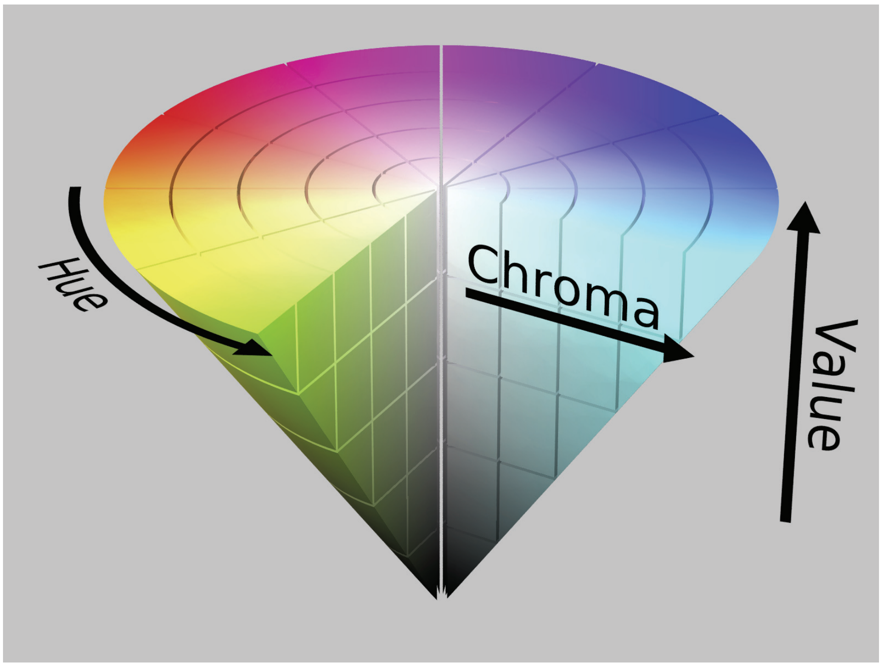


Figure 1.6 Color solid.

It is known that the human visual system perceives only those photons whose wavelength goes from 400 to 700 nanometers. For examples, TV waves, microwaves, radio and X-rays are part of the spectrum, as well. However our sensory system responds only to photons located in the visible spectrum as indicated in the selected range (figure 1.6 above). All the other photons outside this range can only be perceived with the aid of complex devices like X-rays cameras, televisions and radios which can transform them into visible light or audible sounds (Palmer, 1999).

The psychological description of light

Color does not exist in itself, it is a psychological phenomenon which is possible only within an observer. People normally see colors as a property of a surface and this happens because of the light emitted by luminous objects such as the sun or light that bulbs into our eyes. In addition, surfaces appear colored in different ways and this is due to the fact that different surfaces can reflect different amount of light at different wavelength.The psychological experience of perceiving color is different from the physical description given. All color surfaces perceived by people with normal color vision, according to a psychological description are described according to 3 dimensions, which are *hue, saturation* and *lightness.* These three dimensions define color space. Color space is a system where each possible color experience can be represented as a single point and in a unique position. The whole set of colors that individuals with normal color vision can experience is located in a specific area of color space which falls under the name of color solid. A color space with the same intensity in hue and saturation is also called chroma, lightness is also called value. A system like this was originally described by Albert Munsell, an artist and art teacher. Thanks to his work and analysis an Atlas with standardized colors was published in a set of 2 volumes. The Atlas, The Munsell Book of Color, contains 1600 glossy samples of carefully controlled paint chips. Every color surface can find a correspondence in the Munsell chip and it can also be described according to the 3 values of hue, saturation and lightness (Palmer, 1999).

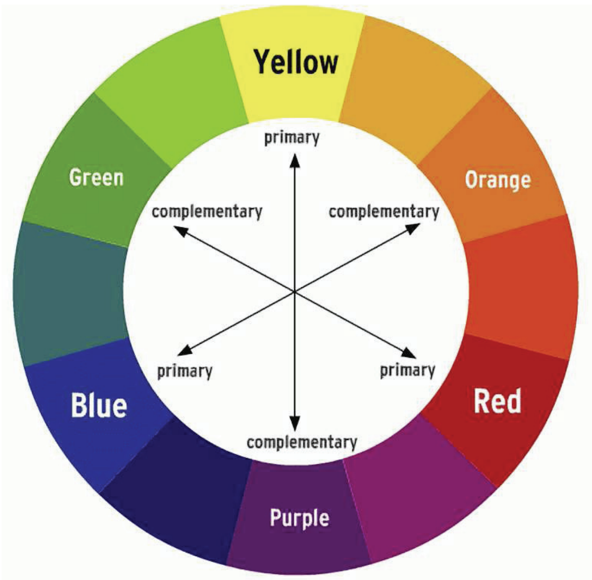


Figure 1.7. The color circle.

Hue

Hue in the dimension which is commonly defined as the basic color of a surface. In the color space, hue is the direction going from the central axis to the exact position which corresponds to the given color. By observing the hue of monochromatic lights, which are those having just one wavelength, there is a smooth progression of violets colors, blues, greens, yellows, orange and reds which makes this psychological dimension very similar to the physical dimension of wavelength, but they are not quite the same, however.

Saturation

Saturation is the other dimension of color, the one that catches the purity and vividness of a given color experience.

Lightness

Lightness is the last dimension of surface color and it defines the height of a color position in the color plate. Each surface color has its on value on the lightness dimension. Lightness can be perceived more clearly in the case of achromatic colors, above all in the case of the grays, because they have the white color at the top and the black at the bottom. The gray lies on the centre while the highly saturated colors are placed around the edges. Hues placed on the opposite sides of the circles are defined complementary colors (figure 1.7). When lights of the complementary colors are blended, they generate achromatic light at some shade of gray.

Light mixture

On of the most intriguing question is: how do color combine?

First of all, it is important to state that only a portion of colors in color shape corresponds to monochromatic lights. In order to see non-spectral colors like purples, and in order to perceive also the pastels and grays colors, two or more different wavelength must be mixed.

The most important element needed in order to produce color technology for example, is the matching of three lights, without whom it would be impossible to perceive colors on our TV and screens (Palmer, 1999).

Anatomy of the eye

It is our anatomical structure of the eye that permits visual perception and highly affects it. It is well known that the human eye works like a camera. The cornea and the lens work together to project an image present in the visual world at the back of the eye. The image projected, is focused on the retina, which works like a film or any other image sensor typical of a camera. The cornea and other structures will be highlighted in the following paragraphs, as they have a strong and salient impact in determining our visual perception. Here below and in the following page, the frontal view of the human eye and its internal structure with some of its important parts labelled, are shown (Figs. 1.8-1.9).

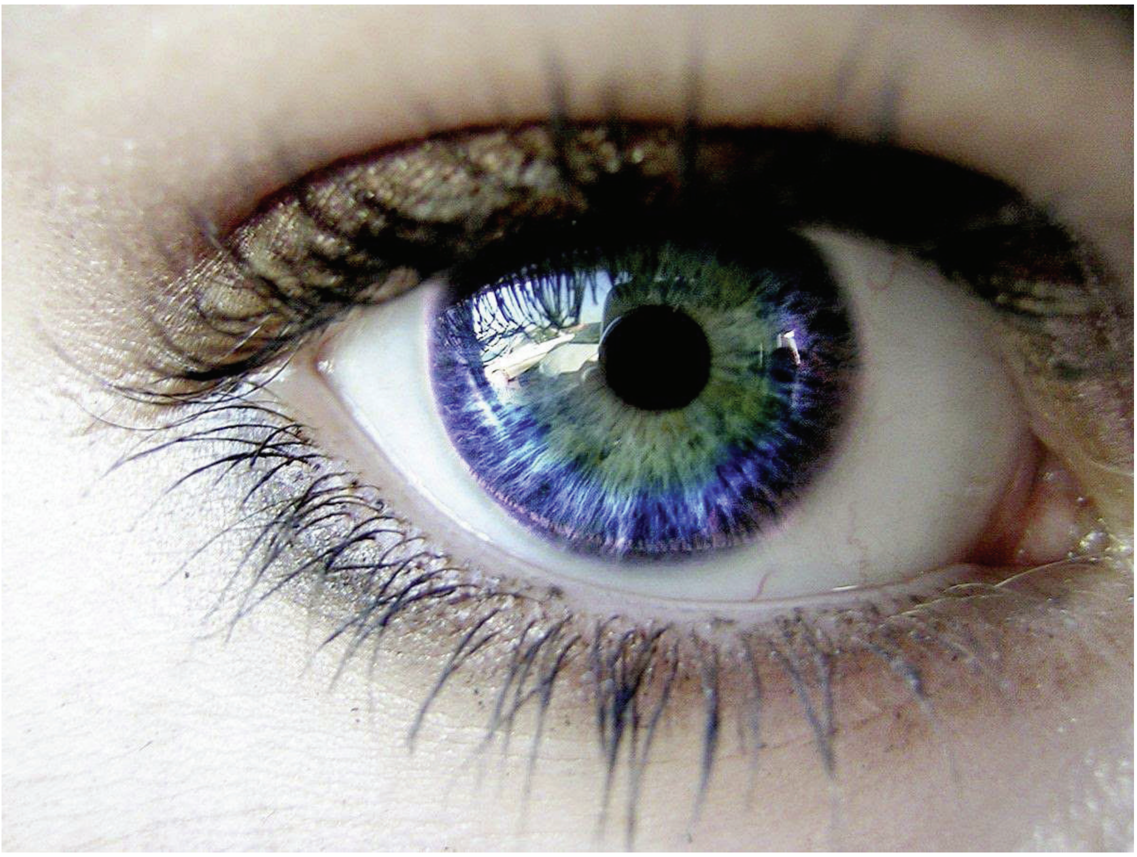


Figure 1.8. Frontal view of an eye.

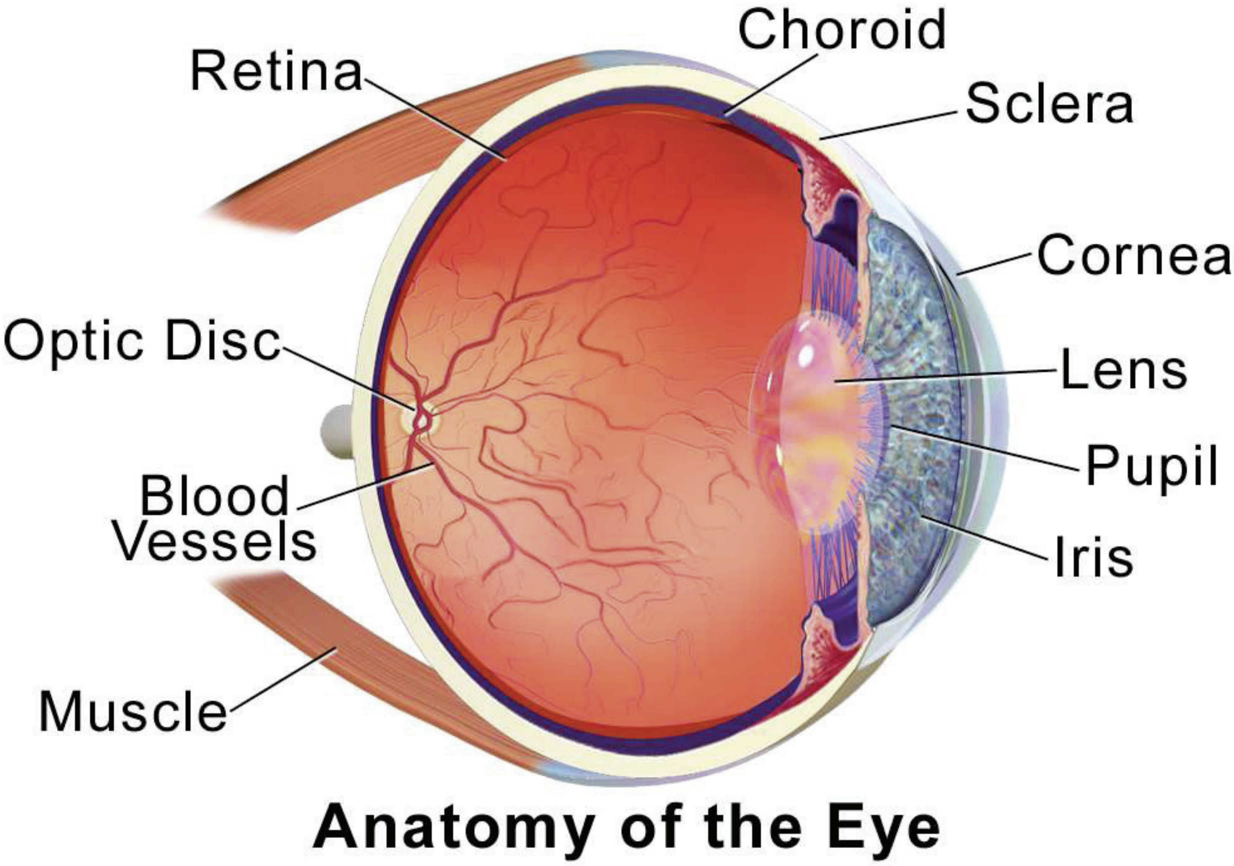


Figure 1.9. The structure of the human eye and some of its important parts labelled.

The cornea

The cornea is the most significant image-forming element of the eye. It is the transparent surface placed in the front of the eye through which passes light. Its curved surface located at the interface with air represents the largest change in refraction index in the eye's optical system. The cornea is an avascular element. It receives its nutrients from the marginal blood vessels and from the fluids that surround it. Nearsightedness, also called myopia, farsightedness, also called hyperopia, and astigmatism, are refractive errors. They are due to variations in the shape of the cornea, and for this reason they are often corrected with laser surgery that reshapes the cornea (Drake et al., 2004)

The lens

The lens are responsible for the accommodation. The lens consist of a flexible structure that varies refraction index. Lens are optical elements with a higher refraction index in the center rather than at the edges. This is an important feature because it helps to reduce some of the aberrations which might be present in the optical system. The ciliary muscles control the shape of the lens. The function of the lens is that to increase or decrease optical power to allow us to focus on nearer or more distant objects. As people grow older the internal structure of the lens changes. In fact, with age, it loses flexibility in a way that it is no longer possible to focus on near objects. This is the case of people who suffer from presbyopia and at around the age of 50, they are prescribed reading glasses or bifocals. In addition to the hardening of the lens, there is an increase in the optical density. In fact, the lens which normally absorb and scatter blue and violet short-wavelength energy, when the lens hardens tend to increase the absorption and scattering of these short wavelength. This is why older people, if compared to younger ones, absorb more of the blue energy reflected by purple objects (Xu, Pokorny & Smith, 1987).

The Humors

The aqueous humor is water which fills the space between the cornea and the lens, while the volume between the lens and the retina is filled with vitreous humor. This is also a fluid but compared to the aqueous humor it has a higher viscosity and it looks like a gelatin. Both humors are important to assure the flexibility of the eyeball. This flexibility is important to reduce injury (Drake et al., 2004)

The Iris

The iris is a sphincter muscle that determines the pupil size. The iris is pigmented and this gives each of us our specific eye color. More importantly, the concentration and distribution of melanin within the iris is responsible for eye color. The pupil, which is the hole in the middle of the iris through which passes light, regulates the level of illumination on the retina. Pupil size is mainly given according to the overall level of illumination. However, it can also vary in the presence of non-visual phenomena such as arousal. It is difficult to predict precisely pupil size from the prevailing illumination. Indeed, its diameter can vary from about 3 mm to about 7 mm (Drake et al., 2004).

The Retina

The retina is the location where it is projected the optical image formed by the eye. The retina is a thin layer structure of cells. It has approximately the thickness of a tissue paper and it is located at the back of the eye. It incorporates the visual system's photosensitive cells and the initial signal processing and transmission 'circuitry.' All these cells are neurons, they are part of the central nervous system, and are also considered as part of the brain. The photoreceptors, rods and cones, are essential to transduce the information in the optical image into chemical and electrical signals that are transmitted to the visual system. These signals are later processed by a network of cells and then they are transmitted to the brain through the optic nerve. Behind the retina there is a layer which is known as the pigmented epithelium. It is a dark pigment layer which works to absorb any light that passes through the retina and that it is not absorbed by the photoreceptors. The main function of the pigmented epithelium is that to prevent light from being scattered back through the retina. In this way, it tends to reduce the sharpness and contrast of the perceived image (Drake et al., 2004)

The Fovea

One of the most important areas on the retina is certainly the fovea. The fovea is that structural area of the retina where we have the best spatial and color vision. When we look at an object, or fixate it, we move our head and eyes in such a way that the image of the object falls on the fovea. The fovea is that depression located in the inner retinal surface made of a photoreceptor layer specialized for our maximum visual acuity (Drake et al., 2004)

The Macula

The fovea is also protected by a yellow filter which is known as the macula. The macula function is that to protect this critical area of the retina from intense exposures to short-wavelength energy. It works as well to reduce the effects of chromatic aberration that makes the short-wavelength image to be severely out of focus most of the time. Differently from the lens, the macula does not become more yellow when people grow older, but it is possible to observe significant differences in the optical density of the macular pigment in different observers and, sometimes even between a single observer's left and right eye. The yellow filters of the lens and the macula, which allow our view of the world, are the main sources of variability in color vision between observers with normal color vision (Drake et al., 2004)

The Optic Nerve

An other key structure of the eye is the optic nerve. The optic nerve is made up of the axons (outputs) of the ganglion cells, which are the last level of neural processing in the retina. The optic nerve is made up of one million fibers, which carry information originated by more or less 130 million photoreceptors. For this reason, there is a clear compression of the visual signal before the transmission to higher levels of the visual system. Due to the fact that the optic nerve covers all of the space that would normally be populated by photoreceptors, in each eye there is a small area where no visual stimulation occurs. This area is known with the name of the blind spot (Drake et al., 2004)

How the human brain processes color

How does our visual experience start? Visual perception starts with the absorption of light, and more in details, it begins with the absorption of discrete packets of energy called photons, precisely by the absorption of light possible thanks to the cones and rods which are located in the retina (Fig.1.10)

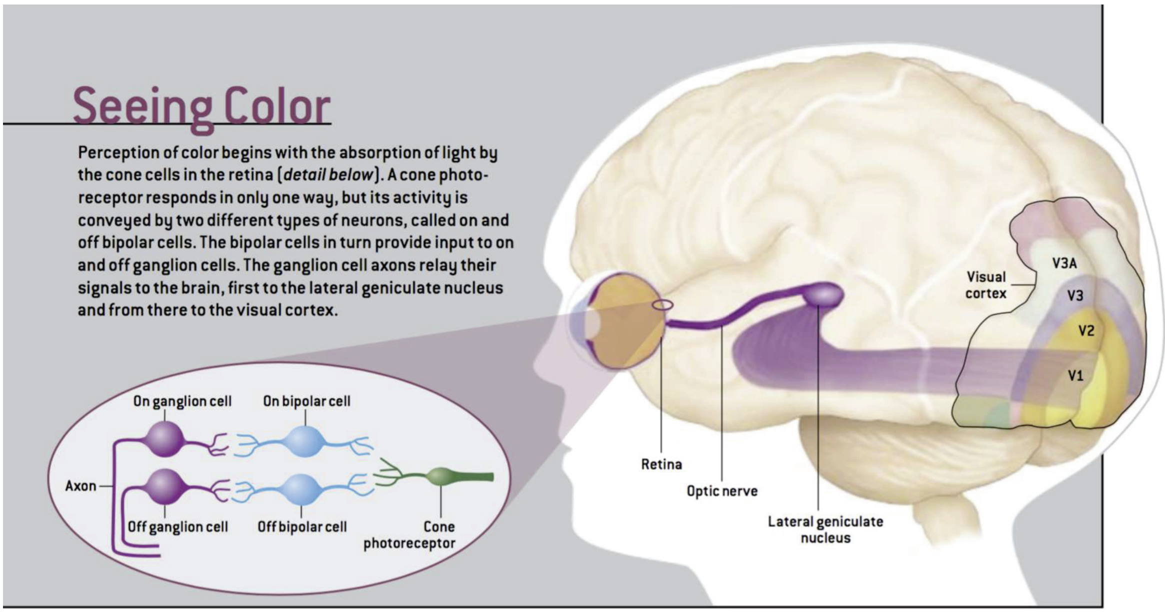


Figure 1.10. Perception of colors

The cones are used for day vision, while rods are responsible for vision at night. A cone photoreceptor reacts in relation to the number of photons it captures, and its response is transmitted to two different types of neurons, the on and off bipolar cells. These neurons, in their turn, provide input to on and off ganglion cells that reside in the retina.

The ganglion cells have a center-surround receptive field. This receptive field of any vision-related neuron is the area of space in the physical world that affects the activity of that neuron. A neuron with a center-surround receptive field responds differently depending on the amount of light in the center of the field and that in the region around the center (Werner, Pinna & Spillmann,2007).

An on ganglion cell fires maximally when the center is lighter than the surround, while it fires minimally when the receptive field is illuminated uniformly. Off cells, instead, behave in the opposite way. In fact, they fire maximally when the center is darker than the surround and minimally when the center and the surround are uniformly illuminated. The antagonism between center and surround is useful to ganglion cells to respond to contrast and to sharpen the brain's response to edges and borders.

Most of the ganglion cell axons (fibers) relay their signals to the brain, more specifically they send their signals to the lateral geniculate nucleus of the thalamus, which is near the center of the brain, and from there, it reaches the visual cortex, located at the back of the brain. Different populations of ganglion cells are very sensitive to different features of stimuli, such as motion and form, and their fibers conduct signals at different speed. Color signals, for example, are carried by the slower fibers.

Nearly 40 percent or maybe more of the human brain is involved in vision. In the areas stimulated early in visual processing, those parts of the visual cortex called V1, V2 and V3, neurons are organized into maps that provide a point-to-point representation of the visual field. From this area, visual signals arrive to more than 30 different areas, interconnected by more than 300 circuits. Each of the areas has specialized functions and it can be responsible for processing color, motion, depth and form. However, no area mediates one perceptual quality exclusively. In some ways, all this information is combined. As a result, in the end, all elements come into a unitary perception of an object having a particular shape and color. So far, neuroscientists do not yet understand in details how this can happen.

There are studies which highlight how bilateral damage to certain visual areas leads to deficits in the perception of form as well as color. This interesting fact provides another piece of evidence that shows that color is not disembodied from the other properties of an object (Werner, Pinna & Spillmann, 2007).

Color is a physical phenomenon

In the physical world color consists of the spectral qualities of the light which are emanated and reflected from an object or from a living being. In the eighteen century it was demonstrated that any color could be generated simply by mixing three sufficiently different colors in correct proportion. This trichromacy is physiologically explained since at each point in the retina there are three structures, sensitive to light, which encode different and overlapping portions of the spectrum (Palmer, 1999), as also confirmed in the studies with micro-spectrophotometry carried out in of the twenty century (Brown & Wald, 1964; Marks, Dobelle & MacNichol, 1964).

Research into color vision, among other things, focussed, on identifying the cone types and the details of their spectra both in humans and in various animals. Some theoretical claims about color vision have originally emphasized the relative poverty of trichromatic and dichromatic systems, because of the necessary existence of metamers, which in humans cannot distinguish a suitable combination of 540 nm and 630 nm light from 580 nm light (both look yellow). It seemed reasonable to maintain that many possible wavelength combinations were not differentially encoded, having attributed too great importance to the details of cone spectra, which determined just what could be encoded by animals. In other words, metamerism came to be much less important than thought. To give an example, human trichromatic receptors encode more than 90% of the variation of natural daylights and pigments, as demonstrated by factor (or principal components) analysis of daylight and natural surface reflectance spectra (Cohen, 1964; Maloney, 1986; Maloney & Wandell, 1986). In a way, this is true even though human cone spectra are far from ideal. In fact, L and M cone spectral sensitivities, being very close compared to those of M and S-cones and S-cones, hardly respond above 580 nm. However, since natural spectra and cone opsins are both broad-band, the exact tuning of the opsins to the creature's environment is not critical to survival. This fact does not deny the drift of the opsins towards the optimum for a particular niche, as with spectral shifting of cones in bottom-dwelling fish, or has it happens in various primates (Regan et al., 2001). All this is only to say that considerations about metamerism and spectral tuning may be relatively minor if compared to the overall role of color in the evolution of visual systems.

In this section, there will be highlighted some considerations beyond trichromacy that concern the role of color in perceptual organization with the hope that in future this research will also be expanded into the different animal visual systems. As a matter of fact, currently, the role of color in perceptual organization is only known to some extent as far as humans are concerned. However, since the human system is not so much different from that of other animals, for this reason, an evolutionary research on the field may be very interesting if it will be developed. As well as this, ecology underlines that color also contributes to perceptual organization in insects and in their co-evolving flowers. In order to better understand the role of color in perceptual organization, physical color must be distinguished from biological coloration. Biological coloration, in fact corresponds to the appearance of a living organism. It depends on the relative location of colored areas on an organism, in greater detail, it also depends on the quality and intensity of the light falling on it, on the shape, posture and movement of the organism which possesses this coloration and finally on the visual capabilities of the organism which is looking at it. As above defined, biological coloration concerns the way color and shape interact but it also regards how color affects perceptual organization. Furthermore, how these elements could vary over time, due to movement, could also be an important issue for further exploration, but it is not the topic here. The main object in this section is to highlight some of the biological and visual meanings of color also trying to provide some possible answers to the following questions in terms of perceptual organization: why are some animals so colorful? What are the adaptive and perceptual meanings of polychromatism? What is color for?

What is color for? Biological and visual meanings of color

In the animal kingdom, the ability to perceive colors, not just luminance, has evolved independently several times over the millennia. For example, dichromacy evolved 500 m years ago in vertebrates, (Nathans, Thomas, & Hogness, 1986). This means that there has been a high evolutionary neural investment but it also suggests that color vision surely has some fundamental and specialized functions, which provide biological advantages. But what are these advantages? What is color for? Why are animals so colorful? These questions have become a focus of recent research (Dresp & Langley, 2006, 2009, 2010; Chalupa & Werner 2003). Other interesting issues are the following: Why are fruits relatively narrow band? How is color organized in flowers and plants? What are the adaptive meanings of polychromatism? Indeed discrimination between objects and between objects and their backgrounds is of crucial importance in life, and this is clearly suggested by color vision (Regan et al., 2001). It seems that chromatic discrimination may have evolved first of all in vertebrates in shallow water environments to help other organisms to distinguish the variations in light level caused by ripples in water which determined variations in color but due to the presence of predators (Maximov, 2000). The term "visual understanding" includes both discrimination and perceptual organization. These are processes elaborated in lowland mid-level vision, while, for color memory, color "movies" as for example in the case of the movement of surface colors during predation, or as in object perception high-level processes may also be involved.

The great variety of colors in animals and plants highly suggests that coloration may play a very relevant and crucial role for their survival (De Valois, 2004; Endler, 1991; Poulton, 1890). Indeed, coloration is highly important for species identification, sexual dimorphism and sexual attraction within the same species. Coloration is also fundamental in spotting the presence of other individuals, in signaling that they are dangerous, poisonous or unpalatable, and they are also useful to show the strength and age of potential contenders.

However, in nature, there is often the case where animals instead of advertising their presence with warning colors, they want to use colors for cryptic camouflage and as a defense against predation. In fact, in the course of millennia they have evolved a very complex set of unobtrusive colors and patterns that allow them to blend with the environment. Flowers, for examples are brightly colored in order to attract the attention of insects and other organisms for their pollination and reproduction and simultaneously color is important, to hide themselves from pests. The use of color helps to increase the figural salience of the fruits within the surrounding leaves and vine-branches and it helps to reveal which fruit is ripe enough to be eaten (De Valois, 2004). The vision of insects could have developed to give visual understanding of shapes, parts, colors, etc., first of all because one insect wants to eat another, and surely wants to avoid being eaten, secondly, the insect needs to be able to detect complex patterns in flowers which are essential to satisfy their insect pollinators and perhaps they want to avoid bugs and pests that can destroy them. Evidence of visual understanding can be found in honey bees: Apis mellifera. These bees, respond to certain Gestalt properties such as radial, circular, and bilateral symmetry. In fact, they prefer symmetrical to asymmetrical flowers. The fact that bees can extract properties such as size and color from objects (Lotto & Wicklein, 2005) can be trained to break visual camouflage, and it can be even useful to learn to recognize human faces (Srinivasan, 2010). The term 'visual understanding' as it is used here does not necessarily mean either thought or visual learning, in fact, the circuits that mediate such complex behaviors may be innate and reflexive.

To sum up, color shows the biological fitness and the capability of an individual of a certain genotype to reproduce and propagate its genes to the next generation. To achieve these goals, color system uses reflectance information in order to code the presence, the position, and the figural properties of an individual, as well as it facilitates the ability to segregate, locate and organize the world into objects and parts. This implies that there are interesting visual meanings and organizational properties, promoted by the color system. More importantly, Pinna & Reeves (2013) in their work reduce the previous biological questions about color to an epistemologically lower level underlying the biological role of color. What is relevant is the sort of questions they want to answer, and precisely: is there a basic perceptual structure, on whose basis the main evolutionary functions occur? and if that is the case, what is the particular perceptual structure created by color? What is the visual organization induced by color that determines and favors the evolutionary and adaptive functions, and more, what is the evolutionary meaning of color? In trying to give an answer to these questions it will be possible to understand, at least in part, what functions the organism must have evolved. It is not, correct to think of the evolutionary meanings of color as epiphenomenal consequences of the underlying biology. As a matter of fact, the "epistemologically lower level underlying the biological one" is essentially functional. There are aspects of nature, which an informed visual system should know in order to function well, but a priori it is not possible to imply more than that. Considering that many color-form structures are fairly complex and multidimensional, for example many prey animals are spotted to help them escape from their predators. Besides, it is possible that even this weak restriction which is correlated to the underlying epistemology is likely to constrain evolution in many detailed ways. However for a full account, all levels of explanation must be included: functional, anatomical, ecological, and physiological.

To be perceived, or not to be perceived: that is the question

The answer to the question "what should be perceived" is highly related to three visual dilemmas that living beings must solve in order to survive. These dilemmas are favored by conditions that require a choice and their solution may provide the key to better understand the role of color in biological terms and in the vision field.

The first dilemma derives from the following question: all else being equal, is color used by living organism to be perceived, or not to be perceived? Pinna & Reeves (2013) suggest that as in the case of fruits and flowers, the dilemma does not exist. Indeed, in both cases the color is used first of all to be perceived. However, it can also be used to prevent detection by a predator. Under these conditions, the role of color is fundamental at determining the phenomenal wholeness and part–whole organization and consequently, it is essential to define the identity and oneness of these organisms and their parts. The dilemma regarding the to be or not to be perceived is a huge dilemma for a number of organisms, mostly animals, which need to be and not to be perceived at the same time. This is clearly the case of most animals which in some way "want" to be perceived by other individuals of the same species but at the same time, they do not want to be perceived by those other species, which can be potential predators. This dilemma is both a biological and a perceptual matter that needs to be visually solved. In the case of the Batesian mimicry, (Bates, 1861) in order to solve the dilemma the mimic shares chromatic signals with a model, but does not have the attribute that makes it unprofitable to predators. This is also the case of the Müllerian (Müller, 1879), which describes conditions where two or more species, sharing one or more common predators, have very similar warning or aposematic signals to put in act genuine anti-predation attributes.

A second dilemma is strictly connected to the part–whole organization. When an individual "wishes" to be perceived, does it have to be perceived as a whole or is it possible to be perceived as a set of parts? In the case of fruits, the answer is that it is good to be perceived as part of a plant or, as a whole, if the fruit is considered in itself. In the case of a flower it is best to be perceived as a set of nested parts which belong to a larger chromatic whole. As far as an animal is concerned the complexity of the part vs. whole dilemma tends to emerge more easily, above all when the biological purpose is sexual attraction. In fact, in this case, when several parts of the body of an organism are highlighted with brilliant and saturated colors or pop out because of special colored shapes such as horns, crest, etc. they serve for sexual functions. The dilemma in this case is related to the fact that the chromatic emergence of these parts tend to weaken or break the wholeness, giving too much visual importance to these parts to the detriment of the whole. So, this dilemma in nature is solved thanks to a part–whole organization, according to which the whole emerges as a result of the segregation of the parts and vice versa. Under these conditions, oneness and multiplicity are two complementary elements logically related and which reciprocally support each other. For example, this is the case of some kinds of flower, which double their floweriness through a part–whole organization, so that, each of them appears like a flower within a flower (see Fig. 1.11 in the next page). This synergistic reinforcement of the part–whole organization, in which parts and wholes are mutually determined, strongly tends to increase their visibility and conspicuousness.

Figure1.11. Oneness and multiplicity are mutually related in these flowers, which double their floweriness through a part–whole organization.

A third dilemma seems to suggest a paradoxical question. When an organism "does not want" to be perceived, how is it supposed to be perceived? Here are some possible means used: it could become invisible creating a misleading part–whole organization, or by becoming a mosaic of unconnected fragments, which do not create a wholeness. This device is called, part vs. fragment dilemma. Indeed, invisibility and misleading through part–whole organization are, respectively, the cases of cryptic and disruptive camouflage. The fish and the butterfly illustrated in Fig. 1.12 below show parts that are not natural parts, their function is to induce a clear misleading part–whole organization in order to deceive predators. It is useful to distinguish the typical disruptive camouflage used, for example, by African zebras, where the stripes disguise the form and shape of the animal, from the misleading part–whole organization of butterflies and fishes (Fig. 1.12). In the case of butterflies and fishes the aim is to discourage the predator to attack vital parts of the body of the animal so as to protect these parts to the detriment of others parts which are illusory and not so important for their survival. The reduction of the wholeness due to a mosaic-like chromatic fragmentation is a third possibility useful to disrupt, break up or parcel out the phenomenal wholeness in a different and in new way from disruptive camouflage. This fragmented camouflage re-establishes the "to be or not to be perceived" dilemma which is solved in a peculiar way by these species and it is also recognized by individuals of the same species. An example of fishes and butterflies showing parts that are not natural in their body are presented in the next page. These colored parts are especially useful to discourage predators.

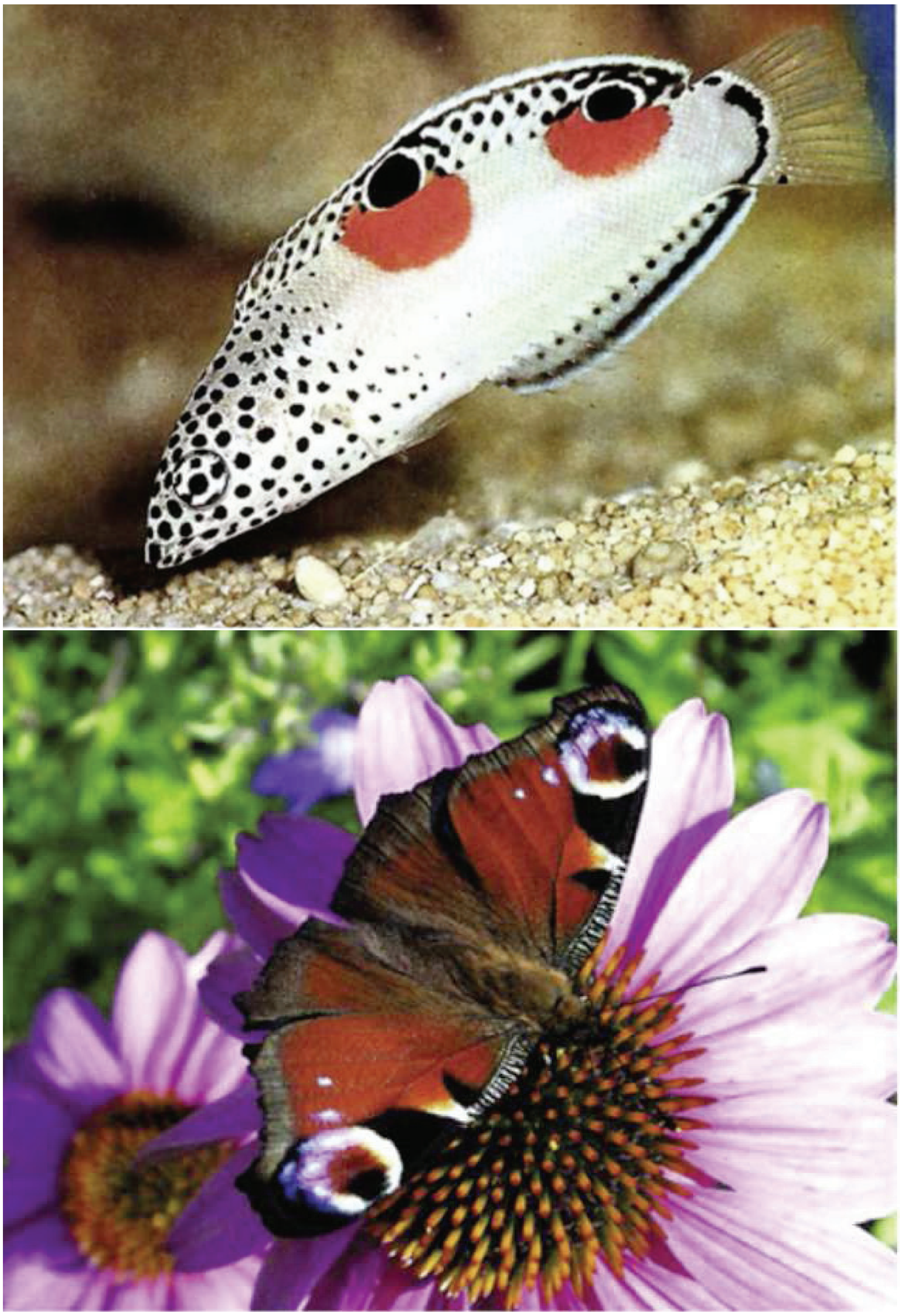


Figure 1.12. The fish and the butterfly show parts that are not natural parts thus inducing a clear misleading part–whole organization to deceive predators.

The coloration list to show wholes, parts and fragments

The three dilemmas highlighted in the previous paragraph are a set of complex interconnected alternatives which are not mutually exclusive one another. They are all present simultaneously and the solution of one dilemma brings a species to another dilemma. Pinna & Reeves (2013) assume that the solutions which generate in nature due to natural selection best respond to the three kinds of dilemmas which are simultaneously present and belong to a relatively stable ecological niche. According to these three dilemmas, the biological meaning of color is strictly related to the main purpose of color, which is that "to show". In fact, the purpose of coloration for a the living being is showing something either, the whole organism, part–whole organizations or fragments. If coloration is a tool to show, Pinna & Reeves (2013) have provided a list of things which are best candidates to be shown and these are the following: to show the whole, to show a part, to show some parts more clearly than others, to show something that would be otherwise invisible, to show parts that are not natural parts, to show fragments, to show in order to hide, to show to break, to split, etc. This list means that the visual foundations of the biological meaning of color, in more specific terms its visual keys, are based on three main terms strictly linked to the dilemmas and emerging as a consequence of perceptual organization. These main terms are: the whole, the parts and the fragments . At this stage, the question on how the dilemmas are solved by living beings, can be answered observing how the visual system solves the problem of perceptual organization and, consequently, how the formation of phenomenal wholeness, partition and fragmentation are used. Pinna & Reeves (2013) propose that this distinction can be useful and it is necessary to understand the evolution of color vision, to learn how color is used and perceived by different organisms and, finally it is fundamental to recognize how color brings extremely useful information stimulating strong interactions among different species as it happens, for example, in the case of interaction between flowers and insects.

Phenomenal wholeness, partition and fragmentation

In order to understand the role of color in perceptual organization, it is essential to define its contribution to the formation of the phenomenal wholeness. Wholeness is the core of perceptual organization. It can be defined by its main attributes which are: homogeneity, continuity, univocality, belongingness, and oneness. As a matter of fact, perceptual organization represents the key issue of vision science and it is related to the problem of why we perceive a world articulated in wholes such as people, animals, plants, flowers, objects, and so on. This problem was studied by the Gestalt Psychologists like Wertheimer, (1912a, b, 1922, 1923), by Ehrenstein (2008) by Spillmann & Ehrenstein (2004) in terms of grouping and by Rubin (1915, 1921) in terms of figure–ground segregation. The main questions they answered were, respectively, "how do individual elements group into parts that in their turn group into larger wholes separated from other wholes?" and also, "what does appear as a figure and what as a background". The well-known principles of grouping, such as proximity, similarity, good continuation, closure, convexity, exhaustiveness, symmetry, Prägnanz and past experience were studied by Wertheimer, whereas Rubin (1921) defined principles concerning figure–ground organization and in particular he studied surroundedness, size, orientation, contrast, symmetry, convexity, and parallelism. It needs to be stated that phenomenal wholeness is more than grouping and figure–ground segregation, in fact, it also includes the organization of other basic properties of an object. Pinna & Reeves (2006) studied and discovered the notion of "figurality" and some other principles which define the phenomenal appearance of what is perceived as a figure within the three-dimensional space and under a given illumination. Figurality is considered as part of a set of properties related to a visual object, which does not depend from grouping and figure–ground segregation principles, but it starts from them. These set of properties related to the visual object are the following: the color, the volume of the object with light and shaded regions, and the direction and the color of the light reflected by the object itself. Recently, Pinna (2010) and Pinna & Albertazzi (2011) claimed that each perceptual object has a shape which is related to other shapes that convey one or more meanings in relation to other shapes and meanings, thus, creating all together the complex perceptual shapes and meanings that constitute the complex world we perceive. When we perceive people, animals, plants, flowers and objects, we see at least four main sets or forms of organizations. These forms of organizations consist of: grouping/ figure–ground segregation, which are integrated in the same kind of form, then, in later stage, we perceive shape, figurality and meaning. Phenomenal wholeness naturally includes all these forms of perceptual organization. However, forms do not always play synergistically, but tend to create a long gradient going from the most integrated and uniform wholeness to the most scattered and fragmented mosaic crossing a way station that is the part–whole organization. The whole, the parts and the fragments are the three main steps of perceptual organization in which color plays a basic role. In addition, perceptual organization is closely related to scene segmentation and form perception as also pointed out by Li & Lennie (2001), who demonstrated how variations in color and brightness are used by the visual system to distinguish textured surfaces that are different in their first- or second-order statistics. Furthermore, Kingdom (2003) stressed the basic role for color vision in determining the three-dimensional structure of an image: the one that exploits the natural relationships that exists between color and luminance in the visual world. Within the whole, it is necessary to distinguish between parts and fragments. In fact, "parts" are the basic visible components of a whole. Their perceptual existence and properties depend on the whole and, consequently the whole depends on them. Also, angles/vertexes and sides of a square are parts. They can be perceived as something else within the phenomenal wholeness but they still are its basic components. To say more, "fragments" are not phenomenally distinct or segregated parts of a whole but they indeed are portions arbitrarily cut, broken or disunited pieces of the same whole. Examples of fragments are the chromatic markings and those patches typical of butterflies and birds as in the case of "Harlequin camouflage". Normally, fragments disintegrate, divide and split up the homogeneity, continuity, univocality, belongingness, and oneness of the whole. They do not create a strong illusion of multiplicity as it happens under the misleading part–whole organization of certain butterflies, but they weaken the phenomenal wholeness. Thanks to chromatic fragmentation a prey is supposed to gain enough time to run off and survive. Some examples of the Harlequin camouflage are shown in the next page (Figs. 1.13-1.14)

Figure 1.13. Examples of Harlequin camouflage.

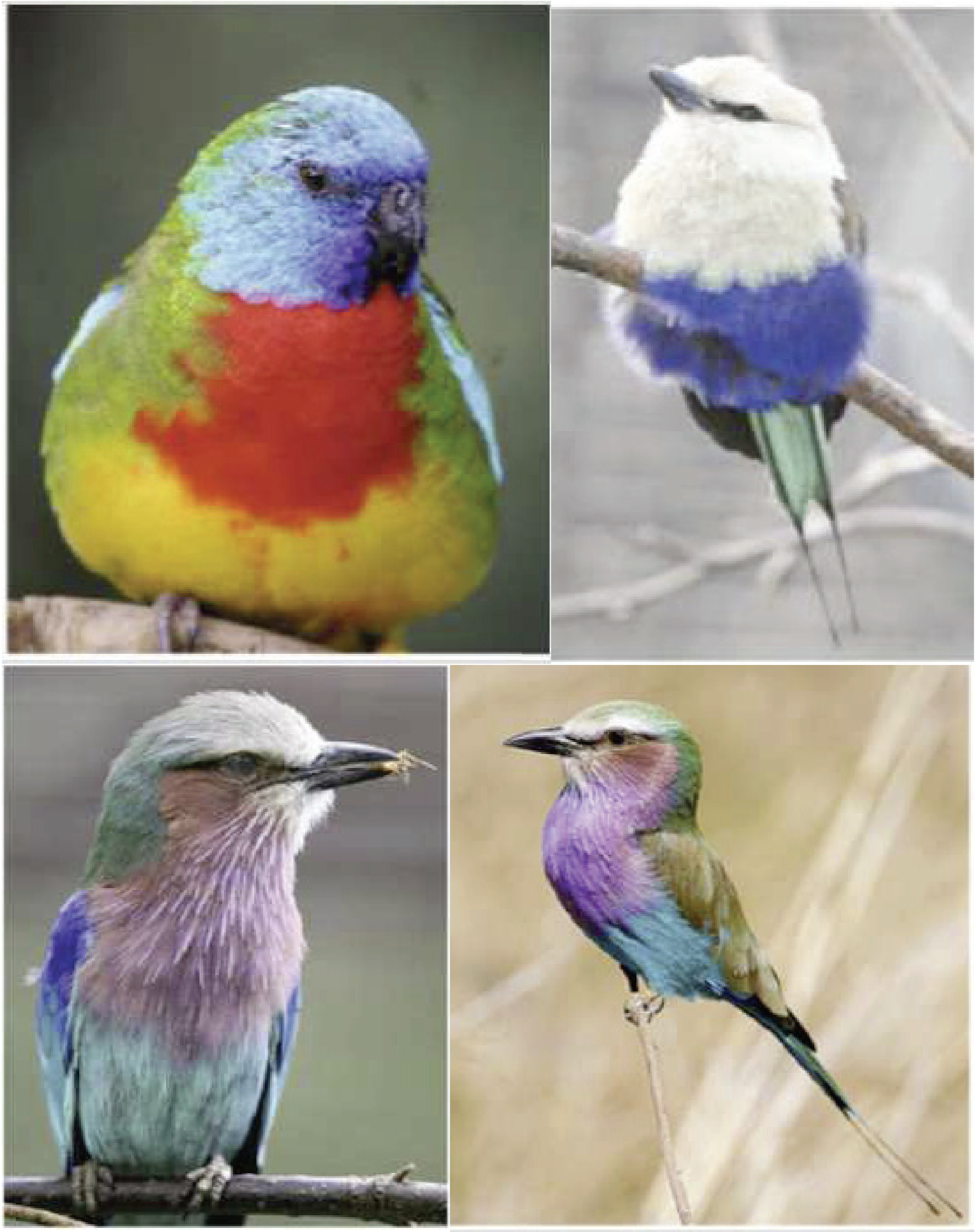


Figure 1.14. Examples of multicolor fragmentation and parcelling out.

Spatio-chromatic interactions

In primates, color vision has developed in such a way to receive a massive neural investment, which is considered independent of luminance system which is evolutionarily older if we compare it to color system. However, as it has been highlighted in the previous sections these evolutionary changes suggest that color vision has some crucial and specialized functions which promote some biological advantages.

Color and luminance are somehow usually correlated. However, It is not yet clear enough what the main role of color in spatial vision is and how it is related and interacts with the luminance system. In fact, they cannot be easily separated, although it is clear that the color system is especially programmed to absorb information about variations in reflectance that constitute further important attributes useful to segregate the visual world into different objects and components. The role of color in spatial vision and its distinctive traits as well as its emergent spatio-chromatic properties within visual scenes are soon visible comparing side-by-side the color photographs with the corresponding black-and-white ones (see Figs 1.15-1.24 b in the next pages) and the color-color photographs of Fig. 1.22.

The pictures, Figs 1.15-1.24 in the following pages show how color has special and unique advantages completely absent or weak when there is just luminance variations and not color. One of the most important roles of color system is the reflectance information used to code the presence, the position and the figural properties of objects which populate the visual world. More importantly, color system enables to segregate, locate and organize the world into objects and parts, and into lights and shades which are very important elements to model their volume and their illumination (Pinna 2016).

In Fig. 1.15 (above) shown in page 34, the difference in color of the various pumpkins enhance the presence, and the salience of the different species of pumpkins that in the achromatic photograph, Fig.1.15 (below) have nearly the same luminance and are not easily distinguishable in terms of species one another. The segregation based on shape similarity could be sufficient to induce a figural segregation, but color, indeed, strongly increases the figurality of each pumpkin.

A further example can be seen in Fig. 1.16 (above), where the circular shape of fruits is not sufficient to induce a clear object segregation. In Fig. 1.16 (below), on the contrary, not only does the color increase the figural salience of the fruits within the surrounding leaves and vine-branches, but also it reveals which one of them is ready to be eaten. Color variations permits a depth segregation between the segregated components.

The depth segregation of the flowers presented in Fig. 1.17 (above) is strongly enhanced if compared to those in the achromatic version below. In fact, color also promotes the emergence of the illumination and of the light reflected by the flowers. Both of these phenomenal properties in synergy contribute to increase the volumetric 3-D appearance and the figurality of the flowers that can be seen and distinguished at long distance.

The use of color clearly helps to define illumination as observable in Fig. 1.18 (above). Color also enhances the chromatic properties of the light reflected by the Nuraghe (Sardinian monument: Paleolithic tower-like building) and, consequently, it puts in evidence the right time of the day (late afternoon in this picture). What is worthwhile noting is that the chromatic Nuraghe appears much brighter and lighter than the cloudy sky. All the opposite qualities are true as far as the dark achromatic Nuraghe is concerned. Indeed color, also in the case of this picture, enhances the 3-D appearance.

The illumination and its properties, determined by colors, are even more clearly perceived in Fig. 1.19 (above). Here, the achromatic counterpart does not show any illumination, at least not in terms of richness of properties perceived in Fig. 1.19 (above). The color of the reflected light not only does it indicate the time but also it reveals the latitude of the region.

By employing color, it is also possible to make visible other complex and indirect objects like the seasons. In Fig. 1.20 (above), autumn, is easily recognized because of the color of the leaves, this information goes lost completely in the black and white picture.

Starting from these basic general advantages brought by color, Pinna (2006) highlights as follows. First of all, color aids to detect and identify things of interest like conspecifics (De Valois K., 2004) or other species, possible partners (Fig. 1.21), food, objects, preys or predators, etc. The opposite fact is also true. Some animals wish to hide themselves using colors (Figs. 1.22 above and below). In fact, they make use of camouflage by means of color in most cases. Also plants evolved the use of colors both to exhibit and to offer their flowers to some creatures as well as to hide themselves to some other creatures (Fig. 1.23). Mimicry is also a common device related to colors. In Batesian mimicry, a defenseless living being gains protection from predation by resembling mostly because of its colors to a harmful or poisonous organism. In Müllerian mimicry, again, two organisms derive protection from predation by tasting repellent, in fact, predators tend to avoid both mimics by tasting only one.

Color vision is also a special tool for conspecifics to discriminate and communicate. For example, color vision is surely used for signaling sexual receptivity or the gender or, as it happens in the case of humans, to communicate emotions, ideas, personality characteristics or civilizations as it can be perceived in Fig. 1.24. In the end, secondary cognitive processes also derive from the main properties of color perception and they are the following: colors tend to elicit encoding, retrieving from memory, color helps categorizing as well, and describing and attributing new and emergent phenomenal properties or meanings to objects, animals and perceptual scenes. It is proved that color perception reaches its maximum expression, meaning and application in human cognition beyond perception itself. All the abstract creations of human mind, going from science to art, make use of color as a basic element in conjunction and in relation to other visual properties which are figural and spatial organization, shape formation, figure-ground and depth segregation as highlighted by Wertheimer (1923).

Figure 1.15. Colors permit the perception of the presence, the salience, the position and the nature of different kind of objects and fruits.

Figure F1.16. Use of color makes the foraging for food easier: Achromatic fruits are almost invisible.

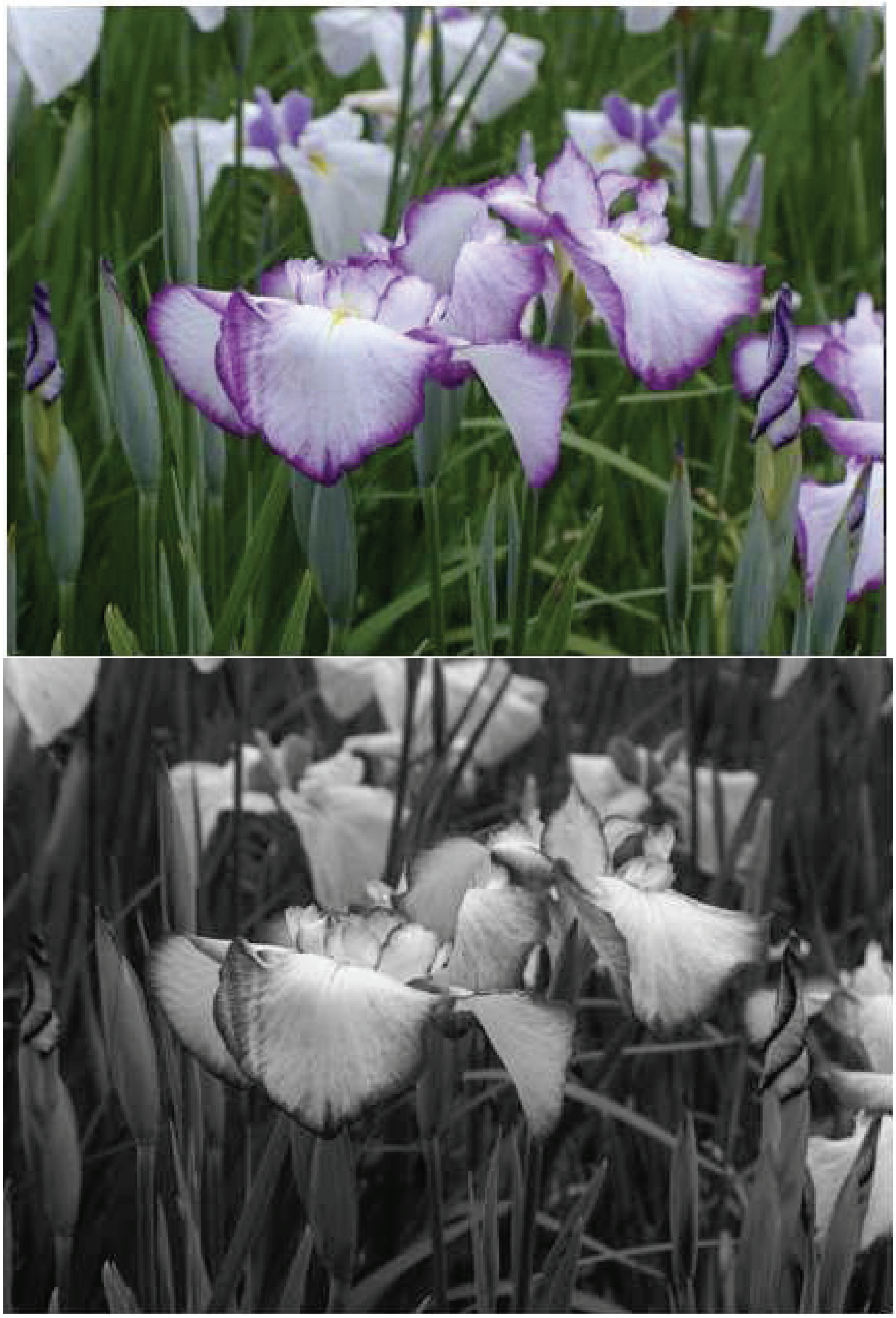


Figure1.17. Use of color strongly contributes to enhance the figurality, the illumination and the 3D appearance of flowers.

Figure 1.18. Color makes objects appear illuminated and brighter. Objects tend pop out due to the perceived illumination.

Figure I.19. Color defines the illumination, the light reflexes and their chromatic properties that, on their own, it also defines the time of the day, the weather, the season, etc.

Figure1.20. Color makes visible complex and indirect objects like autumn, otherwise completely invisible.

Figure1.21. Colors help in conspecifics discrimination and communication.

Figure 1.22. A grasshopper merges into the branches (above). A grasshopper and a cricket confront each other (below).

Figure 1.23. Colors use reflectance information and color contrast to determine the presence of objects otherwise almost invisible. Only some target animals or insects can easily perceive these flowers, others cannot.

Figure 1.24. Colors enable to define and to communicate human values, ideas, personality characteristics and/or civilizations.

In the previous paragraphs, phenomenal observations reported, confirm the largely accepted hypothesis that luminance and color systems are coded and processed on separated pathways (De Valois K., 2004). In general terms, our visual system depends on different and parallel pathways responsible for the ability to perceive different kinds of information. Vision is activated by the absorption of photons deriving from three different classes of cone (photopic vision) and one class of rods (scotopic vision). Color-opponency starts in the retina through cones which are sensitive to long (L), middle (M) and short (S) wavelengths of the visible spectrum and by superimposing excitatory (ON) and inhibitory (OFF) signals coming from different regions of the spectrum. An achromatic channel is generated by parasol cells, by summing their cone contributions. A red/green opponent axis is generated by midget ganglion cells that compare photon catches between L and M cones. A blue/yellow color axis generates with small and large bistratified cells that send ON signals from S cones and OFF signals from L+M cones (blue-ON receptive fields).

The three kinds of ganglion cells transmit their outputs to the LGN that is made of six layers. The upper four layers posses some small cell bodies and are innervated by the midget ganglion cells. These are called parvocellular layers. The lower two layers instead include large cell bodies where the parasol cells project. These are the called magnocellular layers. The bi-stratified cells project to the intercalated layers underneath the major layers of the LGN.

The three parallel pathways: magno-, parvo- and koniocellular, (Kaplan, 2004) project to V1, which is layer 4 of the striate visual cortex. Neurons in magnocellular layers project the achromatic signal from parasol cells in layer 4Cα of V1, whereas parvo neurons carry the red/green signal of midget cells to layer 4Cβ of V1. Furthermore, neurons in koniocellular layers, which may receive blue-ON input from small bistratified cells, project into the cytochrome oxidase-rich zones of the superficial layers, the CO "blobs". The properties of other ganglion neurons that project to the K layers of the LGN and from here to the primary visual cortex are not yet well known. From V1 the patterns of M-P-K signals are sent to the rest of the visual system again through parallel streams, each coding some portions of the neural image. The functional implications of these three pathways are the following: the M large cell bodies are responsible for perception of space, motion, spatial position, depth and they also convey information about achromatic luminance. On the other hand, color system strictly depends on a different pathway containing P small cell bodies, which are best developed in primates, and are also responsible for the ability to perceive and analyze form, as well as to recognize in greater detail objects and also faces. The K cells are also involved in some aspects of color perception. The M, P and K streams, in fact, provide inputs to two main visual pathways: the magno-dorsal stream which defines the so-called "where" system, while the parvo-ventral stream which defines the so called "what" system. (Pinna, 2006)

To conclude, together with some anatomical information concerning vision circuitry, the phenomenal observations reported in this section wish to highlight how colors not only represent basic information helpful to determine and perceive what a specific portion of the visual world is, but also they strongly influence where the perceived objects (3-D organization and illumination) are located and organized in space and time. According to Pinna (2006), the previous implications seem to support the hypothesis which considers object recognition and color perception, on one side, and motion, spatial position, depth and figure-ground segregation, on the other side. This believe is even strengthen for the fact that in general terms shape and color are coded by totally different and independent populations of neuron. However, by observing the previous figures here reported, it seems that the visual system and, more importantly, its particular phenomenal functions, as color perception, may be rather difficult to be associated to a unique and specific anatomical substrate pathway.

The principle of similarity

According to Gestalt psychologists, grouping and figure-ground segregation by color is not as effective as other attributes such as luminance, shape and motion, (Arnheim, 1997; Helson, 1947; Katz & Revesz, 1921; Koffka, 1935;Vicario, 1968).

If we look at Fig. 2.1a the local grouping of the small empty and filled squares appears in rows on the left and in columns on the right. This phenomenon is explained by the Gestalt principle of similarity which maintains that, all else being equal, the most similar elements in color, brightness, size, tend to be grouped together. In this specific condition, the fact of being empty and filled shapes, makes the squares be grouped together. In Fig.2.1b, the opposite direction given by the luminance contrast of the black and white squares on gray background is a powerful perceptual condition for grouping elements by similarity in rows and columns. Furthermore, in Figs. 2.1c and 2.1d, we can see how the equiluminant blue and orange colored squares (respectively either filled or empty) determine the dynamics of grouping. When we compare Figs. 1a-d, it can be noticed that figs.2.1a-b due to their luminance variation seem to enhance stronger grouping effects within the elements than the chromatic variations do in Figs. 2.1 c-d.

The fact that luminance prevails over color can be explained because luminance variations define objects and shapes and not colors. Moreover, the perception of an object is normally considered identical to the perception of its shape and not to the perception of its color, which is mainly considered as a secondary attribute.

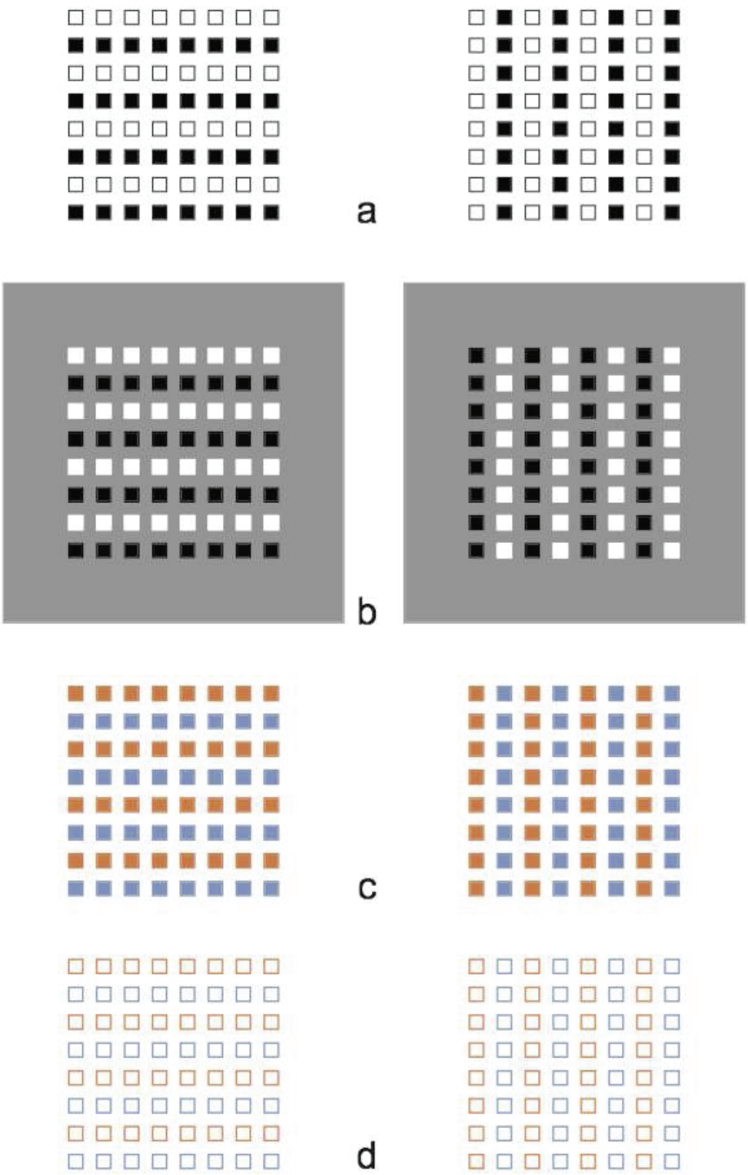


Figure 2.1. The local organization of the small squares is due to the Gestalt grouping principle of similarity.

General methods

Pinna & Deiana (2014), carried out several experiments in order to show how chromatic variations can determine visual meanings and organization properties. Through these experiments, it has been demonstrated how chromatic variation is effective for grouping and segregating a figure from its background and how it is relevant for organizing in parts or wholes in visual and cognitive domains. Color is indeed a powerful attribute to group and ungroup but it is also especially powerful to make an object/element emerge or disappear. In this study, I have replicated the experiments done by Pinna & Deiana duplicating the number of subjects involved in this last study. I wanted to replicate this study, firstly, to demonstrate the robustness of these data and of the phenomena reported, and second, to carry out further experiments with other subjects, normal readers and dyslexics.

Subjects

Participants to the experiments were several groups from the undergraduate courses of linguistics, from the the Department of Humanities and Social Sciences of the University of Sassari. In each group there were 30 subjects and all of these subjects completed each experiment described in the procedure section. Subjects had only some knowledge of the Gestalt psychology but they were completely unaware of the purpose of this research and of the phenomena studied. In the groups there were male and female and they all had normal or corrected to normal vision. They also showed normal color vision tested on the Ishihara test plates and on the Farnsworth-Munsell 100 hue color.

Stimuli

The stimuli were created using 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, 5600Åã K: Osram, Munich, Germany). All conditions were displayed in the frontoparallel plane at a distance of 50 cm from the observer.

Procedure

Two were the tasks proposed.

A phenomenological task. Participated in the phenomenological descriptions several groups of 30 undergraduate students. They were naive subjects and in order to avoid contaminations and interactions between them, they were given only one stimulus. The method used was a free method report and for a question of brevity, here in the analysis only the most representative data consisting of similar words or phrases are reported. At least 28 out of 30 free descriptions are always reported. The reports descriptions were fairly spontaneous and no limit of time was given to subjects to accomplish the task. During the experiment the students were free to see in different ways and to change their report. They could also receive from the experimenter questions or suggestions such as: What is the shape or organization of each element? What is the number of elements? All the variations highlighted by the subjects during the free exploration of the stimulus were noted down in order to observe any emerging phenomena.

A scaling task. Every group of subjects were asked to scale in percent the strength and salience of each stimulus.

The role of color in perceptual organization

In this section it will be shown several examples of the role of color in perceptual grouping. The examples will focussed on how the color can group and ungroup whole objects. If we consider Fig. 2.2a in the next page, we can see that a checkerboard is immediately perceived. What emerges here phenomenally is a whole object but with a regular pattern of black and white squares. What needs to be stated is the fact that every single square is an essential part of the checkerboard but it is the alternation of black and white checks and the oblique grouping of these same elements going from right to left that determine the clear identification of the object as a checkerboard.

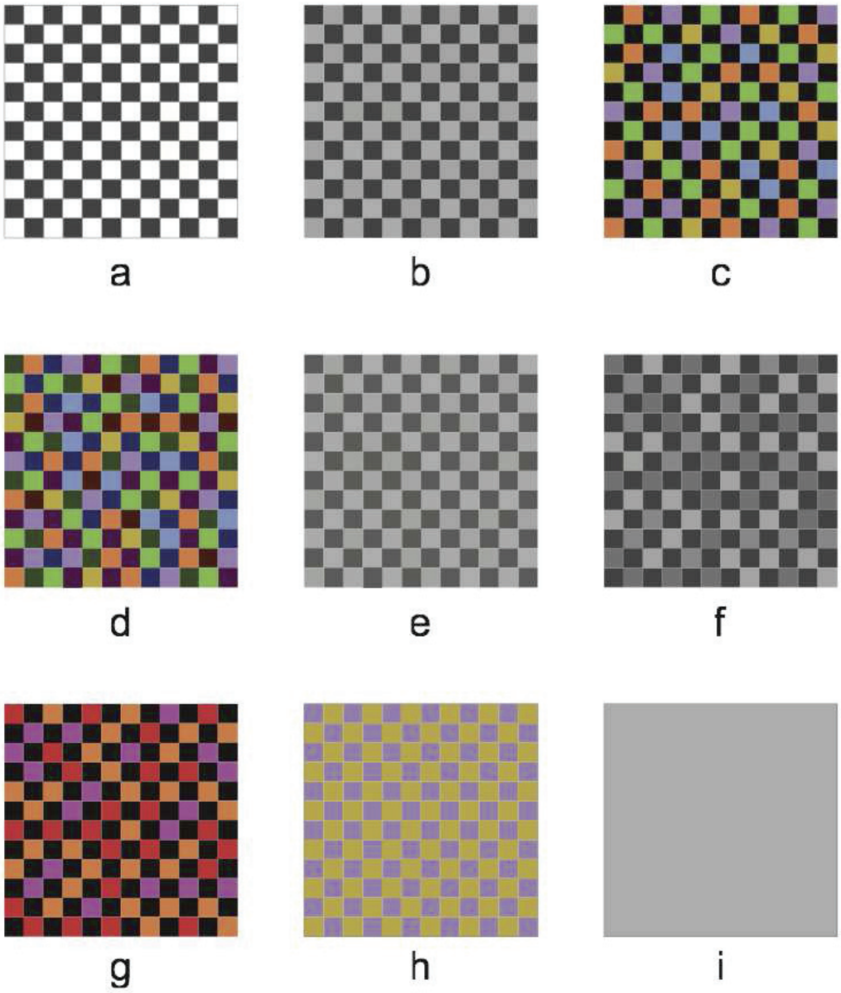


Figure 2.2. Examples of how color weakens or restores the Gestalt whole attribute of being a checkerboard.

The fact of being a checkerboard is also clearly perceived when the white checks are replaced with grey ones. On the contrary, when the gray checks are replaced with chromatic ones, although the black checks remain alternated and although the luminance contrast is kept constant, the perception of a checkerboard is weakened and destroyed, as shown in Fig. 2.2c. Also, when the black checks are replaced with checks of different colors even if the luminance is kept the same, as it happens in Fig. 2.2d, the perception of a check board is further weakened. Please see the control Fig. 2.2e to appreciate the phenomena. As observed in

Fig. 2.2f, the perception of the checkerboard is re-established thanks to the black and gray checks, while in Fig. 2.2g, the checkerboard is also clearly perceived by introducing an alternation of different shades of red and black squares. Also in Fig. 2.2h, due to the equilluminant and chromatically alternated checks, the perception of a checkerboard is restored Fig. 2.2i, all gray, is a control figure).

To sum up, Fig. 2.2 shows that color prevails over luminance and above all it demonstrates that color can strongly influence perceptual organization of the whole object, in this case the checkerboard, by ungrouping the squared patterns or by confusing and reorganizing a homogeneous distribution of the luminance of the checks.

The emergence of shape through color

Another important property of color is the fact that it helps the figure-ground segregation of single elements to emerge. In Fig. 2.3a several overlapped and all jammed stars are presented. Here, they appear extremely confusing and they cannot be easily counted though it is not impossible to do so. To improve the perception of the stars, another condition is shown in Fig. 2.3b. Here the black and white stars on a grey background permit a better segregation, each star is better isolated/segregated and the effect of confusion and crowd is reduced to such an extent that the stars can be easily counted. In order to improve the segregation of the stars even more, in Fig. 2.3c the stars are much better segregated and the effect of crowdedness and density is further reduced. Due to the chromatic dissimilarity of each star, every element is perceived as a single figure emerging from the background but it also tends to aggregate with other stars of similar color.

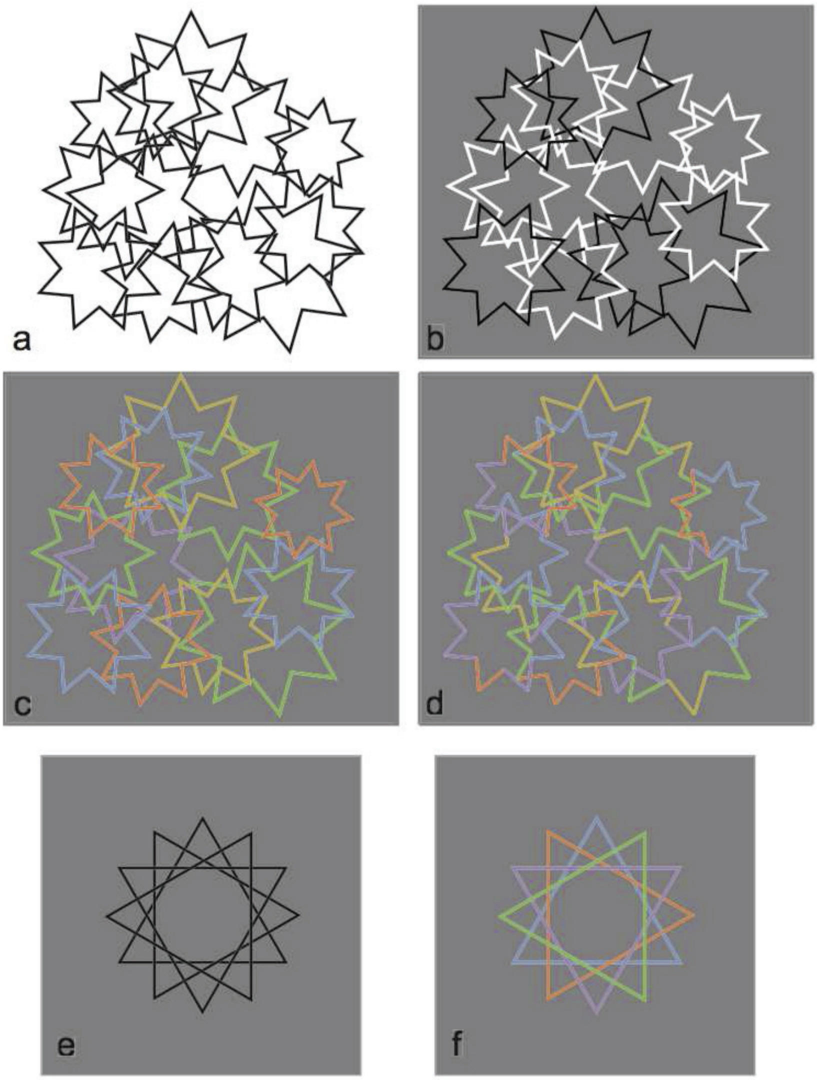


Figure 2.3. Stars and triangles segregated thanks to chromatic variations.

Another interesting phenomena occurring due to the different chromatic variation is the illusion of numerousness (Pinna & Deiana, 2014).This is, in fact, a phenomenon which consists of the apparent reduction in number of the stars. Due to this illusion the whole amount of the colored stars seems less in number than the stars presented in the control stimulus Fig. 2.3a). On the contrary, if colors among the same star are mixed, the effect is totally reversed and again crowdedness, density and confusion is again restored Fig. 2.3d). A further example of the illusion of numerousness is also given with Figs. 2.3e-f. As can be noticed, it is much easier to distinguish and count the 4 triangles in Fig. 2.3f than those in Fig. 2.3e which look to be many more in number and the whole figure tends to emerge as a unique star rather than 4 distinct triangles. What clearly emerges from these examples is that the multiplicity of colors, in a contest where crowdedness and intersecting objects are presented, more than luminance contrast alone (Fig. 2.3a) and more than the opposite direction of contrast (Fig. 2.3b), are more efficacy to create new forms of organizations.

The bulging wholeness and the emergence of an object by means of color

The figure below (Figs. 2.4a-b-c) is a another example of the role of color to help segregate objects and wholes.

In fig. 2.4a color segregates patches similar to islands recalling the cards of the Rorschach test. Such patches are called "Mooney face". In Fig. 2.4a the Mooney face is not clearly perceived due to the fact that blobs are in different colors (Andrews & Schluppeck, 2004; Dolan et al., 1997). In this figure all parts colored with the same color tend to emerge and segregate as wholes. When the whole picture is all in gray color as it appears in fig. 2.4b, the single blobs group together and what is perceived is an unknown figure. On the other hand, when the color groups smaller surfaces than the whole, 3 different male face are perceived. They are the same faces of figure 4a but now, thanks to the chromatic variation, these faces emerge very clearly.

In the case of these last Figs. 2.4 a-b-c, it is not only the similar color of the patches which groups together that help to define the faces, but a relevant role is also played by the past experience and by the pareidolia or high sensitivity to faces. Furthermore, it needs to be pointed out that, the bulging of a face, both made of bright and dark patches, or made of colored ones, in order to be recognized as a face, needs the inclusion of the white surrounding or background to complete the image.

At this stage, I would like to highlight a new kind of organization process referred to as "bulging wholeness" (Pinna & Deiana, 2014). In order to understand this phenomenon, let us compare Fig. 2.1 with Fig. 2.5a. Fig. 2.1 presents a situation in which single elements group together, nevertheless they keep their individuality and separation from the other elements while, in fact, under this condition, the white and gray background is only a background, it is inactive, independent and it just plays a complementary role.

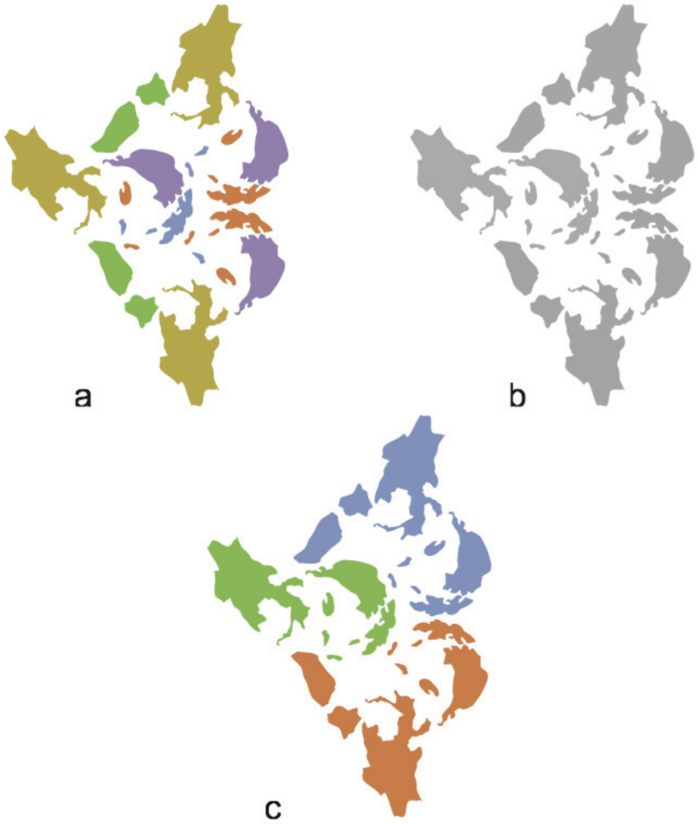


Figure 2.4. (a) Color highlights single surfaces similar to patches reminiscent to cards of the Rorschach project test (b-c) Male faces.

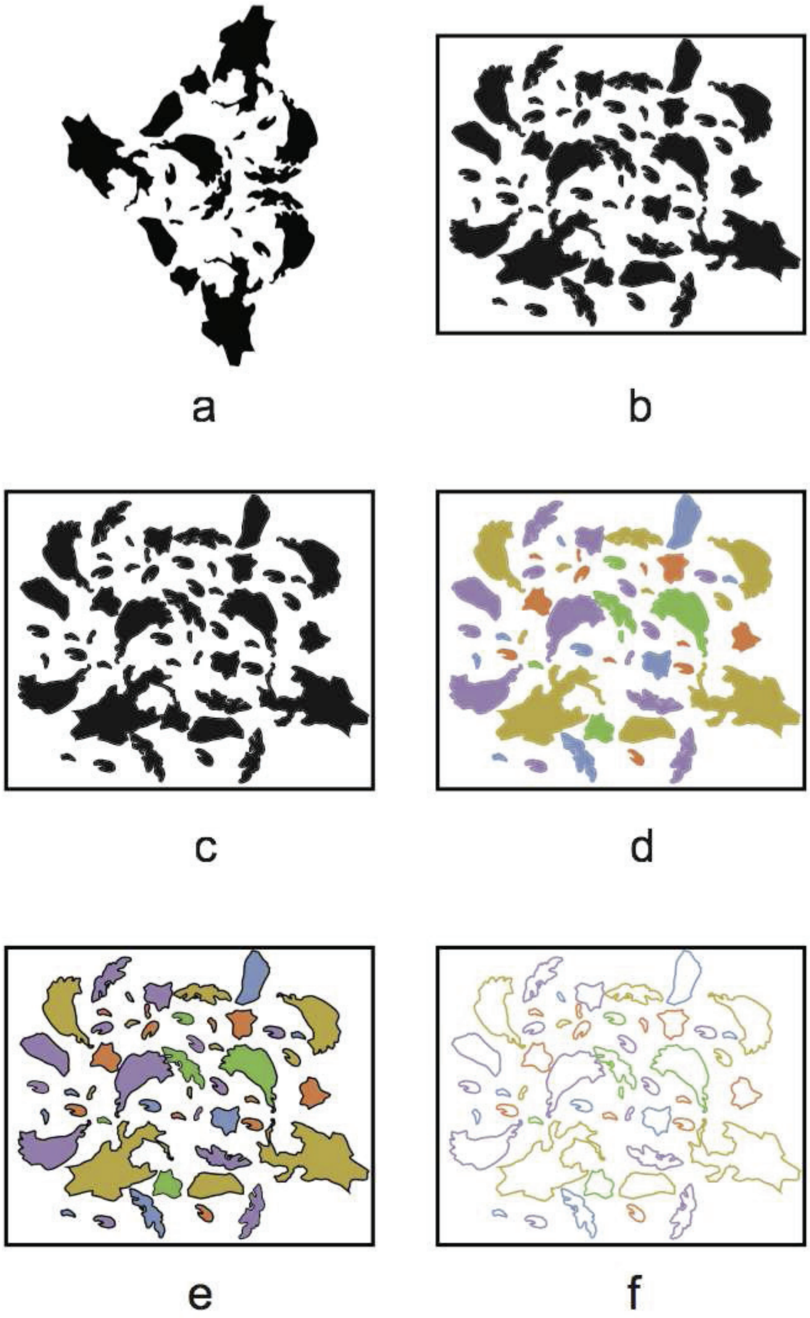


Figure 2.5. The bulging wholeness of faces and volumetric objects parceled out by the chromatic dissimilarity.

The bulging wholeness and the figure-ground segregation are two distinctive concepts, although they are somehow related. As can be noticed, the patches which compose the face segregate clearly from the white background but at the same time, the white background becomes part of the face and it does not appear as a background anymore. In fact, it results as an essential part of the face, which is made of dark and white components. The background is indeed integrated to the face and it is an essential part for its recognition as such. This new formation and organization is not at all illusory. (Fig. 2. 5a)

According to Gregory, (1972, 1987) objects are some kind of unconscious inferences. They derive from inductive conclusions, similar to those used for the formation of scientific hypothesis. It is a top-down cognitive hypothesis similar to that occurring in the Kanisza's triangle when completing the missing sectors of the disks and the missing parts of the outline triangle (Pinna, 2012a, 2012b, 2012c, 2012d; Pinna, Ehrenstein, & Spillmann, 2004). A similar process occurs in the recognition of the male face. It is in fact a top-down cognitive hypothesis and it is important to explain the patches which, could be seen as the volumetric parts of the face, as if the face were exposed under bright light. Gregory's object hypothesis, is also based on Helmholtz's and it is related to the Bayesian statistical decision theory, which refers to the idea of perception as inference (Feldman, 2000; Landy, Maloney, Johnston, & Young, 1995; Mamassian & Landy, 1998; Nakayama & Shimojo, 1992; Weiss & Adelson, 1998).

These theoretical object hypothesis, based on the role of past experience, though interesting are not exhaustive and sufficient to explain the bulging wholeness. In fact, in Fig. 2.5b, it is not only the face which emerges very clearly but also the surrounding components tend to emerge as unknown bulging wholeness, while the central face appears quite distorted. In brief, the surrounding components also emerge and appear as volumetric objects and as distorted and broken faces. (Figs. 2.5 b-c)

As a matter of fact, the black surfaces of Figs. 2.5b-c do not look as flat surfaces, they do not segregate from the empty background but they seem to emerge as a three-dimensional object in relief. However, at this stage a question arise spontaneously and it is the following: Can color influence the bulging wholeness? What happens in Fig. 2.5d is the the result of the chromatic dissimilarity among patches which tends to weaken and parcels out the bulging wholeness. The figure is even further weakened in Figs. 2.5e-f where by highlighting the boundary contours, the segregation effect and the peculiarity of each element is put in relief. In brief, it can be stated that color not only does it influence grouping but also it affects bulging wholeness.

Implicit shapes are made explicit by means of colors

We have seen that the previous results demonstrate how color can influence the grouping and the bulging wholeness. Here, Fig. 2.6 shows that the shape of a visual object can be determined by its color. Differently, in Fig. 2.1, we could see that the chromatic similarity tends to group separated squares and determines the shape of the grouping, i.e. in rows or in columns. Under these conditions, the similarity is the only factor playing all else being equal. On the contrary, in Fig. 2.6, the chromatic similarity is pitted against good continuation, closure, symmetry and Prägnanz principles.

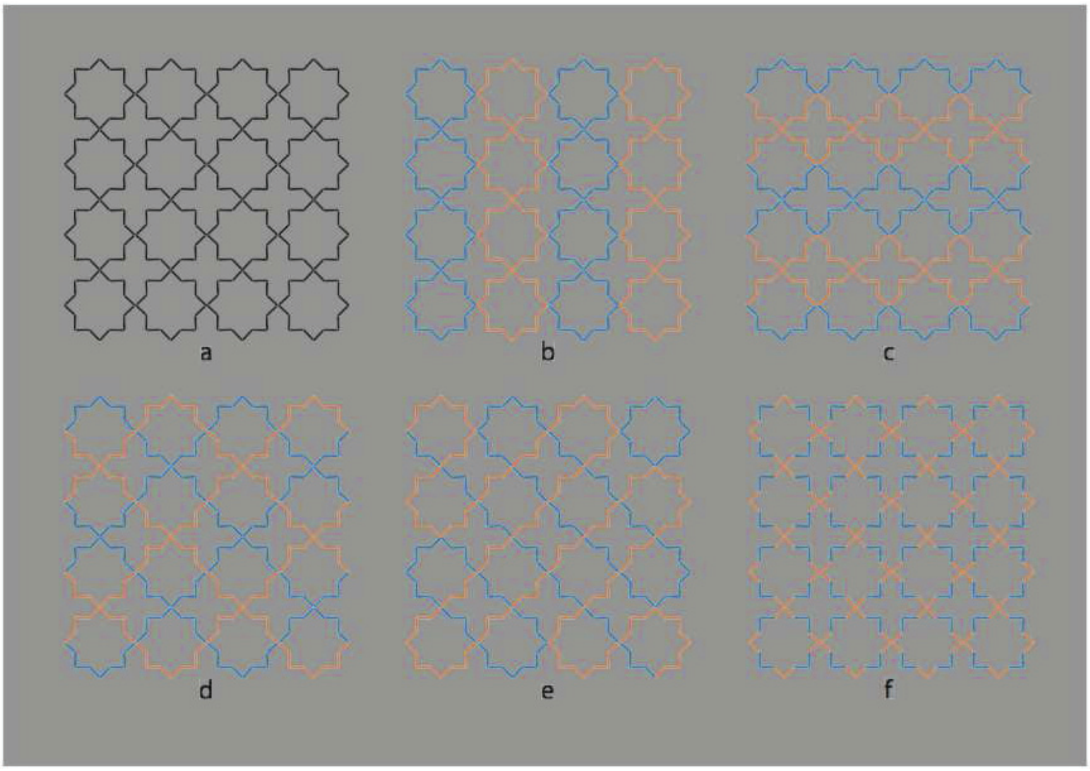


Figure 2.6. In line with the principle of chromatic similarity/dissimilarity the same pattern of stimuli can be grouped, ungrouped and reshaped in different ways.

In Fig. 2.6a, eight-pointed stars and crosses can be alternately and reversibly observed. When the stars are perceived the crosses are invisible and vice versa. According to Rubin (1921), this can happen because of the unilateral belongingness of the boundaries. A further possible result that can be observed is the tessellation of stars and crosses although this result is not as strong as the alternation of the stars or crosses. In Figs. 2.6b-c only the stars (Fig. 2.6b) or the crosses (Fig. 2.6c) emerge while respectively, the crosses and stars become invisible. This is due to the chromatic similarity. In Figs. 2.6d-e, new shapes are now created. They are generated only by their boundary contours and they appear reciprocally intersecting. In Fig. 2.6f, regrouping the same pattern of segments by chromatic similarity, blue squares overlapping an orange lattice of oblique parallel and orthogonal lines amodally completing behind the white squares are perceived. To conclude, using the same principle of chromatic similarity/dissimilarity the grouping of segments and shape formation tends to be ungrouped and reshaped.

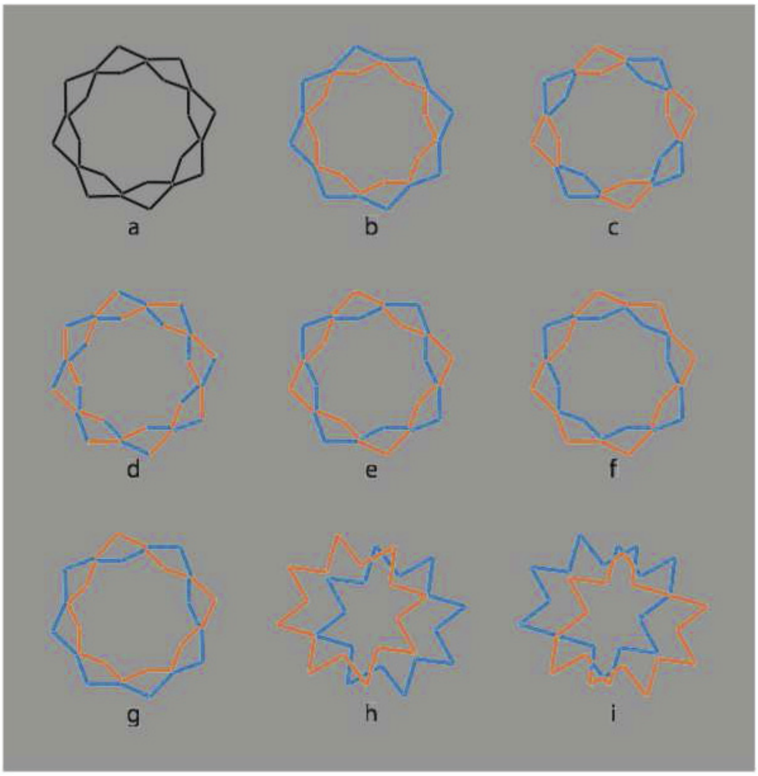


Figure 2.7. The chromatic similarity enhances new shapes and plays the main grouping role winning against the principles of good continuation, symmetry and Prägnanz.

The results of Fig. 2.6 shows that many possible shapes within one stimulus pattern can be generated and made phenomenal through chromatic variations. In addition, the results of Fig. 2.7 confirm this statement. Fig. 2.7a is the control condition, where two eight-pointed stars, one inset into the other are mostly or uniquely perceived, even though this pattern may contain a very high number of other potential implicit shapes. These previous results are corroborated in Fig. 2.7b, by means of the chromatic dissimilarity of the two stars that does not allow other implicit shapes to emerge. In Fig. 2.7c, if the distribution of equiluminant colors are changed, the stars become implicit and a chain or two kinds of rotated and intersected square-like shapes, with four closed quadrangular shapes on their vertices, clearly pop out. In Fig. 2.7d, two intertwined and spiraled star-like shapes having equal size, are now segmented from colors. In addition, by changing the colors within the same pattern of segments, the two stars of Fig. 2.7a disappear and what emerges here are respectively two wavy quadrangular shapes overlapped as in Fig. 2.7e, two different symmetrical novel shapes, Fig. 2.7f and two overlapped irregular objects, Fig. 2.7g. In the end, irregular shapes can also be generated playing with the equiluminant colors of the overlapped stars of Fig. 2.7h, as it appears illustrated in Fig. 2.7i. Under the conditions shown in Fig. 2.7, the chromatic similarity enhances new shapes and plays the main grouping role winning against the principles of good continuation, symmetry and Prägnanz. These results demonstrate that different shapes within the same pattern of segments can emerge by means of colors according to the following general statement: the emergence of one shape makes invisible or visible only partially the perception of other possible shapes that are inside the same pattern of stimuli. In fact, the notion of shape can be phenomenally described as if it were a whole visual "holder" that may contain other sets of phenomenal possible shapes placed along a visual gradient of perceptibility. According to this concept, what is invisible at a first sight can become visible with a phenomenological exploration, due to the action triggered by new principles or thanks to the psychophysical action of pushing and pulling one principle against the another. Therefore, the set of possible 'things', located in the gradient of perceptibility, may become more and more visible or invisible.

Within the gradient of perceptibility a push and pull phenomenal action which has been typically used by living organism evolutionally to adapt their appearance affecting their shape and color attributes because of the selective pressure. In fact, all complex living organisms both animals and plants play with visual attributes, these are diematic and chromatic patterns. For example, the presence of diematic patterns is typical of butterflies and moths. Diematic pattern, have a design which simulate the eyes of monkeys and raptors. These diematic patterns are normally located along the wings of the insects, for this reason, they are essential strategic and defensive tools useful to help better guarantee the survival of certain species. Precisely, the diematic defense can be consider 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 to make it escape. Moreover, ocelli play as an effective deterrent for starling and frightening potential predators and more they are fundamental to make implicit some vital parts of the body of an insect/ animal. This may be the case of butterflies, where the presence of a false eye is quite common, in fact, toward their wings borders, it is possible to observe diematic patterns with chunks, pecked out by birds. Indeed, the ocelli work as an attractor useful to avoid the predator's attack or to divert it to a non-vital area, such as the wings, which are not so vital part in the body if damaged because of an assault Pinna & Deiana, 2014).

Shapes from color

If the shape is considered like a holder, then, the inner possible shapes, placed all along the gradient of visibility, emerge by making explicit/implicit different shape attributes. Some of those attributes are, the horizontal/vertical axes, the gravitational orientation, the configural orientation and the large reference frame which elicits many different well-known phenomena like the square/diamond illusion (Mach, 1914, 1959; Schumann, 1900), the configural orientation effect studied by Attneave (1968; Palmer, 1980, 1989; Palmer & Bucher, 1981), the Kopfermann's effect (Kopfermann, 1930), the finally rectangle illusion (Pinna, 2010b).

Still inside the hypothesis of the shape like a holder, colors can change a shape by accentuating one or another shape attribute. In Fig. 2.8a, a regular octagon is perceived with the vertices oriented along the main directions of space (vertical and horizontal). If chromatic discontinuities are introduced on the vertices placed along the vertical axes of the polygon, as can be seen in Fig. 2.8b, the same regular octagon of Fig. 2.8a is seen. However, if placing the same chromatic discontinuities in the middle of the two opposite sides placed along the oblique axes, as it appear in Fig. 2.8c, the polygon now is similar to the octagon of Fig. 2.8d with the sides oriented along the main directions of space.

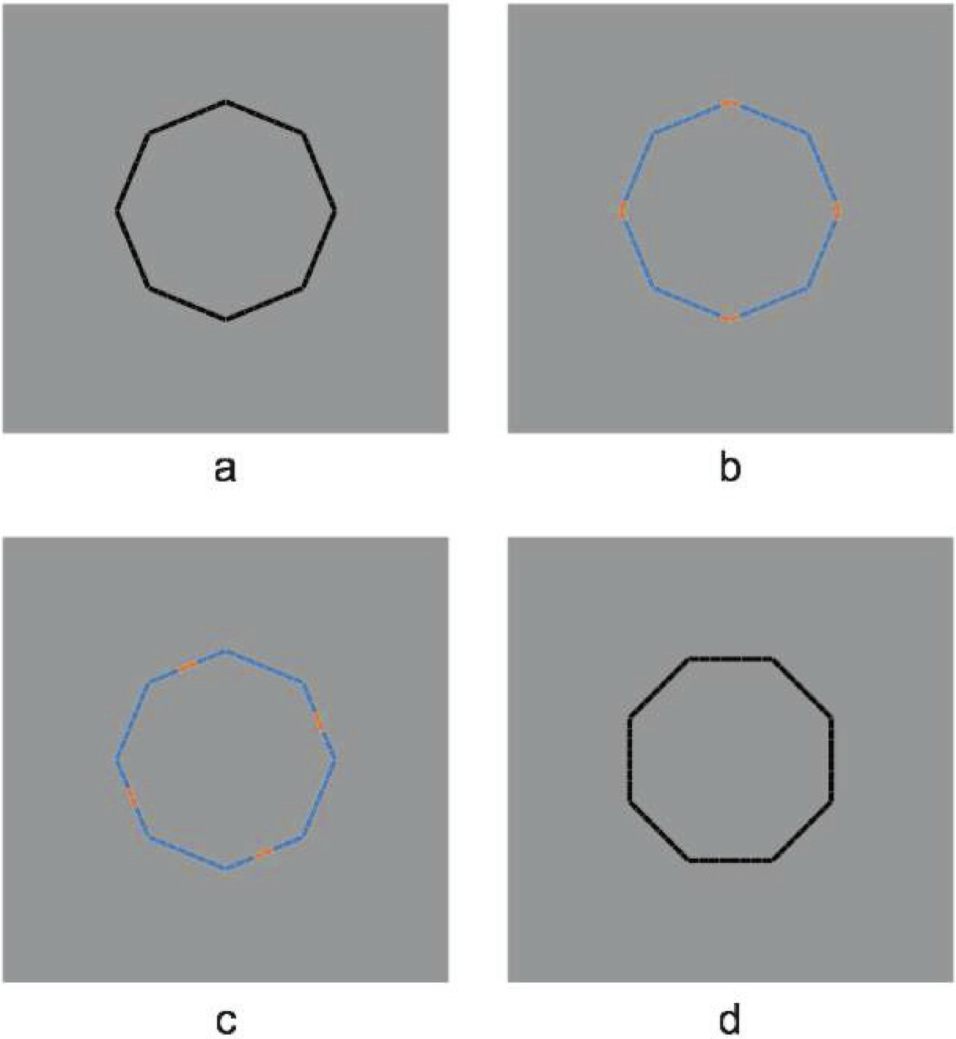


Figure 2.8. The chromatic discontinuities placed on the polygons work like accents on shape attributes, like angles and sides, that induce the emergence of two different polygons, one pointed and the other flatter.

Although the chromatic discontinuities, the wholeness of the polygons of Figs. 2.8b-c are not at all perceived as broken. This is mainly due to the fact that the good continuation principle, oriented only along the boundaries of the octagon tends to maintain the whole shape grouped and unique. Phenomenally, the chromatic discontinuities of Figs. 2.8b and 2.8c, placed on the vertices, angles and sides, enhance and accentuate both geometrically and phenomenally different locations within the direction of space. Furthermore, they also contribute to accentuate different components such as 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 work like accents which induce 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, in fact, the accentuated pointedness and sidedness create respectively two different polygons, one pointed and the other flatter.

As a result, some other effects emerge. In Figs. 2.8a-d and 2.8b-c it can be perceived clearly the illusion of numerousness. In fact, at a first sight, the octagons of Figs. 2.8a-b seem as if they have a higher number of points than the octagons of Figs. 2.8c-d. The opposite is also true if we consider the numerousness of sides. In addition, the vertical/horizontal orientation of the polygon of Fig. 2.8c looks illusory tilted in the opposite direction of the oblique orientation of the chromatic discontinuities.

In greater detail, the orientation of the polygon, geometrically equal to the one of Figs. 2.8a-b, is perceived illusorily tilted more clockwise and beyond the main directions of space (vertical and horizontal). This result could be even better appreciated if we compare the orientation of Fig. 2.8c with the ones of Figs. 2.8a and 2.8b. The notion of shape from color is even clearer in the conditions illustrated in Fig. 2.9. In fig. 2.9 the chromatic dissimilarities break the oneness and the unitariness of the eight-pointed star of Fig. 2.9a. As can be noticed, those chromatic dissimilarities even change the figure's shape. As a matter of fact, chromatic dissimilarities make the shape appear respectively like a concave polygonal rather than a star as in Fig. 2.9b, or make it appear like two rotated and perpendicular square shapes as in Fig. 2.9c, or make it more like a regular and asymmetrical shape different from the star in the next conditions (Figs. 2.9d-f).

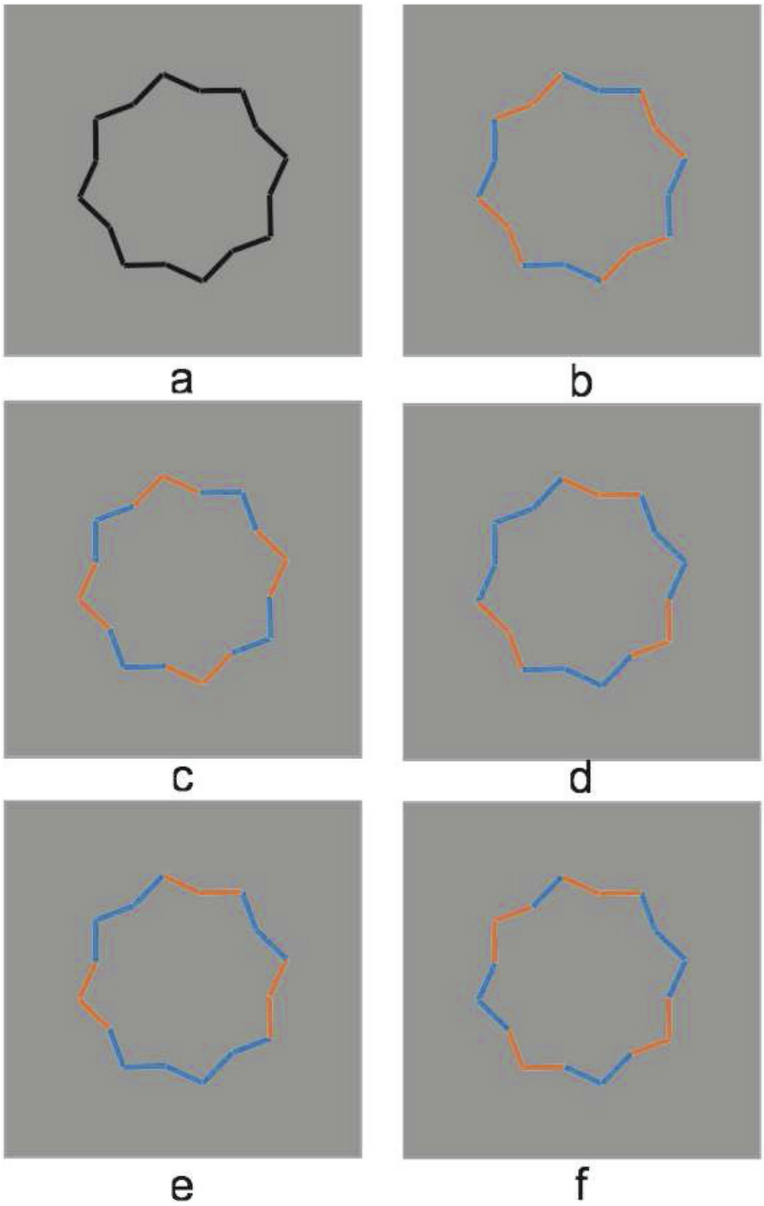


Figure 2.9. Examples of how the chromatic dissimilarities break the oneness, the unitariness, the shape and the symmetry of the same geometrical eight pointed star.

According to these results not only is color implicated in perceptual grouping as the other Gestalt principles but also it is involved in shape formation and, more in details, in the segmentation, partition and accentuation of its figural attributes. As matter of fact, a better understanding of the role of color in perceptual organization can elucidate the perceptual complexity of the notion of shape that, as Pinna (2012a, 2012d) suggested is like a holder full of figural attributes which defines the perceptual meaning of shape.

In the above section it has been shown with different examples how color is not simply a marginal attribute. In fact, it has been suggested by phylogenetic and paleontological evidences that the ability to perceive colors has existed for more than half a billion years and this means that there has been a high evolutionary neural investment and that specialized functions have also evolved to promote biological advantages such as using information to identify the presence the position and other figural properties of an object or animal. Furthermore, color helps to improve the biological ability to segregate, locate an object as well as organize the world into wholes and parts. (Pinna, 2010; Pinna & Reeves, 2013; Pinna, Uccula, & Tanca, 2010b). Indeed biological advantages in nature are determined more by chromatic variations and are independent from luminance properties.

The role of color in cognitive organization

Making the visible invisible and invisible visible by means of color

Let us consider here a few examples of the advantages and importance of color in biology. First of all, color accentuates the figural properties of a living being and tends to highlight or hide certain vital parts of an organism. In addition, by means of color we can perceive wholes, segments and parts. Color is indeed fundamental to determine different kinds of camouflages. Cryptic camouflage (Beddard, 1895; Cott, 1940; Edmunds, 1974; Endler, 1978, 1991) is a form of disguise, a defense device, concerning both shape and color. In addition, it helps an organism to avoid detection and predation by assimilating itself almost completely within the natural environment around so as to become invisible. Cryptic camouflage is essentially based on chromatic variations occurring on the body of the animal and making the animal hard or even impossible to be seen by other living beings. Disruptive camouflage (Cott, 1940; Cuthill et al., 2005; Merilaita, 1998) is another sort of camouflage which differently from the cryptic one, thanks to its high contrasted and eye-catching colorations and markings of stripes and patches disguise the whole shape. This is the case of zebras, leopards and giraffes. So, if with cryptic camouflage what is visible becomes invisible, on the contrary, with disruptive camouflage, what is invisible becomes visible by means of contrasts boundaries and colors (Pinna & Deiana, 2014).

There is another interesting camouflage, which is purely chromatic, this is the Harlequin camouflage (Pinna, 2010b; Pinna & Reeves, 2013). This last camouflage, differently from the others previously described, works by breaking up and parcelling out the chromatic oneness and uniqueness of the whole organism imparting a sort of chromatic rhythm (Fig. 2.10). We are talking here about rhythm as if we were in music, because of the constant repetition of regular and irregular parts, that similarly to music with strong and weak beats, (Pinna & Sirigu, 2011) determine the creation of the whole object or symphony. Rhythm imparted by color is different from the one imposed by shape and its boundary contours. For example, the disruptive colors of the male Mandarin duck break the continuation of edges and tend to parcel out the wholeness of the body of the animal. This brings the male duck two biological advantages. The first is the possibility for the male Mandarin duck to make himself very visible to the females of its species for reproduction, and, at the same time, this disruptive plumage is also a good device to make himself not visible to potential predators by means of the parcelling out due to chromatic variations. Furthermore, in nature and biology there is always the issue of sexual attraction, this is the reason why some parts of the body having sexual functions are highlighted with very brilliant and saturated colors: this is the case of specially colored shapes like horns and crests.

Indeed, thanks to color, which in nature largely contributes to the emergence of wholes, or eventually weakens and parcels out the wholes, living beings adapt to the environment, preserve a high adaptive fitness, save their lives and guarantee the survival of their species. However, this division between wholes and parts, oneness and multiplicity creates in nature a sort of dilemma. This is due to the chromatic emergence of parts which breaks the wholeness but at the same time helps to maintain a vital equilibrium in the natural world. So, this equilibrium between wholes and parts, created by color is another effective mean which makes wholes and part-wholes fragmentations be seen as complementary and absolutely essential one another.

A similar dilemma is also present in color vision, where the issue of color and shape is often discussed. Color belongs to a shape and it is subjected to it. To make this concept clearer, an example from the natural use of adjectives in English language will be used. People say "a red square" not a " square red" which sounds strange and incorrect. (Pinna 2012a, 2012b). It can be noticed that color is subjected to shape but at the same time it qualifies shape without affecting shape negatively but rather giving it a multitude of possible other shades without hiding it or making it invisible. This means that color is a figural attribute and tends to preserve an equilibrium between the concept of oneness and multitude in linguistics as well as in nature.

This can be well noticed, for example, in the spontaneous way of using colors, as shown in fig. 2.11, in which highlighting different countries in different colors within the map of Europe surely enhance the emerging wholeness of each country among the multiplicity of countries. In addition, when introducing boundary contours among the countries, the perception of the multiplicity is even strengthened to the detriment of the oneness, similarly to what is observed in Fig. 2.5e. These findings highlight that chromatic rhythm phenomenally tends to induce some kind of spatial movement or sets of changes marked by some kind of regulated succession of more or less strong regions or beats (Pinna & Sirigu, 2011). In fact, chromatic rhythm segments, groups and parcels out in subsets regions of space otherwise invisible or visible in different ways. In addition, the complementation, similarity and dissimilarity of color is the best requisite to reorganize the visual world, to provide camouflage or implicitness of several sequences of elements or phrases and to accentuate or make visible and explicit other phrases or parts. This mechanism is very similar to what everybody spontaneously does by using highlighters of different colors in order to draw attention to certain sections of a text. In this way, certain parts emerge immediately as relevant bits. In fact, both with a highlighter or in the case of fruits and flowers, color is used to attract attention and to highlight exactly a portion or a part within a whole (part-whole segregation). In brief, considering that the process of chromatic highlighting is very effective, very common in nature and with a very high adaptive fitness, it is legitimate to suppose that the role of color in perceptual organization is much more effective than the one affirmed by other Gestalt principles.

To conclude this section, only a few examples of the strength of color and its fundamental role, above all in biology, have been presented. In fact, we have seen how chromatic variations are especially effective to hide, show wholes and part-wholes. This is why it should be important to demonstrate that the role of color in perceptual organization can not simply be the one stated by the Gestalt principles, but a more salient role can be attributed to color. This is why, in the next section, the metaphor of the highlighter is directly applied for the understanding of the role of color in inducing a rhythm in perceptual organization and in particular, it will be studied the way in which color can influence the reading process when pitted against other Gestalt principles of grouping.

Figure 2.10. Example of Harlequin Camouflage, the male Mandarin duck.

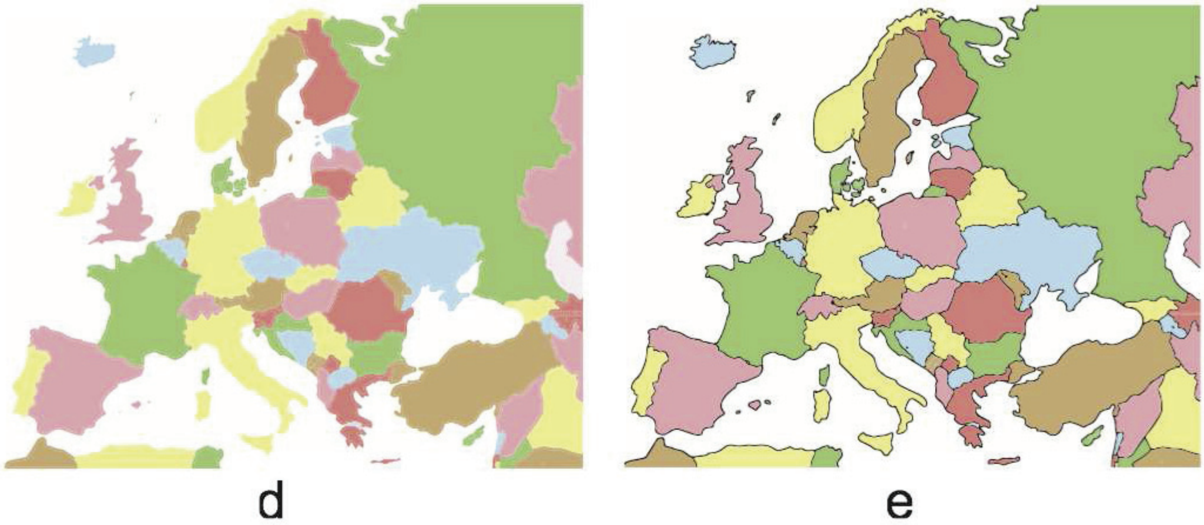


Figure 2.11. Color favors segmentation, partition and accentuation of figural attributes and it elicits equilibrium between oneness and multiplicity.

Reading in color: grouping and ungrouping by means of color

Pinna & Deiana (2014) studies visual grouping and wholeness in relation to similarity attributes but also in relation to other principles such as proximity and past experience. Above in Fig. 2.12 some examples of the role played by chromatic similarity are presented. Below are presented the examples named from a to i.

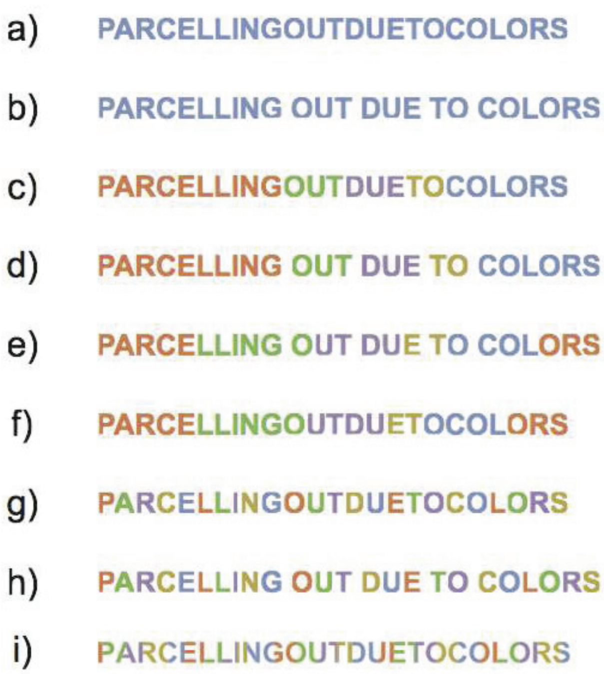


Figure 2.12. Examples from the role of color by chromatic similarity in the reading process.

Fig. 2.12a shows a long monochromatic set of letters where no blank space separates words. This is a reading condition which is hards to read. However, by introducing a blank space as in Fig. 2.12b, the reading becomes easier because of the proximity principle of grouping that gives a sort of visual rhythm which facilitates the reading process. In Fig. 2.12c again words are not separated by any blank space however, all words are colored in different colors, so since the long sequence is now segmented, a new rhythm is given by chromatic similarity in such a way that reading this time results easier, even easier than the reading proposed in Fig. 2.12b. In Fig. 2.12d, words are still colored by different colors and more each word is also separated by the blank space so that this is the newest and easiest reading condition among the stimulus created. On the other hand, to make a text difficult and even more difficult to read, it is sufficient to pit one principle against the other as in Figs. 2.12e-i. For example, in Fig. 2.12e the text is made unreadable or very difficult to read because of the chromatic similarity which in this case splits the words into two colors and strategically makes the ending color of each word the starting color of the following one. This, of course, produces, in the set of words, a segmentation and a visual rhythm which can be disturbing and confusing to read. To make the reading process even more difficult, in Fig. 2.12f the same chromatic condition as in Fig. 2.12e is maintained but, this time, no blank space is left between words so that, here the chromatic similarity enhances the emerging of non-words and tends to camouflages words that instead are there. Three control stimuli are also presented in Figs. 2.12g-i. In these controls the chromatic dissimilarity among adjacent letters tends to fragments each word. In fact, these control conditions make the reading difficult. As a result, the reading of Fig. 2.12g and of Fig. 2.12i are more difficult to read than the reading presented in Fig. 2.12a and the reading of Fig. 2.12h is more difficult than that presented in the Fig. 2.12b.

These results above are only a brief anticipation of the studies concerning the role of perceptual organization involved in the process of reading studied by Pinna & Deiana (2014). In fact, in the section which follows, it will be demonstrated more clearly how chromatic accentuation can influence visual organization and by means of it how it can affect other perceptual and complex processes involved in reading and in visual word recognition. In the conditions which will follow, color, will be used against some of the Gestalt principles: the past experience and others at the same time, of course. In the starting section of this chapter, some paragraphs have been dedicated to the role of color and in particular it has been demonstrated the power of color in inducing wholeness and fragmentation as well. With this experiment, Pinna & Deiana (2014), studied the role of different colors among words and letters belonging to the same word.

As a matter of fact, in this experiment color has been used in both ways: to create wholes and to fragment, at times working synergistically and in some other times going against some of the famous grouping principles and similarity attributes.

Stimuli

The stimulus used is "the War of Ghosts" translated in Italian language and written by Bartlett in 1932. Fig. 2.13 is the full text in English language. The version translated in Italian Language is the one used as the base for the creation of the stimuli used in the experiment. Moreover the stimuli used in the experiment, are all differently arranged by color. Please see picture below (Fig. 2.13) to see the complete stimulus from which all the others stimuli used derive.

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.

Figure 2.13. The war of Ghosts by Barlett (1932) in English language.

The stimuli were varied using 5 different equiluminant colors as described in the stimuli on page… The color was used first of all to pit similarity in favor or against the grouping principles of proximity (the distance between two adjacent words or the breaking off of the words by adding a blank space was observed in the creation of the stimuli), the element of connectedness (Palmer, 1999) and that of past experience. Secondly, color was used against other similarity attributes like orientation (Italian typeface) and width (bold typeface).

The color was used to create 4 chromatic conditions as follows (Fig. 2.14): (i) a *monochromatic condition* - the whole text is colored with only one of the five equiluminant colors chosen; (ii) *a word condition* - each word in the text is colored in different color; (iii) *a half word condition* - half word is colored with a different color from the second half; *a letter condition* - each letter is color with a different color.

Figure 2.14. Example of the four chromatic conditions used as stimuli.The tasks

The tasks

The reading task. Subjects were asked to read the text as clearly as possible and in a loud voice.

The scaling task. subjects were also asked to scale in percent the reading easiness of the stimuli used in each experiment

The reading comprehension test. Subjects were also required to answer a multiple-choice reading comprehension test in relation to the story read.

Subjects

Several groups of 30 subjects were given one condition to read. For three times, during the scaling task, subjects were invited to compare freely the reading easiness of the stimuli of each experiment by going through them on a computer screen and by going back and forth until they were ready and satisfied with their judgment. They were also asked to read the text more carefully and accurately and as fast as possible. However, for this study, only the results of the first experiment will be reported and that of the scaling task.

The role of color and past experience

This experiment studies the effect of color organization in the four chromatic conditions, created without any blank space between words as described in the previous section and as also observable in Fig. 2.14. In this condition, color works synergistically or is pitted against word recognition during reading.

The results

Data collected show the following results. Please see Fig. 2.15 (next page). Stimuli in English language, can be read in Fig. 2.14 to test phenomenally the results obtained.

According to the results, the chromatic similarity strongly affects the three tasks. As expected, color has determined wholeness and segmentation, so that, the word color condition proved to be the best reading condition when compared with all the others, since, it fastened the reading time, improved the reading easiness and enhanced the reading comprehension score. Opposite results are obtained where each word is fragmented as it happens in the half word condition or when a different color is used for each letter.

To sum up, the best results were obtained in the word color condition, then the monochromatic color condition also obtained the second best results, afterwards there is the letter condition and finally the worst results were those obtained for the half word color condition.

A one-way ANOVA, for each task, highlights significant variations in the four conditions: reading time: $F_{3,42} = 17.8$, $p < 0.001$; reading easiness: $F_{3,42} = 18.2$, $p < 0.001$, and comprehension score: $F_{3,42} = 20.5$, $p < 0.001$). All the Fisher PLSD post hoc analyses of the possible pairs were significant ($p < 0.05$). The results of this experiment can be seen in figure 2.15.

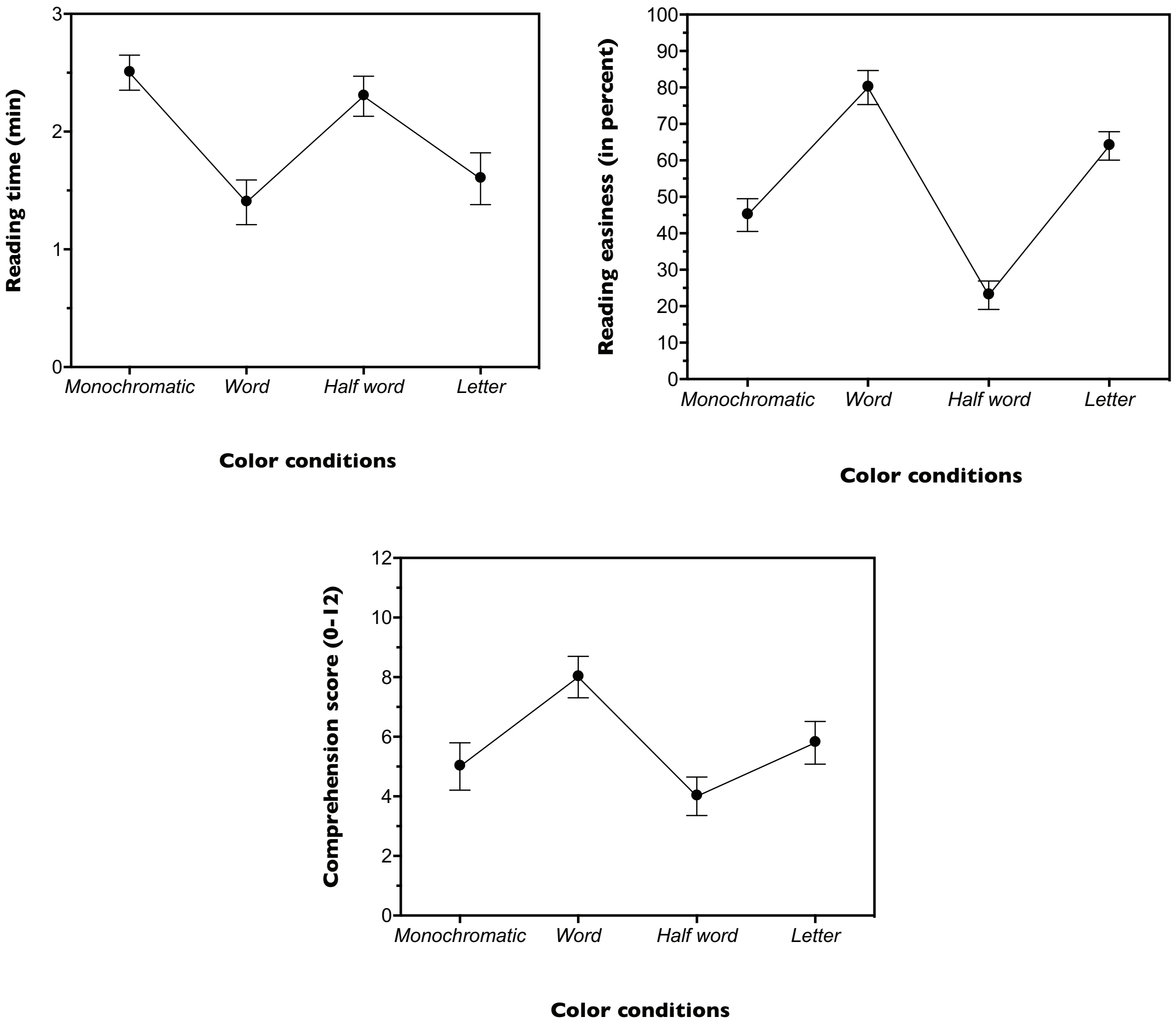


Figure 2.15. Chromatic similarity and past experience. Results analysis for reading time, reading easiness and reading comprehension test.

The role of color and proximity

With this experiment it was tested the reading easiness in the four chromatic conditions. This time the stimuli proposed were those reported in fig. 2.16 but inter-word separation (color and proximity principles of grouping were regarded). In fig 2.16 are reported the examples of the stimuli with one blank inter-word separation used for this experiment. Fig. 2.17 shows instead the results for the reading easiness obtained with the four inter-word separations plotted as a function of the chromatic conditions.

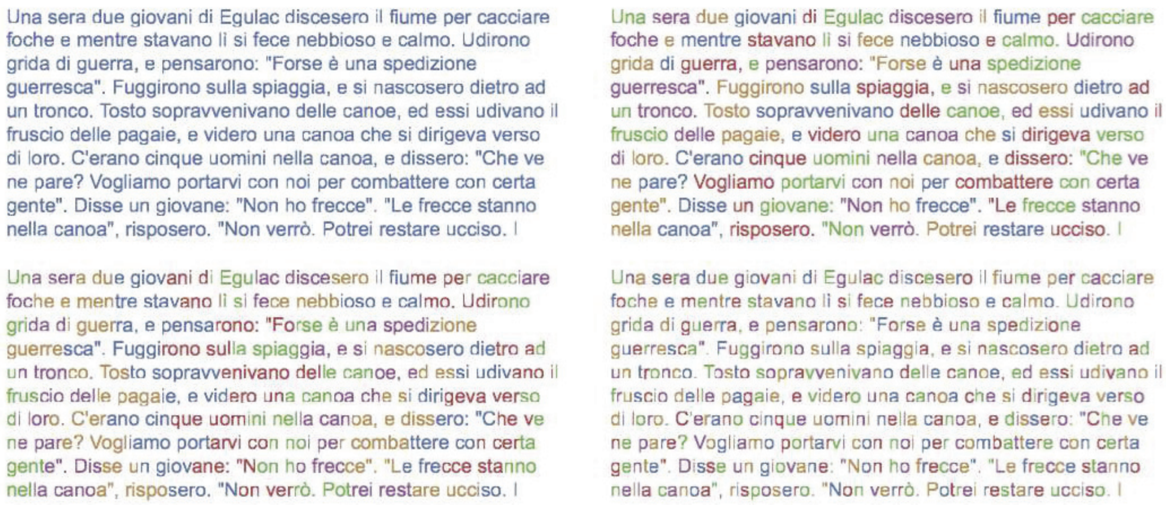


Figure 2.16. Examples of the stimuli with one blank inter-word separation (Chromatic similarity and proximity).

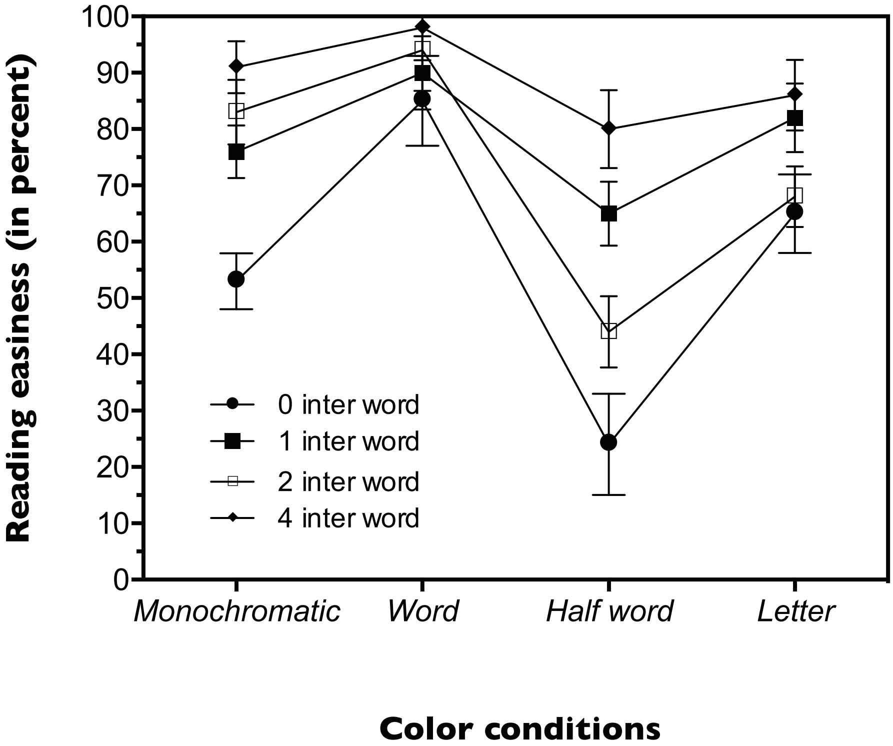


Figure 2.17. Results of the reading easiness for chromatic similarity and proximity principles.

These results corroborate the previous ones and demonstrate for each of the four blank spaces the same order among the four color conditions used. In detail, the half word color condition was the most difficult reading condition, then came the letter color condition, the monochromatic color condition and finally the easiest color condition was the word color condition. A two-way ANOVA showed significant variations in the four conditions for the four inter-words separations ($F_{3,42} = 15.9$, $p < 0.001$ and $F_{3,42} = 20.1$, $p < 0.001$). 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 to highlight that the color organization in the chromatic conditions also affected the apparent interspace extent between two contiguous words, together with the letter and word density, the chromatic saturation and finally, the size and the numerousness of letters and words. In Fig. 2.16. those results are clearly observable at a glance. The strength of these illusory effects would need to be measured psychophysically with specific and accurate measurements that are not the main purposes of this work.

Color and Proximity

In this experiment, the four chromatic conditions were administered with stimuli where each word was broken off in the middle by a blank space (color and proximity principles of grouping were regarded). In Fig. 2.18, are presented two examples of the stimuli and the results (fig.2.19) of the reading easiness are plotted as a function of the four color conditions. The results obtained in this experiment are similar to the ones found in the previous experiments. This demonstrates one more time the basic role played by chromatic similarity in the reading process both synergistically and against other Gestalt principles. As can be observed in the graph, the absolute percentages of the reading easiness, this time are lower than those obtained in the previous experiments. This data can be read in relation to the fact that the broken words make the reading very difficult, as the rhythm of the reading process is usually marked by a blank space. In the end, what clearly emerges is that the words are phenomenally "glued" and restored thanks to the chromatic similarity.

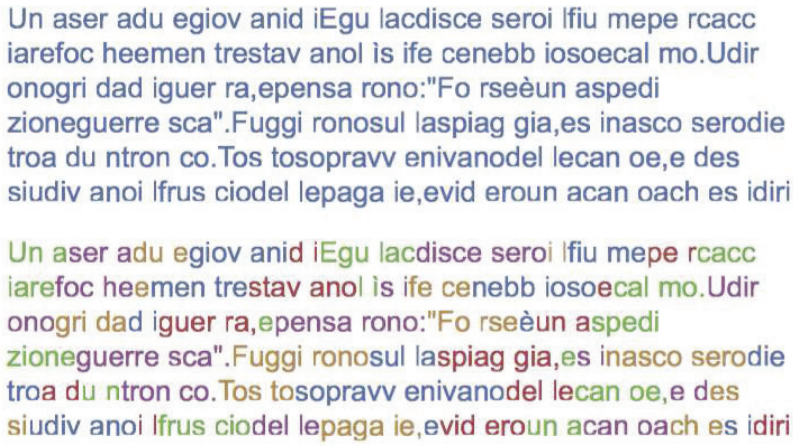


Figure 2.18. Stimuli of color and proximity.

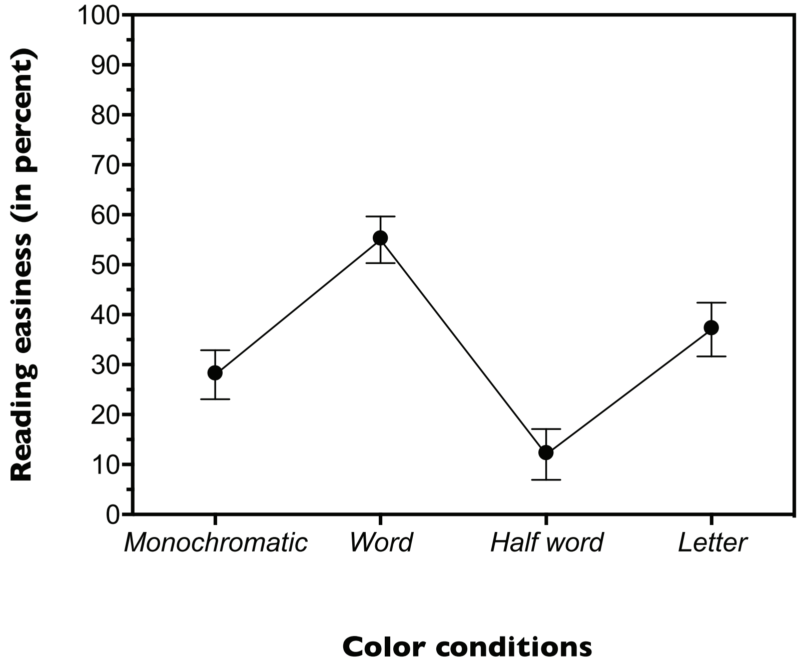


Figure 2.19. Results of color and proximity.

A one-way ANOVA demonstrated significant variations in the four conditions ($F_{3,42} = 18.7$, $p < 0.001$). All the Fisher PLSD post hoc analyses of the possible pairs were relevant ($p < 0.05$).

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 are regarded). In Fig. 2.20 scan be seen two examples of the stimuli with the whole word underlined or half word underlined and the mean ratings of the easiness reading. The findings of this experiment are the same as the previous ones, they are also in the same order and are also similar in strength (Fig. 2.21) A two-way ANOVA showed significant variations in the two word/half word conditions for the four chromatic similarities (respectively $F_{1,14} = 22.9$, $p < 0.001$ and $F_{3,42} = 21.1$, $p < 0.001$). The interaction between the two factors was not significant. All the Fisher PLSD post hoc analyses of the possible pairs were significant ($p < 0.05$).

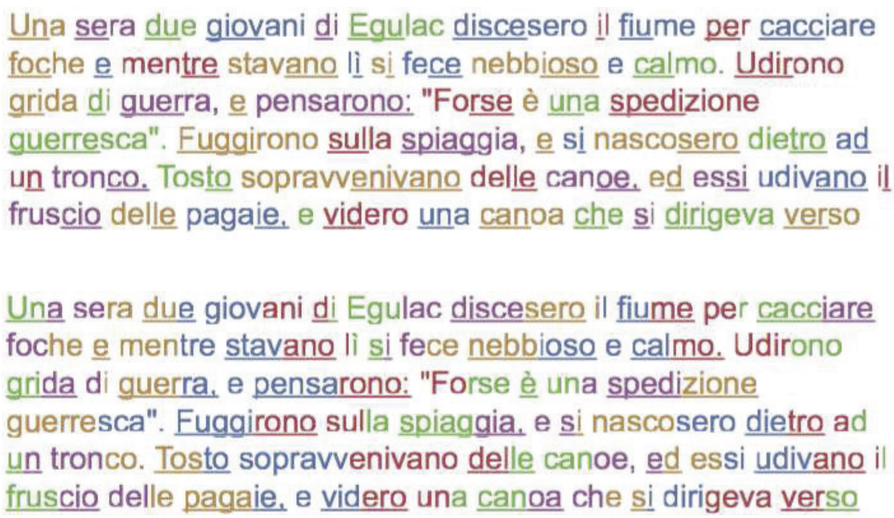


Figure 2.20. Stimuli of color and element connectedness.

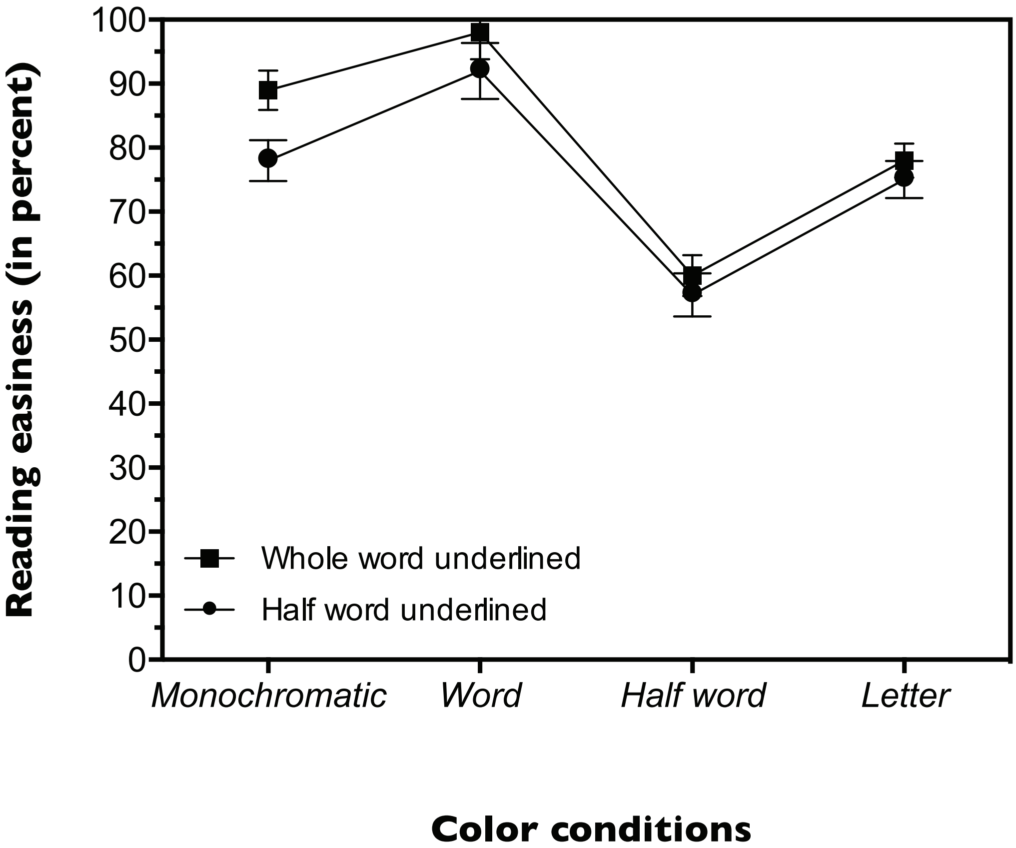


Figure 2.21. Results of color and element connectedness.

Color and Orientation/ Width

In Fig. 2.22 are shown, two examples of the stimuli with the whole word or with half word only in italic and bold typefaces and the results (Fig.2.23) of the color organization in favor or against italic and bold typefaces (color and similarity by orientation/ width).

The results confirm the previous ones. They demonstrate the basic role of colors in typesetting and they proved to improve the reading. Two two-way ANOVAs showed relevant variations in the two word/half word conditions for the four chromatic similarities respectively for the Italic typeface ($F_{1,14} = 23.9$, $p < 0.001$ and $F_{3,42} = 21.2$, $p < 0.001$ with not significant interaction) and for the bold typeface ($F_{1,14} = 19.8$, $p < 0.001$ and $F_{3,42} = 23.3$, $p < 0.001$ with not significant interaction). All the Fisher PLSD post hoc analyses of the possible pairs were significant ($p < 0.05$).

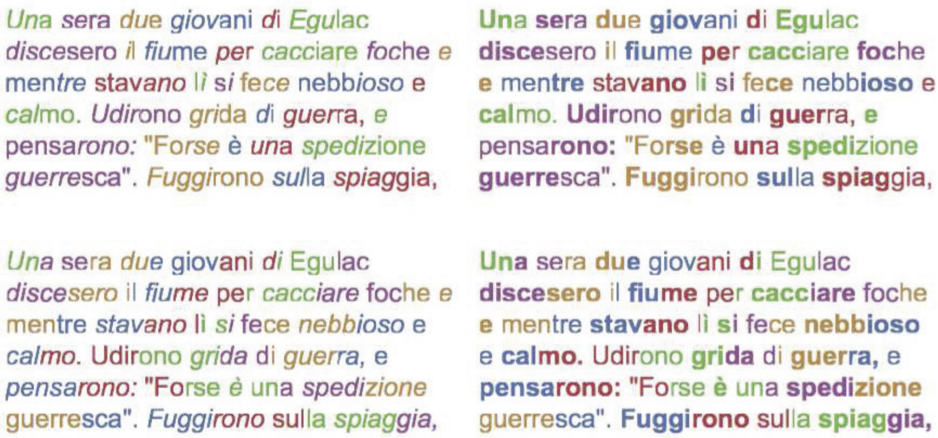
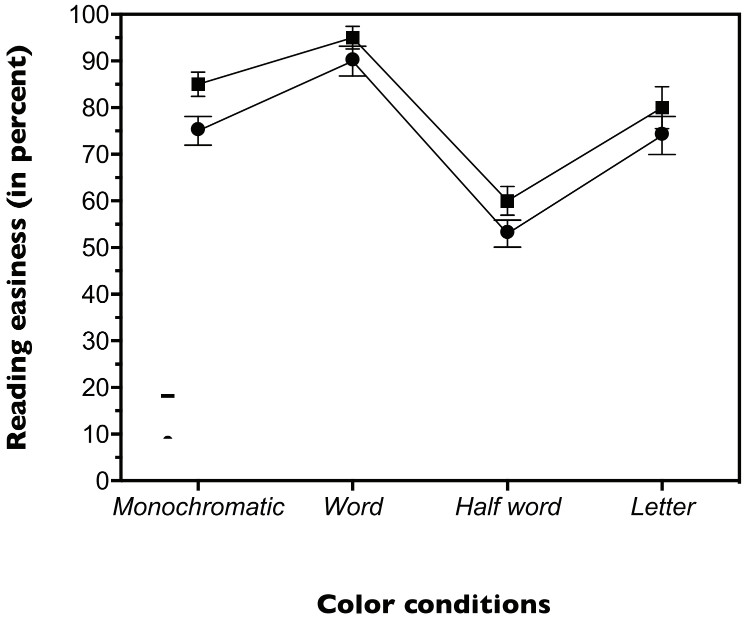


Figure 2.22. Stimuli of color and similarity by orientation/width.



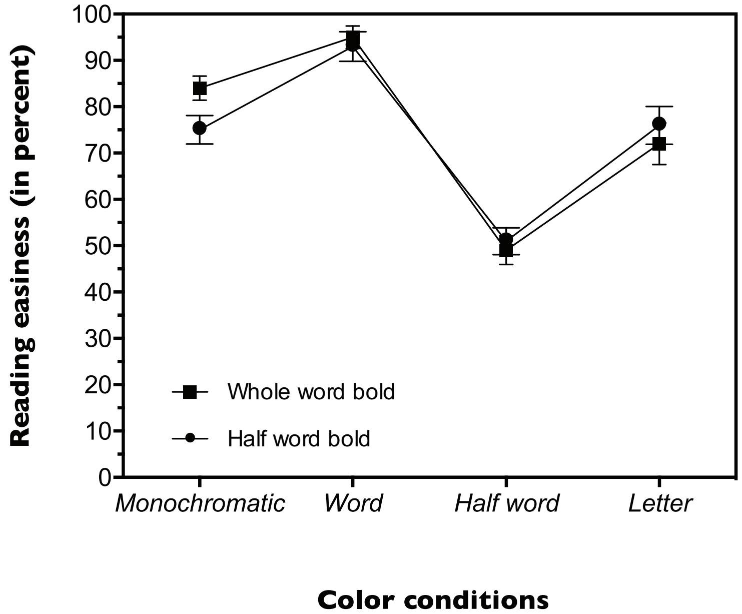


Figure 2.23. The results of color and similarity by orientation/width.

Color and all other Typeface Attributes

In the last experiment underline, italic and bold typefaces are tested. They are taken together in the whole or half word (Fig. 2.24) pitted in favor or against the color organization of the four chromatic conditions (color and all the other typeface attributes are taken into account).

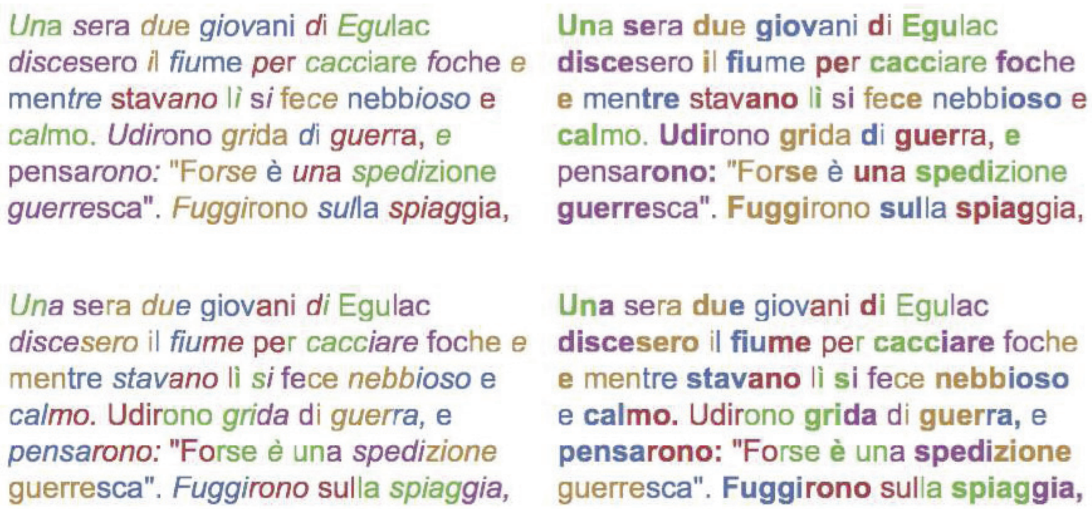
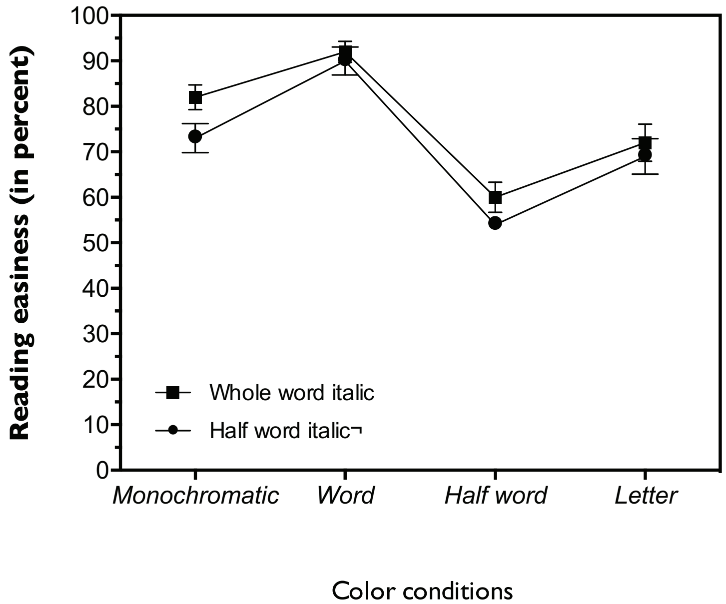


Figure 2.24. Stimuli of color and all the other typeface attributes.



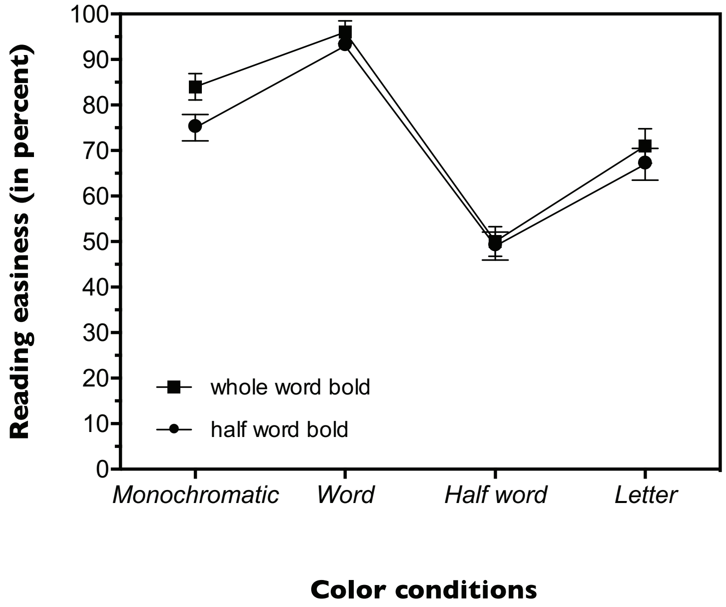


Figure 2.25. Results of color and all the other typeface attributes.

In Fig. 2.24 can be seen two examples and the results (Fig.2.25) of the reading easiness are plotted as a function of the four color conditions. 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 : $F_{1,14} = 25.4$, $p < 0.001$ and $F_{3,42} = 23.6$, $p < 0.001$). 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

It can be concluded that, phenomenally, there is a general principle of "unilateral belongingness of color to shape". This principle states that color is a visual attribute that belongs to an object and to its shape and not the contrary (Pinna, 2012e, 2012f). The perception of an object is usually identified with the perception of its shape and not to its color, which is normally considered a 'secondary' syntactic property, like the adjective of the shape, the noun. Consequently, color is believed to have little influence in both shape formation and perception. In the above sections, the studies carried out by Pinna and Deiana have demonstrated the capacity of color similarity to group and segregate a figure from its background as well as to organize the figure in parts and wholes as a shape in both visual and cognitive domains. All this, as already mentioned, was phenomenologically studied by Pinna and Deiana (2014) through new phenomena and new conditions and it has been in the above sections reported.

The results have shown unique and relevant visual meanings and organization properties imparted by means of the chromatic variations. In greater detail, It has been demonstrated how the role of color turned out to be crucial in visual organization and segmentation, in imparting spatial rhythm and unification, in grouping and ungrouping wholenesses, in uncrowding shapes, in making implicit shapes explicit, as a whole, in shaping and reshaping the same pattern of stimuli in different ways. These findings were strengthened and extended also studying the way color influences the reading process and in detail the reading time, reading easiness and reading comprehension) when chromatic similarity is pitted in favor or against other Gestalt principles of Gestalt grouping. The principles taken into account were proximity (distance between two adjacent words and breaking off each word by adding a blank space), element connectedness (underline typeface) and past experience. However, in addition, other similarity attributes were used against and they were orientation (italic typeface) and width (bold typeface). The results from these experiments have highlighted that chromatic similarity can affect the process of segmentation of words and, above all, phenomenal grouping and shape formation. Furthermore, it has been proved that color wins against all the known typesetting similarities such as underline, italic and bold typefaces playing together. This means that color not only is one among the many factors of grouping but it is also an essential element useful for the foundation of a more complex organization whose aim is to create wholeness, part-whole formation and fragmentation.

This above statement is not in contradiction with the principle of "unilateral belongingness of color to shape". In fact, color tends to impart to shape a multiplicity of other possible attributes without damaging, hiding or annulling the shape which represents the visual oneness and the basic most invariant visual attribute. Indeed, color complements shape. This is, for example, the case of fruits that, through color variations, change their visual and cognitive meanings.

Furthermore, by means of color, shape can be reshaped like in the case of shape from color, or it can be camouflaged as in the case of an "Harlequin camouflage", besides it may become totally or partially invisible through colors. This means that color, differently from shape and from other visual properties, is the most adequate tool to find the best equilibrium and compromise between the poles of oneness and multiplicity, two poles belonging to every object which is also made of many parts.

The literature of this chapter, proved how chromatic rhythm tends to segment, group, unify or parcel out in subsets regions of space, which without color would be invisible or visible in different ways. The chromatic similarity/dissimilarity is what is needed to organize and reorganize the visual world but, it can also, favor the camouflage or implicitness of different sequences of elements or wholes, as well as it can accentuate or make visible and explicit other elements or wholes.

Finally, this work suggests that the phenomenological study on the role of color in perceptual organization is essential for 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. In other words, 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?

According to these results, the answers to the previous questions are based on the main roles of chromatic similarity to the visual organization. The main roles of chromatic similarity are the followings: (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 sum up, this work suggests that one of the main purposes of color for living beings is to show wholeness, part-whole organization and phenomenal fragmentation.

Chapter 3

This third chapter is the one which fully describes the experiments carried out. In details, I will explain the procedure used, then, the data found will be analyzed and discussed by means of statistical analysis. In the end a final discussion will also close the chapter. However, since participants in this research are also dyslexics, before focusing directly on my experiments, a whole section will be dedicated to highlight the main traits of people affected by Dyslexia. In addition, some relevant literature which concerns the use of color in normal readers and dyslexics subjects will also be presented.

Dyslexia

What are the main features of Dyslexia and Visual Stress for which colors have been largely employed?

What is Dyslexia

Dyslexia is not at all an intellectual disability even if it is thought to be the result of a neurological difference. Dyslexia is in fact a neurological disorder that specifically impedes the development of expertise in reading skills (Gabrieli, 2009; Lyon et al., 2003). It is considered a reading disability and it is related to a defect in the brain's processing graphic symbols. In short, it manifests as a reading\learning disability that modifies the way the brain processes written material. It needs to be stated that Dyslexia has nothing to do with reading difficulties occurring from other causes: it is not related to vision or hearing problems and it does not derive from poor or inadequate school reading instruction (Peterson & Pennington, 2012). In many cases Dyslexia occurs in comorbidity with Scotopic Sensitive Syndrome, whose symptoms are explained below.

What is the Scotopic Sensitive Syndrome or Meares-Irlen Syndrome, also simply called visual stress

Visual Stress stands for Scotopic Sensitivity Syndrome. It consists of a series of symptoms related to Asthenia, a visual perceptual distortion generally accompanied with visual fatigue during reading. People suffering from Visual Stress often report that this perceptual distortion consists of the blurring of the text, doubling or flickering of letters or lines as well as shadowy outlines. (Cardona, Borràs, Peris & Castañé, 2010) Most of these symptoms occur in patients with photosensitive epilepsy, autism, migraine, multiples sclerosis and also dyslexia (Wilkins, Huang & Cao, 2007).

Symptoms of Dyslexia

Many people both children and adults are affected by Dyslexia. Those people affected by Dyslexia have to deal with several annoying problems. For example, they have problems with spelling, writing words, sounding out words in their head, pronouncing words when reading aloud and understanding the meaning of what they read. Often these difficulties are first noticed at school when the child begins to learn reading and writing.

However, it seems that symptoms linked to a diagnosis of Dyslexia also confirm delayed onset of speech, difficulty distinguishing left from right, difficulty with direction (Hiroshi & Patrick, 2014) and a lack of phonological awareness, as well as being easily distracted by background noise (Handler & Fierson, 2011).

It is reported that in Dyslexia it is frequent to mirror writing and reading letters and words backwards, they reverse, rotate and transpose letters (Lilienfeld et al., 2011). However, this last characteristic is not a peculiarity only concerning dyslexics but it is also observed in many children when they are learning to read and write (Handler & Fierson, 2011).

Furthermore, children with Dyslexia have difficulty in identifying or generating rhyming words, they have problems in counting the number of syllables. All of these problems depend on a poor phonological awareness. Besides, they also manifest difficulty in segmenting words into individual sounds and they tend to blend sounds when producing words, thus indicating their reduced phonemic awareness (Peer & Reid 2014, Paulesu et al., 2001, Ramus et al., 2003).

Other symptoms associated with Dyslexia are difficulties in naming things, and in retrieval. In fact, in addition, they tend to have spelling problems and they may also be affected with dysorthographia or dysgraphia, which also depend on orthographic coding (Handler & Fierson, 2011).

Problems related to Dyslexia persist during adolescence and adulthood. Besides, dyslexics also experience difficulties in summarizing stories, memorization, reading aloud, and learning foreign languages. Adults with Dyslexia, may have learned some useful compensation strategies, so they may often read with good comprehension, even if they tend to read more slowly than others. However, they still manifest worse performance in spelling tests or when reading nonsense words. This last characteristic seems to be a question of phonological awareness (Jarrad, 2013).

Dyslexia, does not manifest in people always in the same way, but it tends to vary from one person to another. However, it is absolutely relevant the fact that all people with Dyslexia, read at levels significantly lower than expected for their age.

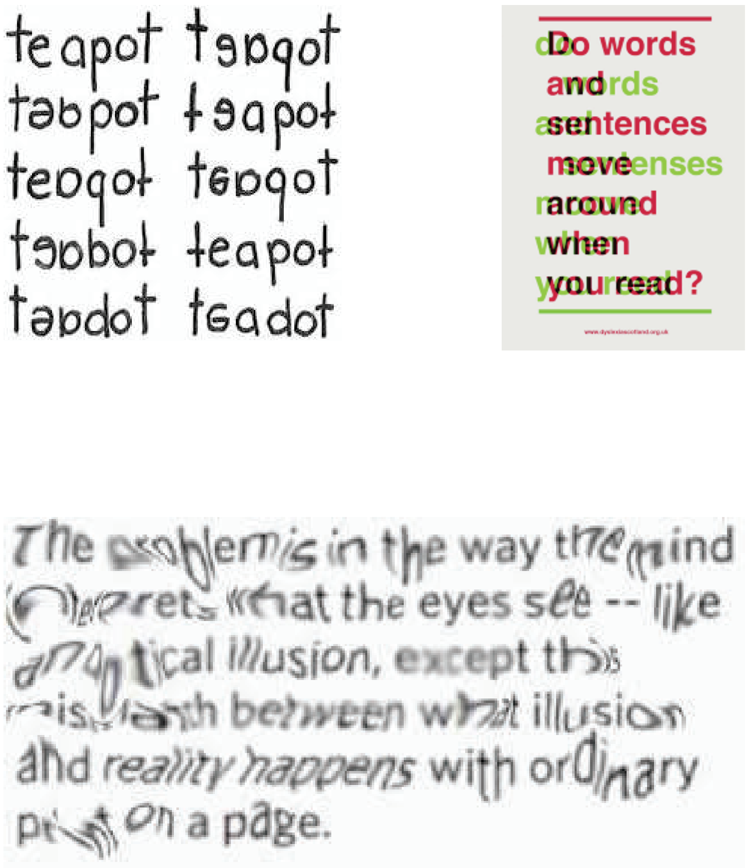


Figure 3.1. Typical examples of how dyslexics may view a text: reversing letters, moving around and blurring, distortions and blurring.

Causes and classification

Two are the main reported causes for Dyslexia. The first one says that Dyslexia is related to a language process cause. In fact, the main cause for reading difficulties and Dyslexia are to be attributed to the so called "phonological hypothesis", because phonological processing is one of the most relevant factors for the acquisition of reading skill (Wagner & Torgesen, 1987; Snowling et al., 2000; Uccula et al., 2014). Then, the second cause refers to the visual and perceptual skills which also are involved in reading (Watson et al., 2003). As a matter of fact, visual and perceptual skills have been brought to much more attention after discovering that some dyslexics subjects are affected by a perceptual dysfunction called Scotopic Sensitive Syndrome or Meares-Irlen Syndrome, simply also called Visual Stress, (Chouinard et al., 2012; Evans 1997) which is defined in the previous section.

Dyslexia is considered a cognitive disorder and not a problem related to intelligence. Nevertheless, emotional problems may arise because of it (Campbell, 2009). The National Institute of Neurological Disorders and Stroke defines Dyslexia as a difficulty with phonological processing and manipulation of sounds. People with Dyslexia do not have a "rapid visual-verbal responding". To give another definition, the British Dyslexia Association defines Dyslexia as "a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling" and it adds it is characterized by "difficulties in phonological awareness, verbal memory and verbal processing speed" (Philips, Kelly & Symes, 2013).

Dyslexia may also be caused by brain damages because of stroke or atrophy. When Dyslexia occurs after brain damages it is called Alexia (Woollams, 2013). Forms of Alexia are: pure alexia, surface dyslexia, semantic dyslexia, phonological dyslexia, and deep dyslexia. (Heilman et al., 2011; Spivey, 2012)

Neuroanatomy

Functional magnetic resonance imaging (fMRI) and Positron emission tomography (PET) have highlighted both functional and structural differences in the brain of children with Dyslexia (Whitaker, 2010). There has been evidence that in some dyslexics there is less electrical activation in some parts of the brain in particular in the left hemisphere of the brain, in greater detail in the area involved with reading: the inferior frontal gyrus, the inferior parietal lobule and the middle and ventral temporal cortex (Pammer 2014).

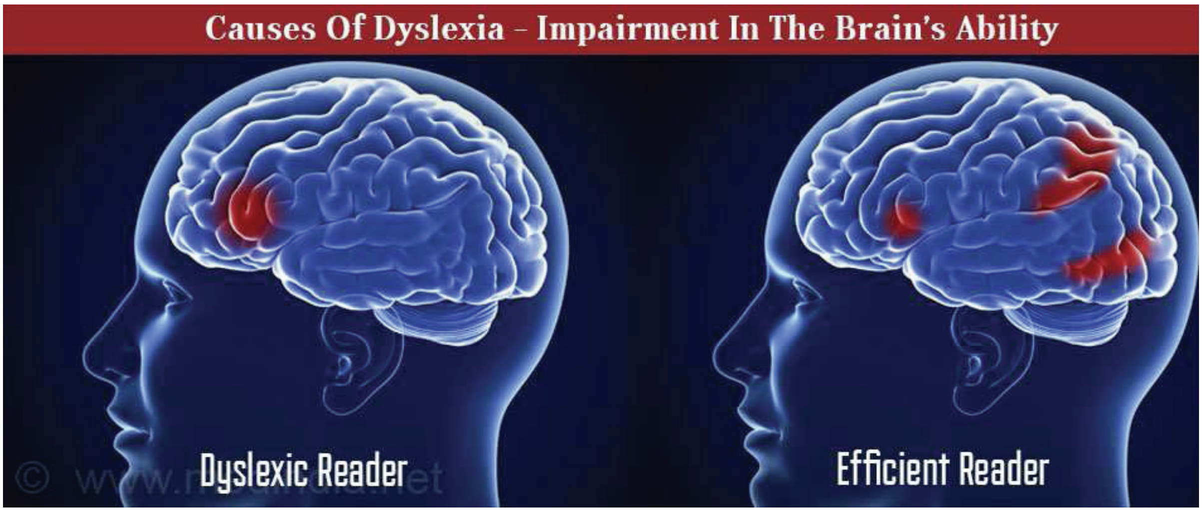


Figure 3.2. Activation areas in the a typical dyslexic brain, It shows less activity in the posterior language area.

Figure 3.3. The cerebellum.

New studies with PET have shown that neural bases of developmental Dyslexia is task specific. This means that it is functional more than structural (Price, 2012). Besides, recent studies have given a great contribution in the field thanks to fMRI which has highlighted an interactive role of the cerebellum, the cerebral cortex and other brain structures (Sharifi, 2014; Brandler, 2014). The theory of cerebellum concerning Dyslexia maintains that the muscles controlled by the cerebellum: the tongue e the facial muscles are impaired and this may affect the formation of words and fluency which are some of the characteristics of dyslexics. In addition the cerebellum is responsible for the automatization of some tasks among which is reading (Cain, 2010).

Most recent research on Dyslexia: The genetic factor and the Dysfunction of Rapid Neural Adaptation

It seems that mutations in a gene, Doublecortin domain-containing protein 2 (DCDC2) have been associated with reading disabilities (RD) among which developmental Dyslexia (Lind, Luciano, Wright, Montgomery, Martin & Bates, 2010; Marino et al., 2014). There has been shown evidence that DCDC2 gene is involved in neuronal migration and is most highly expressed in the entorhinal cortex, as well as in the inferior and medial temporal cortex, in the hypothalamus, amygdala and hippocampus (Meng et al., 2005). In fact, altered alleles have been frequently found in dyslexic children with difficulties with reading and writing. Furthermore, it has also been demonstrated that the DCDC2 is strongly related to the processing of speech information (Meng et al., 2005; Schumacher et al., 2006; Marino et al., 2012).

Since reading is a cultural invention, it does not derive from an adaptation due to natural selection, for this reason it has been claimed that impairments in reading development must be related to a difference in the structure or function of the brain in dyslexics (Price, 2012; Rueckl et al., 2015; Schlaggar and McCandliss, 2007; Wandell et al., 2012).

According to recent research made in functional brain imaging, visual and language areas have been explored and it came out that the reading network is altered in individuals with dyslexia (Paulesu et al., 2014; Pollack et al., 2015; Shaywitz et al., 1998). Considering that learning to read is a real complex process, which involves aspects of vision, language, motor control, due to eye movements and attention, it seems unlikely that only a single mechanism may be on the base of all answers explaining dyslexia. However, it needs to be stated that, there is evidence that, many individuals affected with Dyslexia show deficits in rapid perceptual and motor learning during nonverbal tasks. Differently from what happens in normal readers, who have shown enhanced perceptual thresholds in discrimination, during experiments when a target stimulus is held constant (Braida et al., 1984), in readers with Dyslexia, these perceptual thresholds are often noted to be absent or at least reduced (Ahissar et al., 2006). In short, more up-to date research has helped to highlight a series of physiological and behavioral impairments in the brain of those individuals with reading difficulties. In addition to the following neural signs such as unstable neural representation (Hornickel and Kraus, 2013), diminished top down control (Boets et al., 2013; Chandrasekaran et al., 2009), susceptibility to noise (Sperling et al., 2005; Ziegler et al., 2009) and inability to construct robust short-term perceptual representations (Dìaz et al., 2012; Lehongre et al., 2011) more recent studies have demonstrated that reading impairments can derive from a general dysfunction in the processes linked to rapid neural adaptation (Perracchione et al., 2016).

But, what has been done so far to help in case of Dyslexia. Many studies report that the use of color has been helpful to face and diminish the discomfort related to this impairment. So, how has color been used in reading for dyslexics and skilled readers? What its impact and what the effects in efficient and dyslexic readers?

How color has been used in reading

Color has been used in reading in a number of ways and for different purposes either to ameliorate normal readers performance and for improving reading and increasing speed and fluency in those people reporting Visual Stress and Dyslexia. Although still controversial, it has been stated that colored overlays are especially useful for those people suffering from eyestrain or experiencing different kind of distortions affecting color and shape and\or perceiving movement illusions while reading. For now, as a brief introduction to the problem, it will just be mentioned that a significant portion of people are normally affected by those problems, as a whole a 46% of the population including dyslexics also in comorbidity they report to suffer from visual stress (Uccula et al., 2014).

Colored filters

The role of colors in reading can be traced back to 1958, when Jansky (1958) brought to attention the case of a smart boy with normal intelligence but with a series of language dysfunctions, who claimed he was not able to read printed words on a white paper but he was able to read them on a yellow one.

Later, Meares (1980), pointed out that what makes reading difficult in children is due to the perceptual instability of the visual input because of the organization of the figure against its background. What does it mean? The problem arises due to the black words (the figure) printed on a white paper (the background). This is indeed the typical organization of printed books and the usual condition in which we all normally read. However, it seems that the classical organization of printed words can make reading difficult for some individuals because of the reflex that the white paper may produce. Starting from the fact that visual stress may be caused by reading black on white, changing this organization could also provide the changing of the symptoms related to Visual Stress (Wilkins, 2003; Irlen, 2010).

Scott et al. (2002) and Kruk et al. (2008) demonstrated that after 10 minutes of reading black on white the symptoms of Visual Stress started to arise while those symptoms did not manifest when reading the text through a colored overlay. According to Irlen (2010), if visual stress affects reading and reading acquisition then employing colored overlays might well improve reading and consequently reading acquisition.

Overlays and tinted lenses in Dyslexia

Since the Visual Stress Syndrome is often observed in dyslexic students (Irlen, 1991; Singleton & Trotter, 2005; Singleton & Henderson, 2007), a large use of colored overlays has been done. Colored filters have been used so far in classrooms and homes with the intent to eliminate or alleviate reading difficulties learning disabilities including Dyslexia. It is believed that the symptoms of this syndrome are provoked by sensitivity to frequencies of the light spectrum (Hoyt,1990).

Different forms of colored filters can be found in commerce or are prescribed by doctors, these are lenses and overlays. Colored lenses are simply lenses tinted with color and placed on eyeglasses to be worn. Colored overlays are transparent plastic reading sheets tinted with color and placed over a text (Wilkins 2003) to filter the light. It has been reported by many subjects that colored overlays can help in a wide range of difficulties arising while reading and in Dyslexia (Wyman, 2013).

Although the use of overlays has been largely employed, their effect on reading has long been discussed and their efficacy has not yet been fully confirmed. Indeed, their results are a bit controversial though they are still in use.

Figure 3.4. Tinted lenses and overlays.

How color has been used for increasing reading fluency

Although the Visual Stress Syndrome has not been so far well understood and exhaustively explained, it is said to be particularly prevalent in people with reading difficulties, such as in case of Dyslexia. In fact, often SSS, comes in comorbidity with Dyslexia (Bruce & Evans, 2002). For this reason the literature here reported will no purely refers to cases of dyslexia per se, but it will also be referring to those studies including subjects also reporting symptoms of SSS. Furthermore, also the results obtained by readers no reporting any problems in reading will also be part in the literature quoted.

In the section below it will be highlighted how color overlays and the use of color by other means may increase, if that will be the case, reading fluency.

Wilkins (2002) demonstrated a relevant difference in the rate of reading in a group using a colored overlay placed on a written text when compared to a control group who did not. He stressed that the data analyzed are not the results of a placebo effect, and confirmed that the subjects chose their own color. The 5% of the participants in Wilkins (2002) read 25% more quickly with an overlay than without.

Another interesting study by using color to increase reading speed is that proposed by Arnold et al., (2005). It is known that the effects of color on reading fluency are not the same for each individual (Wilkins et al 1994, 2002). However, how specific the tint has to be in order to be effective is not yet been suggested. The study of Arnold et al. (2005) seeks to determine this specificity in order to say what is the effect of color on reading fluency. It is known that people who benefit from colored filters usually claim to suffer from perceptual distortions of the text consisting of apparent movement of the letters, blurring, or colored halos, abnormal micro-fluctuations during steady-state accommodation, that diminishes when the text is illuminated by colored light or when color glasses are worn (Simmers et al., 2001). Others meaningful experiments by means of color in reading are also here reported.

Increasing reading speed by means of color in the studies of Wilkins, Sihra and Myers (2005)

Subjects

Participated to this experiment individuals who had been assessed with the MRC system and who habitually wear colored glasses for reading.

Methods

They were asked to read a text aloud under light of different colors in order to determine to what extent and how reading speed was affected by the chromaticity of the illumination. The stimulus consists of a text with common words randomly ordered, arranged as if they were a paragraph, but, due to the random order, that did not constitute a sentence, nor they could not be guessed from context, they had just been placed to be seen and read.

Results

The data demonstrated across all the participant that the reading speed was generally slowest under white light, but not under the color complementary to the optimum (Wilkins, Shira & Myers, 2005).

Increasing reading speed accuracy in adolescents with good and poor academic performance by means of tinted lenses. A study by Cardona et al., (2010)

Cardona et al. (2010) also wanted to try the benefits of tinted lenses in adolescents with good and poor performances in reading. Their target object was to see whether colored lenses could influence reading accuracy and reading speed.

Subjects

Two different groups of teenagers participated in this study. They had no visual anomalies and they were adolescents with good and poor academic performance.

Methods

As a stimulus it was created a rate reading test especially designed for Catalan first language speakers. These subjects were asked to read the test aloud, in two different sessions. Subjects were first asked to read the test without lenses and, later, to read it again but with lenses of their own choice, and finally, they had to read it another time with a placebo set of clear lenses. Their reading speed and reading accuracy were taken into account and monitored.

Results

Data revealed that there was not a significant difference between the baseline reading speed and the accuracy from the first and second sessions. However, when comparing reading speed and accuracy without lenses, in placebo conditions, and with tinted lenses, then, the reading accuracy was noted to be more sensitive than reading speed. Indeed, these differences were found even more evident in the group with poor academic performance. In conclusion, this study revealed that lenses were more beneficial only among subjects with poor academic performance. Cardona et al., (2010)

Further studies

Another study on color is that carried out by Ritchie et al. (2011). Their aim was to test the efficacy of Irlen colored overlays to reduce reading difficulties due to Irlen Syndrome.

Subjects and Methods

Their subjects were schoolchildren between 7 and 12 years old with reading difficulties. They were all subjects reported with the Irlen Syndrome. To carry out the experiment, they decided to adopt a within-subject study designed in order to examine the differences in reading rate. Subjects were tested across 3 conditions: using an overlay of a prescribed color, using an overlay of a non-prescribed color and finally using no overlay at all.

Results

With this study Ritchie et al., (2011) claimed that there was no such immediate alleviation due to colored overlays on subjects with reading difficulties.

Also, Denton & Meindl (2015) studied the effects of colored overlays on 3 subjects with Dyslexia. In detail, they wanted to prove the effect of tinted overlays in relation to reading fluency.

They checked the rate of reading fluency while subjects were reading with and without colored overlays. Their results demonstrated that the use of overlays was not of any help. In addition, as they declared, overlays were "ineffective and potentially detrimental to the participants reading abilities" (Denton & Meindl, 2015).

How does color as a background and special font influence reading performance in dyslexics

According to studies conducted by Kriss & Evans (2005) with colored overlays on a group of 32 children with Dyslexia and with a control group of same size, although not a big statistical difference was found, they concluded that Meares-Irlen Syndrome is common in the general population and possibly a little more common in those subjects affected with dyslexia. Since, children with dyslexia have revealed to benefit more from colored overlays if compared to non-dyslexic children, the authors maintained that Meares-Irlen Syndrome and Dyslexia are two separated things, so that they are detected and treated in different ways. In addition, Jeanes et al. (1997) demonstrated that colored overlays helped the reading of children in school even though these children were not affected with Dyslexia and did not suffer from any other visual difficulty. Besides, Gregor & Newell (2000) and later also Dickinson et al., (2002, 2003) stressed out the importance of visual changes in the presentation of a text. In fact, they highlighted how visual changes are fundamental to alleviate some of the problems caused by dyslexia and to any visual comorbidity related to it. On the base of these claims, there is another interesting study carried out with the intent to ameliorate texts readability for dyslexics. These studies, are especially focused on specific designs for computer screen texts. In this specific study brightness and color are used in combination with other parameters, such as font type, character, line and paragraph spacing, column width and language content. All these parameters, which have been proved to be effective for dyslexics, have been adjusted in such a way to make web texts more accessible to dyslexics without affecting other users (Pedly, 2006; Rello 2013; Rello & Baeza-Yates, 2015). In fact, it has been stated that larger texts and larger character spacing help dyslexics and normal readers to read faster (Rello & Baeza-Yates, 2015). Pedly (2006) stressed out that "The Web Content Accessibility Guidelines 1.0" (WCAG) determined which are the parameters and right algorithms for brightness contrast and color difference for a better readability of a text. However, Pedly (2006) and Rello (2013) and Baeza-Yates (2015) also stated that these algorithms may have detrimental effects on dyslexics. Due to color contrast. In fact, many dyslexics tend to have a series of discomforts while reading as also reported in Visual Stress Syndrome (see paragraphs on dyslexia).

General methods

Subjects

96 subjects participated to the experiments. Among them 46 were dyslexics.

Stimuli

8 different texts, altered taking into account the different parameters on readability, and color plus background combinations were created. With this stimuli, 8 experiments were carried out to test the effects of each stimulus on the subjects.

Task

Subjects were asked to read all sets of texts. It was a within subjects design test, and for this reason each subject was required to participate to each of the conditions on the experiment. The stimuli were not given in random order but they were counterbalanced in order to avoid any order effect. An eye tracker was used to monitor the readability of the texts and a comprehension test was included as well.

To have a better overview and understanding of how color and background were used in combination, below is also reported a copy showing examples of texts and background used in combination together with character spacing and font size.

Indipendente variables

Design of the stimuli

In each experiment 4 or 8 conditions were used. Each condition reflects the levels of the parameters which are considered as independent variables. The variables were chosen considering typical difficulties people with dyslexia normally encounter (orthography, phonology, morphology, lexicon, discourse). Previous studies and also recommendations from literature in the field were also considered. The recommendations taken into account for the design of the stimuli consists in the following parameters: text and background grey scale [86,101], text and background colors [11,12,37,71,86], font size [1,12,25,71,86,111], paragraph spacing [11,86], character spacing [66,71], line spacing [71,86] and column width [11,12,86]. Below is the example, Figure 3.5.

Figure 3.5. Examples of color and background used together with character spacing and font size.

Fixation duration

When we read a text, alternate saccades and visual fixations similar to little jumps in short steps and rests on parts of the text occur, and these are parameters which need to be measured to determine objective readability.

Tool

An eye tracker software was used to measure the objective readability determined by eye fixations duration, here considered as a dependent variable.

Subjective preferences

Subjects had to select the texts that they found easier to read. For each experiment they were asked to note down their answers in a paper questionnaire as they were watching the options proposed on the screen. Subjects were given no time constraints when looking at the options, and they could have a look at them for as long as they wanted. Subjects chose one, two, three or four options that they consider as the most readable. The weights 1, 0.5, 0.33 and 0.25 were assigned to those options. In order to calculate the average preference rating the weights are summed and then divided by the number of participants

Comprehension

Reading a text does not guarantee its deep understanding, above all among dyslexic subjects because readability and comprehension for them are two independent factors (Rello & Baeza-Yates 2012).

A multiple choice text with 3 choices with only one correct answer and 2 wrong choices was created to evaluate a deep understanding of the text.

Conclusion

This study is the result of an experiment where subjects with and without dyslexia were tested to prove the objective readability of some texts with changed parameters. The most important finding of this study on readability has highlighted that readability is improved under the following conditions:

- with larger font sizes (from 18 to 24 points) above all with people with dyslexia.
- with larger character spacings (up to +7% - +14%) both for dyslexics and normal readers

• with texts with no grey scales and with larger font sizes
• with font Size : 18, 22 and 26 points (17-Inch screen).
• with character Spacing : ranging from 0%, +7% to
+14%.
• with font/Background Colors : black font on white background, or white font on black background.
• with Typeface : Arial, Courier, CMU, Helvetica, or Verdana.
• With font Style : roman and sans serif.

As far as preferences, are concerned, both groups of subjects (with and without Dyslexia) found more readable texts with standard character spacing and 44 characters per line column width. However, what were their preferences for colors instead? The recommended colors for readability are the pair off/black off/white, however, this combination was hardly chosen by dyslexics. The most preferred colors chosen with Dyslexia was black over yellow which is not recommended according to Bradford (2011) because high contrast causes vibration that affects readability. Also in the experiments done by Gregor & Newell (2003) people with dyslexia chose the combination black and yellow. However, the color combination which turned out to be faster to read was black and creme. According to these results, all pairs of color combination chosen are coherent with those also suggested in the guidelines of British Dyslexia association, apart from dark brown/light mucky green which are not considered due to their brightness difference. Furthermore, since the readability with text and color background is indeed also affected by the size of the text, here in this study the size used is 20 points. Other colors among subjects preferences are the pairs blue/white and blue/yellow. According to this last data, Rello & Baeza-Yates, (2015) suggest using a pair combination of blue/cream for future experiments. As a conclusion, they also suggest that being Dyslexia a learning disability which has to do with language, new techniques to enhance readability may also be approached taking into much consideration not only text presentation but also text content. In fact, the use of complicated language should be avoided for this target group and eventually it should be replaced by more frequent and shorter words. Besides according to Rello & Baeza-Yates (2014) in the future, dyslexics may also benefit from tools that can modify texts content in such a way to provide an adequate lexical simplification.

Reading in color with Synesthetic letter-color association

Another study with involves color in reading is that carried out by Colizoli et al., (2014). This study, was not carried out with dyslexics subjects, the purpose was another one, however, it sounds particularly interesting. It promotes a new method of reading which is reading in color. Aim of, reading in color here is to help develop synesthetic letter color association. Synesthesia is a condition in which a stimulus from one modality evokes the sensation of another, for example the hearing of a sound automatically produces the visualization of a color (Colizoli, et al., 2014). A common type of synesthesia which has been studies is the grapheme-color synesthesia. In other terms, the synesthetic letter color association is the experience of seeing letters in color when viewing, hearing or thinking about letters, words and numbers. For this experiment, synesthetic association of letters and colors have been used in reading. According to Colizoli (2014) reading in color, is a good method for helping learning implicitly associations. In fact, the readers will naturally acquire those associations while reading, without computer direct training methods.

Although this study has not yet been used directly only with dyslexics subjects, but with a wider range of subjects, I have chosen to quote this work for its potentials and a possible future application in dyslexia too. In fact, according to Colizoli et al., (2014), being reading in color a method for training letter-color associations, it could also be useful to examine to which extent cognitive advantages deriving from synesthesia, may help memory under certain stimuli or may induce changes in the brains of the trainees. Colizoli et al., (2014) stressed the important of synesthesia because there is still a great deal to learn in this area and important findings including effects that synesthesia may have in both short-term and long-term memory may be explored. Indeed, the Colizoli et al., (2014) hope that, eventually after proving a basic protocol maybe others could progress in the field and use these training method not only in synesthesia research but also in other cognitive areas of neuroscience including studies in memory and learning field. So, why not trying it eventually to help mnestic retention and improve reading skills in dyslexics in the future? However, How was this study of synesthetic letter-color association carried out?

General methods

Task

Subjects were asked to read books in which 4 high-frequency letters are paired with 4 high-frequency colors given. These subjects were given sets of letter-color pairs according to their preferences for colored letters. A sort of Stroop Task is carried out before and after the reading task in order to test the acquisition of the learned letter-color associations and changes in brain activation. All subjects were also given a questionnaire designed to observe the different experience of subjects. The questionnaire provided a series of questions to understand how well individual could learn the associations from reading in color.

Subjects

Subjects consist of several groups of participants which declared they were willing and motivate to read their chosen books modified with colored letters as required by the experimenters.

Stimuli

The stimuli were books chosen by the subjects for their content but modified as you can see below (figure 3.6). They appeared with 4 high-frequency letters paired with 4 high-frequency colors.

synesthesia is a rare condition in which a stimulus from one modality automatically and consistently triggers unusual sensations in the same and/or other modalities. A relatively common and well-studied type is grapheme-color synesthesia, defined as the consistent experience of color when viewing, hearing and thinking about letters, words and numbers. We describe our method for investigating to what extent synesthetic associations between letters and colors can be learned by reading in color in non-synesthetes. Reading in color is a special method for training associations in the sense that the associations are learned implicitly while the reader reads text as he or she normally would. This is different from previous synesthetic training methods that require explicit computer-directed training methods. In this protocol, participants are given specially prepared books to read in which four high-frequency letters are paired with four high-frequency colors. Participant receive unique sets of letter-color pairs based on their pre-existing preferences for colored letters. A modified Stroop task is administered before and after reading in order to test for learned letter-color associations. Participants also do the Stroop task while brain activation is recorded before and after reading. In addition to objective testing, a reading experience questionnaire is administered that is designed to probe for differences in subjective experience. Factors related to these questionnaires can predict how well an individual will learn these associations from reading in color. Importantly, we are not claiming that this method will cause each individual to develop grapheme-color synesthesia, only that it is possible for certain individuals to form letter-color associations by reading in color and these associations are similar to those seen in developmental grapheme-color synesthetes. The method is quite flexible and can be used to investigate different aspects and outcomes of training synesthetic associations, including learning-induced changes in brain function and structure.

Figure 3.6. Example of a colored text fragment with four high-frequency letters (a, e, n, and r), consistently printed in four high-frequency colors (red, orange, green, and blue).

Conclusion

According to Corizoli et al., (20014) reading in color will not necessarily cause to develop grapheme-color synesthesia in each person, however the associations learned after this training, for some aspects are very similar to those experienced in developmental grapheme-color synesthete. Certain subjects in fact may show higher Stoop effects than others (Colizoli et al., 2014). The obtained results need to be seen in relation to the age, gender, and cognitive aspects of the participants. Individual differences were registered. These differences in the learning effect may be seen in terms of how much the color experience is internalized by the subject, indicating that the subjective experience of color plays a role in training synesthetic associations (Colizoli et al., 2014).

What has been reported in this section are a number of experiments which saw the use of color in reading. What is important to be highlighted is that none of the studies above could really prove the efficacy of color to improve and facilitate subjects' reading performance.

The chromatic accentuation in children/adults skilled and dyslexic readers

Although all the experiments quoted as a background literature look quite interesting, and might have worked in some cases, they do not provide any relevant evidence for the efficacy of color in reading tasks. Furthermore, none of the studies above was conceived and carried out in the way the experiments of this thesis were done. Even though, these background studies are related to color and perceptual organization, they do not investigate directly and precisely the role of color in terms of wholeness, parts-whole formation and fragmentation. Surely, none of them explored the effect on Dyslexia on conditions similar to those which can be observed here in the stimuli section (Figs. 3.8-3.11). In the following sections, in fact, the role of chromatic accentuation in reading and in a comprehension task are investigated with normal and dyslexic children and adults.

In fact, having analyzed the data found by Pinna & Deiana (2014) and having observed how encouraging they were, in order to prove the benefits of chromatic accentuation, I have extended and replicated the research by testing dyslexics subjects in comparison to normal readers.

The experimental hypothesis is that color should not be simply considered as a secondary attribute, since it permits visual organization in wholes, fragments and parts, according to the way it is used by humans and presented in nature.

The technique of chromatic accentuation is very important for a number of reasons. First of all, to understand the role of color in perceptual grouping and figure-ground segregation. Second, to determine psychophysically the role of color in affecting higher level processes, such as reading and word recognition. Third, to test cognitive processes during color vision efficiencies. Fourth, to test the magnocellular theory in developmental dyslexia. In reality, reading requires the acquisition of good orthographic skills in order to recognize the visual form of words, which are absolutely essential to access meaning directly. Besides, reading also involves good phonological skills to pronounce unfamiliar words which in order to be read correctly need knowledge of letter sound and conversion rules. Previous studies have stressed that, in dyslexic readers, the development of the visual magnocellular system is deficient. In fact, the development of the magnocellular layers of the dyslexic lateral geniculate nucleus (LGN) does not work efficiently as expected. This deficiency is confirmed because in many dyslexics motion sensitivity is reduced and, it has also been observed that they have an unsteady binocular fixation and a poor visual localization, especially on the left side. For this reason, those stimuli which in Pinna & Deiana (2014) turned out to be easier for normal readers might possibly be more difficult for dyslexics and vice versa.

Methods

Subjects

Four groups of naive subjects were tested, 300 subjects as a whole. The test was administered to 2 groups of children, one group of normal efficient readers and one group of children with Dyslexia. Also 2 groups of adults participated, they were University normal efficient readers and dyslexics. In detail: seventy five dyslexic children (40M and 35F, mean age 10.2 ± 4.5 years); (ii) seventy five dyslexic adults (38M and 37F, mean age 25.4 ± 4.2 years); (iii) seventy five healthy, skilled children readers (33M and 42F, mean age 11.2 ± 5.5 years) and (iv) seventy five healthy, skilled adult readers (36M and 39F, mean age 25.9 ± 7.6 years).

Target groups DYSLEXICS	Control groups NORMAL READERS
75 children	75 children
75 adults	75 adults

Figure 3.7. Table concerning of number of participants for each group.

Technical details

All dyslexic participants had previously undergone a complete neuropsychological assessment to establish the diagnosis of Developmental Dyslexia. All children had been diagnosed as dyslexic based on standard inclusion and exclusion criteria (ICD-10; World Health Organization, 1992). Their performance in reading was two (or more) standard deviations below the mean in at least one of the age-standardized Italian reading tests included in the battery (word, non-word and text reading), and their non-verbal or performance IQ was above 85. Performance IQ was estimated by the Italian adaptation of the Wechsler Intelligence Scale for Children-revised (WISC-R; Wechsler, 1994), or Cattell's "Culture Free" test (Cattell, 1979). Comorbidity with ADHD or other psychopathological conditions was excluded, based on standard diagnostic criteria (DSM-V; American Psychiatric Association, 2013).

The four comparison groups here studied: normal efficient readers and dyslexic readers, were classified by mean of The Dyslexia Screener (TDS), a rapid 5-minute test, which helped to fit children and adults into categories of either non-dyslexia, different degrees of dyslexia, specifying the 3 major subtypes: dysphonetic (subjects with problems in word-attack coding, thus, being more 'auditory'), dyseidetic (subjects with problems with whole-word coding, thus, being more 'visual'), or mixed (subjects being both dyseidetic and dysphonetic), as specified by Boder (1971). The TDS, although having a very high predictive power (87%) for identifying poor readers who are dyslexic, has also been validated using the Woodcock-Johnson standardized reading tests. Children were classified as dyslexic in grades. Some were dysphonetic, others were found dyseidetic, but some others were mixed, being both dysphonetic and dyseidetic, ranging in severity from borderline or markedly below normal. All dyslexics, both children and adults, were at an appropriate grade for decoding reading. All subjects in each group had normal visual acuity or vision corrected with lenses because of slight miopia or/and astigmatism. All had received an ophthalmic, optometric and orthoptic assessment in order to spot any significant non-corrected visual problem. Only one subject was found with severe visual acuity problem, she wanted to participate to the experiment, however, her results were not integrated in the statistics. They also had normal color vision tested on the Ishihara 24 test plates, except 5 subjects. In order to participate to this study, they also had to have normal intelligence as verified by standardized tests administered by the school, and not known visual abnormalities, or obvious behavioral or neurological disorders of any kind. This research has been approved in each school from which subjects were recruited following a bureaucratic approval documentation, which stated that this research was not meant to test personality nor emotion nor the intelligence nor familiar social issues, and it was stressed that it was only meant to test the effects of chromatic accentuation in different categories of readers. This research, also satisfies the Helsinki declaration.

Recruitment and allocation

All subjects had to give an informed consent in order to participate. I had access to those young and adults dyslexics subjects thanks to schools, teachers, therapists, headmasters and under previous informed consent (as I mentioned above) signed by parents or legal guardian in case of children. Since young and adults subjects were recruited from schools and after school institutes, it needs to be stated that, although they were all certified as dyslexics, they were found to have different subtypes of dyslexia. In other terms, some were dysphonetic and/or dyseidetic. In addition, among them, after years of school education, there were some subjects who were adequately compensated in such a way that they had learned how to deal with their deficiency to overcome their problems efficiently enough so as to give a fairly adequate performance. On the other hand, some others, were surely not so efficiently compensated or at least they were less compensated, so that they had more problems in overcoming the reading difficulties. Among these subjects, some were also disorthographics and/or dyscalculics. However, all subjects were allocated in the right group according to their main characteristics: being a child/adult dyslexic or being a child/adult normal efficient reader. Criteria for allocation came from different sources. First of all, all the details learned directly from reports given by subjects themselves or reported by school teachers and parents together, plus their specific medical documentation, helped to allocate subjects. However, as already observed in the paragraph above, some tests, the TDS, the Woodcock-Johnson standardized reading tests, to detect dyslexics and the Ishihara test for color blindness were also administered in order to be sure to allocate subjects in the correct group. The normal color vision subjects and the color blind or color impaired subjects were allocated in the control groups or in the target groups according to the criteria: child/adult, dyslexic/efficient reader. Only two adults among the normal efficient readers and three children among the normal efficient readers were found with impaired color vision after the Ishihara 24 plates color vision test and the Farnsworth-Munsell 100 hue Color Vision Test. As for dyslexics, although they were found with different characteristics and with different subtypes of dyslexia, again they all came to be part of the same target group, following the differentiation criteria: dyslexic adult or dyslexic child.

The control groups

Two control groups were tested, a group of children and one of adults. In the children control group, there were 75 children, all normal readers going from 8 to 10 years old. They were all recruited from primary schools, and they were not only young Italian children, but they were also children born from immigrates settled in Italy, so, for many of them their first mother tongue was not Italian but Chinese, African, Senegalese French and other languages.

In the target group of adults, there were 75 university subjects, all with normal reading and writing skills. They were recruited from the University of Sassari, in particular from the Department of Humanities and Social Sciences. Most of them were first year student in the new course of Psychological Sciences and Techniques of Cognitive Processes.

In the control groups, after having been tested with the Ishihara color vision test, 24 plates, 3 children were found with color vision impairment as well as 2 adults.

The target groups

Two target groups were also tested: a group of children and one of adults. This target group of children was a group made up of 75 dyslexic children going from 8 to 12 years old. Also an adult target group of dyslexics participated. They were adults going from 13 to 26 years old. In these two target groups all subjects were instead dyslexic readers. In this group there are only children which were found disorthographics, dyscalculic, dysphonethic and dyseidetic. All the dyslexics subjects in this experimental research, both children and adults possess the same characteristics according to the Diagnostic criteria highlighted in the DSM-5(American Psychiatric Association, 2013). In fact they were all found with specific learning disorders certified by neuropsychiatrists medical doctors. They all had, all or at least one of the following symptoms:

- Inaccurate or slow and effortful word reading characterized by reading single words aloud incorrectly, or slowly and hesitantly, frequently guessing words when reading, having difficulty in sounding out words.
- Difficulty in understanding the meaning of what is read. For example not understanding the sequence, relationships and deeper meaning of the text even if reading accurately.
- Difficulty in spelling. For example they may omit, add or substitute vowels or consonants.
- Difficulties with written texts, making multiple grammatical or punctuation errors within sentences, or employing poor paragraph organization and/or having a lack of clarity in written expression when reporting their ideas.

Stimuli

The stimuli were created using 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, 5600Åã K: Osram, Munich, Germany). All conditions were displayed in the frontoparallel plane at a distance of 50 cm from the observer. All subjects were strongly advised to maintain the given distanced from the screen. They were also kindly asked not to move their chair and computer from the given position as well as they were also warned not to move their heads back and forth from the screen during the reading task.

It was chosen "the War of Ghosts" written by Barlett (1932) translated in Italian language as the base for the stimuli. With this text, 18 different combinations of stimuli were created using colors to enhance wholes or to fragment the text. In short, colors were used to put in relief the whole text or just enhance single words, half words, syllables and finally letters.

The word condition stimuli

In greater detail, 5 attached and 5 detached stimuli, made up of real words, translated in Italian language from "The War of Ghosts" by Barlett, were created. The 5 attached and the 5 detached conditions are organized as follows: the monochromatic color condition where the text is all green in color, the same green color of the equiluminat colors described previously in the stimuli; a word condition, in which every single word has a different color, from the words placed before and after; a half word condition were the use of color splits the word into 2 halves, the first half is colored with a different color of the second half and the color of the second half is the same of the one of the first half; a syllable condition where every syllable has its own, a letter condition where each letter is of a different color from the adjacent ones. It is worthwhile noting that the syllable condition is a stimulus which was not explored in previous works, nor in the work by Pinna & Deiana (2014). Please see the detached and attached stimuli condition in Figs. 3.8-3.11 in the next pages.

Una sera due giovani di Egulac discesero il fiume per cacciare foche e mentre stavano lì si fece nebbioso e calmo. Sentirono grida di guerra, e pensarono: "Forse è una spedizione di guerrieri". Fuggirono sulla spiaggia, e si nascosero dietro a un tronco. Subito arrivarono delle canoe, e loro sentivano il rumore dei remi, e videro una canoa che andava verso di loro. C'erano cinque uomini nella canoa, e dissero: "Cosa ne pensate? Vogliamo portarvi con noi per combattere con certa gente". Disse un giovane: "Non ho frecce". "Le frecce sono nella canoa", risposero. "Non verrò. Potrei restare ucciso. I miei genitori non sanno dove sono andato. Ma tu", aggiunse rivolgendosi al compagno, "puoi andar con loro". Così un giovane andò, mentre l'altro rincasò. Ed i guerrieri navigarono sul fiume fino ad una città sull'altro lato di Kalama. Quelli del posto corsero verso l'acqua, ed iniziarono a combattere, e molti furono uccisi. Ma ad un certo punto il giovane sentì uno dei guerrieri che diceva: "Presto, ritorniamo, quell'indiano è stato colpito". Allora pensò: "Oh, sono fantasmi". Non si sentiva male, ma dicevano che egli era stato colpito. Così le canoe tornarono ad Egulac, ed il giovane sbarcò a casa sua, ed accese un fuoco. E diceva a tutti: "State a sentire, ho accompagnato i fantasmi, e combattemmo. Molti dei nostri, e molti avversari, morirono. Dicevano che io son stato colpito, però sto benissimo". Finì il suo racconto, poi stette zitto. Al sorgere del sole lui cadde a terra. Qualcosa di nero uscì dalla sua bocca. La sua faccia fece una smorfia. Tutti si alzarono in piedi gridando. Era morto.

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Figure 3.8. The five detached chromatic conditions: monochromatic, word , half word, syllable, letter.

UnaseraduegiovanidiEgulacdisceseroilfiumepercacciarefochee
mentrestavanolìsifecenebbiosoecalmo.Sentironogridadiguerra,
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piaggia,esinascoserodietroauntronco.Subitoarrivaronodellecan
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versodiloro.C'eranocinqueuomininellacanoa,edissero:"Cosane
pensate?Vogliamoportarviconnoipercombattereconcertagente".
Disseungiovane:"Nonhofrecce"."Lefreccesononellacanoa",risp
osero."Nonverrò.Potreirestareucciso.Imieigenitorinonsannodov
esonoandato.Matu",aggiunserivolgendosialcompagno,"puoiand
arconloro".Cosìungiovaneandò,mentrel'altrorincasò.Ediguerrier
inavigaronosulfiumefinoadunacittàsull'altrolatodiKalama.Quellid
elpostocorseroversol'acqua,ediniziaronoacombattere,emoltifur
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ceva:"Presto,ritorniamo,quell'indianoèstatocolpito".Allorapensò:
"Oh,sonofantasmi".Nonsisentivamale,madicevanocheeglierast
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asasua,edacceseunfuoco.Edicevaatutti:"Stateasentire,hoacco
mpagnatoifantasmi,ecombattemmo.Moltideinostri,emoltiavvers
ari,morirono.Dicevanocheiosonstatocolpito,peròstobenissimo".
Finìilsuoracconto,poistettezitto.Alsorgeredelsoleluicaddeaterra.
Qualcosadinerouscìdallasuabocca.Lasuafacciafeceunasmorfia.
Tuttisialzaronoinpiedigridando.Eramorto.

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Tuttisialzaronoinpiedigridando.Eramorto.

Figure 3.9. The five attached word chromatic conditions: monochromatic, word , half word, syllable, letter.

Nau rase edu nivagio id Elacgu scedirose il mefiu per recaccia chefo e tremen novasta li si cefe sobbione e mocal. Tisennoro dagri di raguer, e sapennoro: "Sefor noso riguerrie". Funoggiro lasul giaspiag, e si sconarose troedi a un cotron. Sutobi noarrirova ledel enoca, e rolo novatisen il rerumo ide mire, e rovide aun noaca che vadaan soverdi rolo. Cenora quecin nimiuo lanel anoca, e rosedis: "Soca ne sapente? Vomoglia vitarpor con ino per rebattecom con tacer tegen". Sedis un nevagio: "Non ho cefrec". "Le cefrec noso lanel anoca", sesporiro. "Non rover. Poitre starere soucci. I eimi nigerito non nosan vedo noso toanda. Ma tu", seaggiun sigenvolrido al pacongno, "ipuo daran con rolo". Sico un vanegio doan, tremen trolal socarin. Ed i rieguerri nogavirona sul mefiu nofi ad nau tacit sultrolal tola di makala. Liquel del stopo rosecor sover qualac, ed zianoroini a rebattecom, e timol nofuro siucci. Ma ad un tocer puton il vanegio tisen nou ide rieguerri che vacedi: "Stopre niamoritor, linquelnodia è tosta pitocol". Alralo sopen: "Oh, noso smitafan". Non si vatisen lema, ma cevadino che glie rae tosta pitocol. Sico le nocae ronatorno ad Elacgu, ed il negiova cosbar a saca asu, ed seacce un cofuo. E cediva a tittut: "State a tiresen, ho gnapatocomac i tasmifan e mobattemcom. Timol ide strino, e timol veravrisa nororimo. Divanoce che io son tosta topicol, rope sto sinisibemo". Nifi il osu toraccon, ipo testet tozit. Al gesorre del leso ilu decad a rater. Qualsaco di rone sciu ladal asu caboc. La asu ciafac cefe aun fiasmo. Titut si nozaroal in dipie dodangri. Rae tomor.

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Figure 3.10. The four detached non-word chromatic conditions: monochromatic, word, syllable, letter.

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Figure 3.11. The four attached non-word chromatic conditions: monochromatic, word, syllable, letter.

The non-word condition stimuli

A non-word condition for each of the mentioned categories, except that concerning the half word, were also created (Figs. 3.10-3.11). It was decided to administer versions in which words were naturally separated by a blank space but also versions were all the words were not separated by a blank space were also used. The stimuli were organized as here described: 4 chromatic detached non-word conditions and 4 non-words attached conditions: a monochromatic condition (all green in color), a condition were each word carried a different color, a condition were each syllable carried a different color from the other syllables and a condition were all the letters were depicted with a different color. In the non-word condition, each non-word stimulus was created by transposing and migrating adjacent letters within each word. The non-word conditions are complete new stimuli not previously studied by Pinna & Deiana (2014).

In these stimuli conditions, color was used to pit chromatic similarity in favor (the word condition pitted against the monochromatic control) or against the grouping principles of proximity (the distance between two adjacent words against the breaking off of the words by adding a blank space), of the element of connectedness (Palmer, 1999) and of past experience. Indeed, in the half word condition stimuli, the color is used to divide, the word into two parts, thus ungrouping what is similar by chromaticity and at the same time grouping each of them by means of chromatic similarity respectively to the previous and the next word. Also the syllable and the letter conditions play with chromatic similarly but not as strongly. Within these last conditions, the ungrouping effect is strong, nevertheless it is not reinforced by the grouping by similarity with the previous and next word as it happens in the half word condition.

To sum up, the five chromatic variations of the stimulus text were aimed to create wholes (monochromatic and word conditions), parts-whole organizations (word condition) and fragments (syllable and letter conditions) and as such they were expected to influence the reading process in time, number of errors and comprehension of the text

Procedure

The setting

All subjects were tested under the same conditions. All adults subjects were tested in the University laboratory, while all children were tested in their own school, in a silent room and under the same light condition created in the laboratory (for better details see the previous paragraph on stimuli) and with the same technology. Each subject was given 2 stimuli to read: a real word stimulus condition and a non-word stimulus condition. Though the stimuli were randomized, it was care of the experimenter to avoid presenting the same color condition to the same subject when alternating the detached and attached version of the stimuli every time. This was done to prevent every undesirable chromatic contamination. In addition, the presentation order of the two stimuli, the word stimulus condition and the non-word, was randomized and their presentation was separated by an hour delay to give each subject the possibility to rest after the first reading and comprehension tasks. Although some visual contamination in between the two stimuli could have occurred, it is supposed to be very small and counterbalanced by the randomized presentation of the two stimuli given.

The phenomenological tasks

The reading task

This task was administer to 75 children, normal readers and to 75 children, dyslexic readers as well as to 75 adults, normal readers and to 75 adults, dyslexics readers. They were asked to read the texts as clearly, accurately and as quickly as possible in a loud voice. They were given no time constraint but the number of errors made while reading and also how long it took their performance were considered and monitored. Every subject could only participate to two conditions: every subject was given to read one stimulus created with the real words of the story and a non-word condition, alternating between the attached and the detached stimuli every time. The reading errors were: phonetic errors, omissions, jumps…etc.

The reading comprehension task

After the reading task, they were also asked to answer to a multiple choice reading comprehension test related to the story " The War of Ghost" from which the stimuli were created, and their number of errors was taken into account. Errors for the reading comprehension task were counted on a scale from 0 to 10, the higher the score, the higher the number of incorrect answers given.

The aleatory variables considered were reading time, number of reading errors, and number of incorrect answers to the reading comprehension task.

Results

The main findings of this research are presented below. They are presented by analyzing separately the main outcomes related to each aleatory variable: reading time, reading errors and the number of incorrect answers in the reading comprehension test in relation to the five chromatic conditions referred to the four groups of subjects (normal children and adults, dyslexic children and adults). First of all, the data concerning the word and non-word conditions of the detached words will be analyzed. After that, the outcomes concerning all the data in relation to the word and non-word conditions concerning those stimuli which were built with not separation in between words will follow in the presentation of the results.

Reading time - detached word/non-word

The outcomes of the reading time under the word condition, concerning those stimuli where the words were left detached, as a function of different chromatic variations and for the four different groups (children and adults, normal and dyslexic readers) are presented in Fig. 3.12. They clearly replicated the previous results found by Pinna & Deiana, (2014). It is worth to note how the similarity and dissimilarity attributes and, thus, the grouping/ungrouping dynamics imparted by the chromatic accentuation in the different conditions highly affects the time needed to read the War of Ghosts. For each group a one way ANOVA showed significant variations within the five chromatic conditions as follow: children-normal readers: $F_{4,36}=20.7$, $p<0.001$; adults-normal readers: $F_{4,36}=17.3$, $p<0.001$, children-dyslexics: $F_{4,36}=19.9$, $p<0.001$; adults-dyslexics: $F_{4,36}=18.4$, $p<0.001$). The Fisher PLSD post hoc analyses of the possible pairs were significant ($p<0.05$).

If it is considered the monochromatic condition as a control stimuli, both normal and dyslexic readers, children and adults, read the word condition (the stimulus were each word emerges by means of different colors) faster than the control one. On the other hand, time tends to increase in the half word condition. These findings came as not very much surprise. As a matter of fact, the same chromatic similarity/dissimilarity principle works in total opposite directions, by grouping or by dividing into 2 parts, and by ungrouping each word. In this way, the reading process resulted faster or slower than the control. The effect of chromatic similarity/dissimilarity is annulled in the letter condition. Each letter, in fact, has a different color from the adjacent one, in practice it is an item on its own. The results obtained with the letter condition, indeed is very similar to the visual structure that can be observed in the monochromatic condition, where, on the contrary, the color of each letter does not change but, the whole test is in fact monochromatic. It sounds like a paradox but, since every letter in the letter condition has a different color, all the letters look similar in their dissimilarity. Consequently, the chromatic grouping/ungrouping push/pull effect, which is remarkably strong in the word and half word condition, in the letter condition is reduced or even completely annulled. This annulment creates an paradoxical effect of homogeneous heterogeneity isomorphic to the monochromatic control condition.

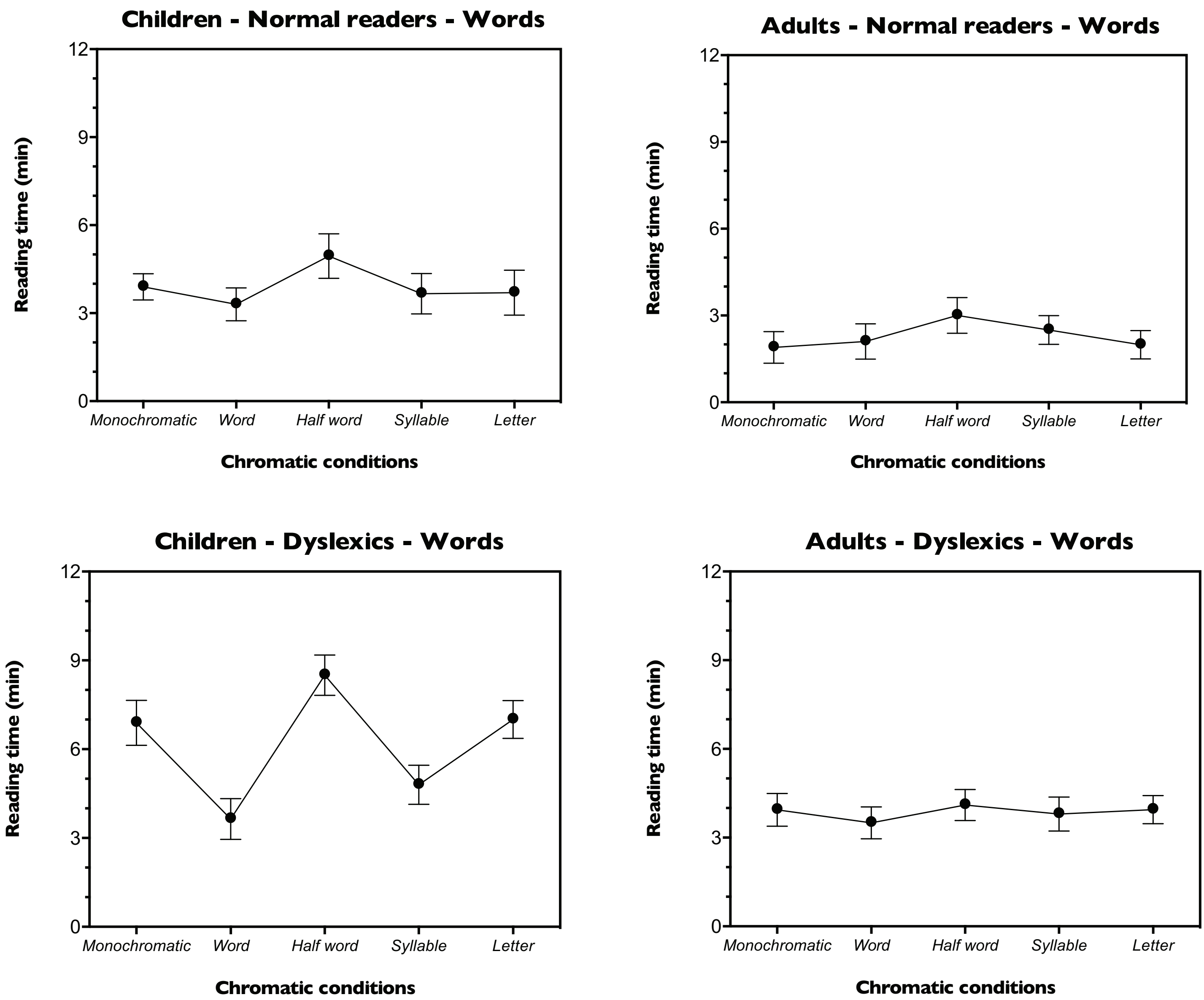

Figure 3.12. Results for the word reading time as a function of the different chromatic conditions and for the different groups of participants: children and adults, normal and dyslexic readers.

What happens than in the syllable condition? The syllable condition obtained some very interesting results and it stands in between the word, the half word and letter color condition. However, before introducing the results found as far as the syllable color condition is concerned, a few lines will be spent to say precisely what a syllable is. This will be done for three main reasons. First, in order to understand appropriately what is intended for syllable, second, it will be useful to help predict the results for the color condition and third, it is essential to understand the choice for including the syllable variation in these experiments. A syllable is a unit of organization for a sequence of speech sounds. This entails that a syllable is a perceptual unity, it is something distinct, and it is the result of a first level of natural grouping which is based on phonological changes. In a way, this is similar to the grouping effect caused by colors in the previous conditions. Syllables can, in fact, be regarded as building blocks of colors that arranged in different ways, can help speed up or slow down the reading time.

In addition, the syllable has the ability to affect the rhythm of the spoken language, its prosody, its poetic meter as well as its stress arrangement. Furthermore, the spelling of syllables, are treated as primitive units during school years, above all when children are learning how to read. Syllables are, indeed, fundamental for all children in this phase of reading acquisition and, above all in the case of dyslexic learners. In reality, it needs to be stated that the spelling of syllable starts to become much less important as far as the learning progress proceeds. This is not true for dyslexics. This clearly emerged from the results where the reading time of the syllable condition turned out to be in both groups of dyslexics, children and adults, faster than the control and that the letter condition. The outcomes of the syllable color condition is comparable in speed to the word color condition. On the contrary, the syllable color condition appeared slower for normal children and adults when compared to the outcomes obtained for the word color condition. This last findings obtained are the most relevant differences between normal readers and dyslexics. Another, easily predicable difference concerns the absolute values of the reading time, which, is significantly slower in both dyslexic groups, children and adults.

In brief, the results observed for the reading time showed that color can significantly influence wholeness and segmentation during the reading process according to a scale where the highest and lowest poles are respectively the word and the half word conditions. Finally, these results demonstrate that color can be a meaningful tool useful to improve the reading performances both for normal and dyslexics readers.

The results obtained for the reading time under non-word conditions are illustrated in Fig. 3.13 . In these graphs is shown the significant strength of chromatic similarity and dissimilarity in grouping/ungrouping elements. A one-way ANOVA showed significant variations within the five chromatic variations also for the non-word condition and in each group, children-normal readers: $F_{3,27}=18.5$, $p<0.001$; adults-normal readers: $F_{3,27}=20.2$, $p<0.001$; children-dyslexics: $F_{3,27}=18.9$, $p<0.001$; adults-dyslexics: $F_{3,27}=18.2$, $p<0.001$). The Fisher PLSD post hoc analyses of the main pairs were significant ($p<0.05$).

The conditions studied in this group of chromatic conditions were: monochromatic, word (here the correct term should be "non-word", but "word" is left to make easy the comparison among the other conditions and tasks), then, the syllable and letter condition. The half word chromatic condition was not included, since this variation aimed at pitting the chromatic similarity, which belongs to a low perceptual domain, against the high level cognitive domain of word recognition, which is linked to what Gestalt psychologists called "past experience". In fact, with these color conditions the role of color is only focused on a reading process without meaning. Here, chromatic similarity is now pitted against the grapheme-phoneme conversion rules mainly addressed to read, in fact, non-words.

According to different researchers, (cf. Friedmann & Rahamim, 2007; Friedmann et al., 2010a; Friedmann & Haddad-Hanna, 2012; Kohnen et al., 2012) a word is normally processed following three main routes: first, the lexical route (orthographic input lexicon to phonological output lexicon), second the lexical-semantic route (orthographic input lexicon to phonological output lexicon across the semantic system), and finally the non-lexical route (grapheme-phoneme conversion). Most of the times, through the lexical and lexical-semantic routes all words are processed with success within a reader's orthographic input lexicon but they cannot succeed in processing non-words. On the other hand, the non-lexical route successfully help sound out non-words and words that follow typical letter to sound rules, but it normally fails to provide accurate pronunciation for irregular words.

These outcomes revealed that the chromatic organization can be pitted successfully in favor or against the grapheme-phoneme conversion process. Although this topic is not a target object of investigation in this work, the results suggest a novel way to explore and understand the way the grapheme-phoneme conversion may work.

The findings concerning the normal and dyslexic readers, both children and adults, corroborate the previous ones showing the same trends among chromatic conditions. However, it has to be noted that for dyslexics, the chromatic variations among words, syllable or letters, although the color was reported to be disturbing and made the reading harder, they showed that subjects took less time to read them in comparison to the monochromatic color condition. Again, the syllable variation reveals the same differences previously described for normal and dyslexic readers.

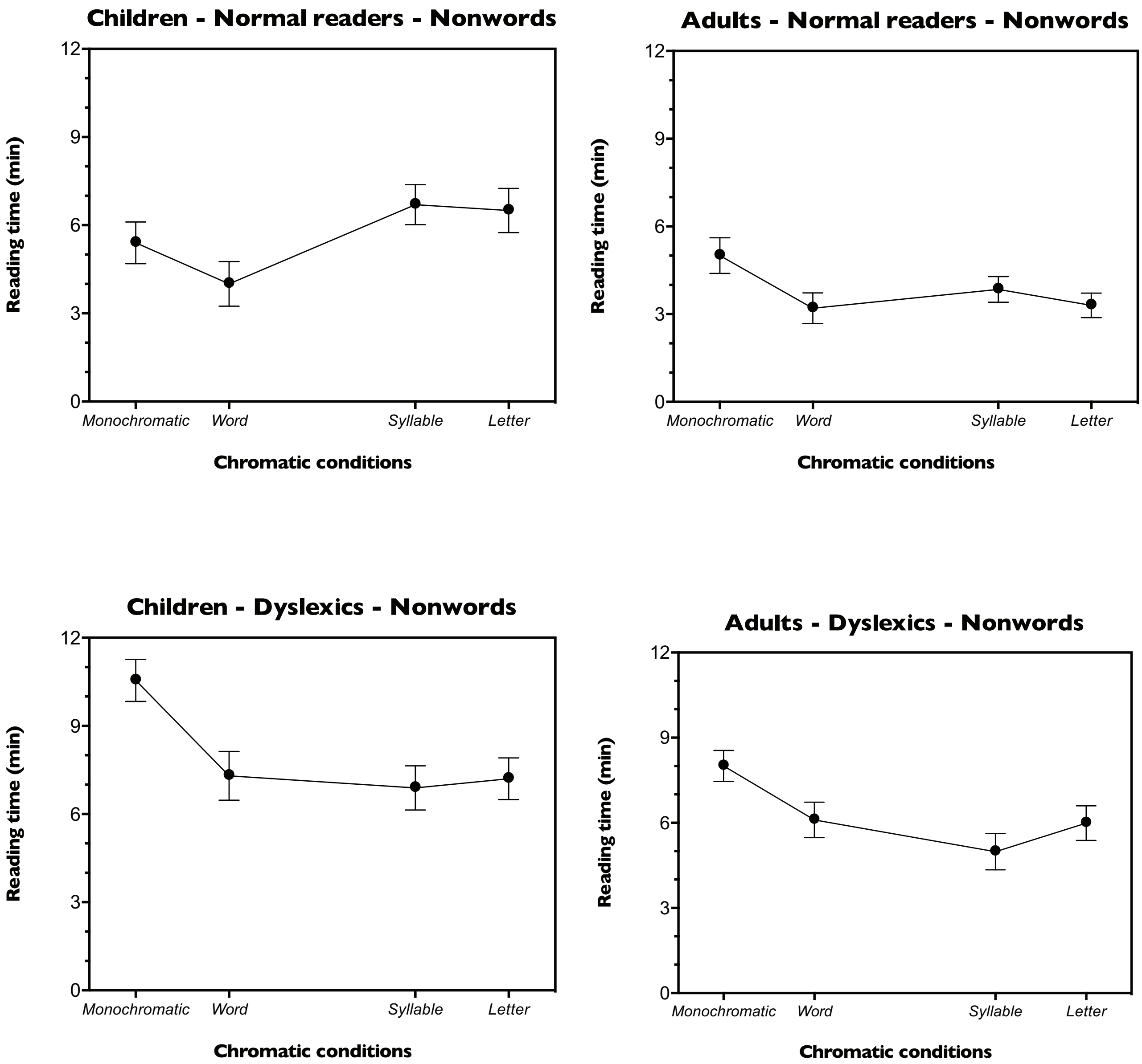

Figure 3.13. Results for the non-word reading time as a function of the different chromatic conditions and for the different groups of participants: children and adults, normal and dyslexic readers.

Reading errors - detached word/non-word

As far as the reading errors are concerned, it is quite natural to assume that the reading time of a text is directly related to its reading difficulties. The more the text was found difficult by the readers, the more the reading errors. This means that the trend of the number of errors is expected to be similar to the trend observed in the reading time. As a matter of fact, this is precisely what Figs. 3.14, 3.15 respectively showed for the word and non-word conditions in the four groups in relation to the chromatic color conditions.

Significant variations within the five chromatic variations were demonstrated through a one-way ANOVA (i) for the word condition and for each group: children-normal readers: $F_{4,36}=15.7$, $p<0.001$; adults-normal readers: $F_{4,36}=19.8$, $p<0.001$, children-dyslexics: $F_{4,36}=22.5$, $p<0.001$; adults-dyslexics: $F_{4,36}=21.8$, $p<0.001$) and (ii) for the non-word condition and for each group: children-normal readers: $F_{3,27}=17.5$, $p<0.001$; adults-normal readers: $F_{3,27}=20.2$, $p<0.001$, children-dyslexics: $F_{3,27}=16.2$, $p<0.001$; adults-dyslexics: $F_{3,27}=20.2$, $p<0.001$). The Fisher PLSD post hoc analyses of the main pairs were significant ($p<0.05$).

It is worthwhile to stress how wide was the gap in the absolute number of errors made by normal and dyslexic readers for both word and non-word conditions.

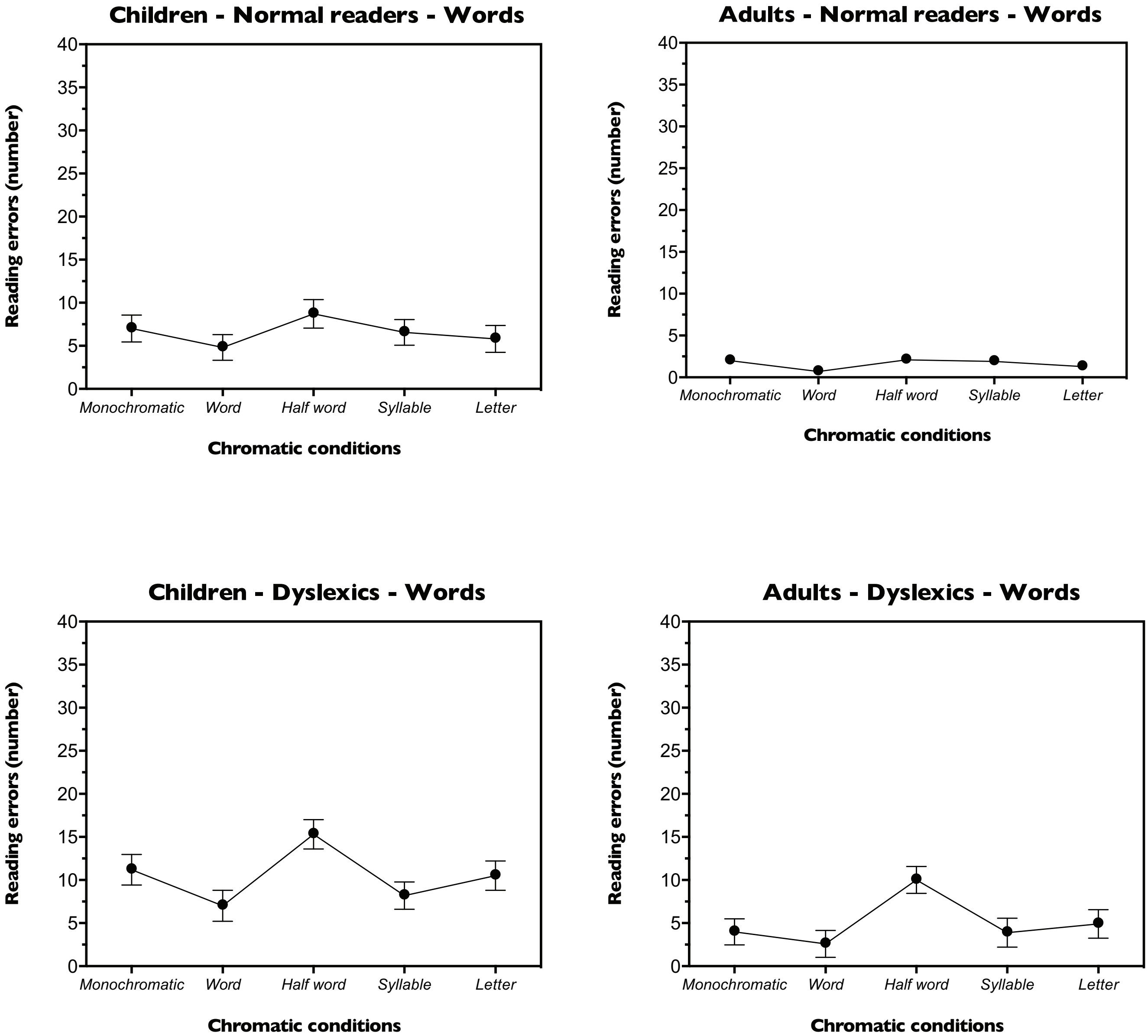

Figure 3.14. Results for the word reading errors as a function of the different chromatic conditions for the four groups of participants: children and adults, normal and dyslexic readers.

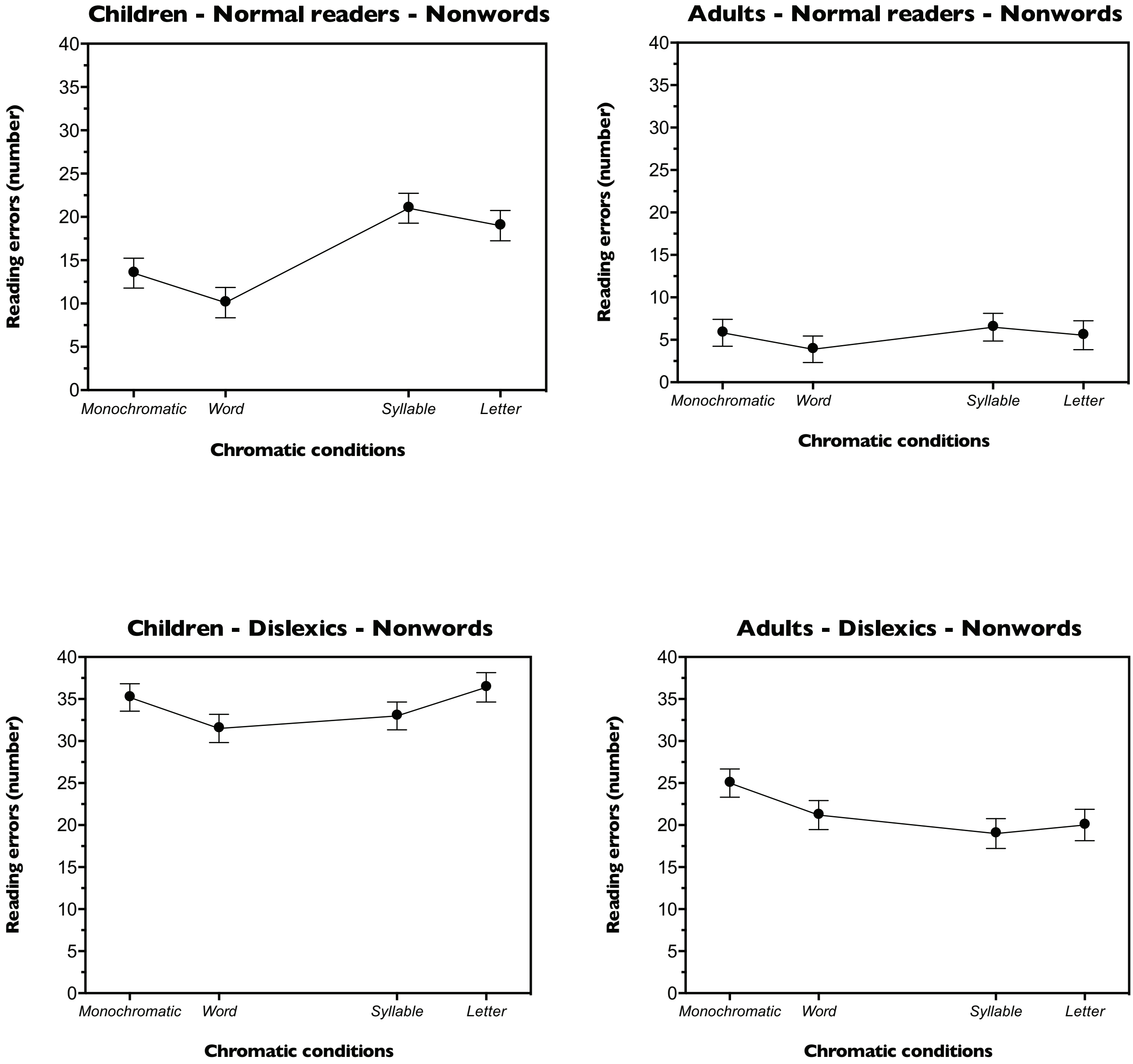

Figure 3.15. Results for the non-word reading errors as a function of the different chromatic conditions for the four groups of participants: children and adults, normal and dyslexic readers.

Comprehension task (number of incorrect answers) - detached word

In Fig. 3.16 are shown the number of incorrect answers given during the comprehension task in relation to the chromatic conditions and referred to the groups of participants. Given the nature of the task, obviously, there was no comprehension reading test for the non-word conditions. A one-way ANOVA for each group highlighted significant variations within the five chromatic conditions: children-normal readers: $F_{4,36}=18.2$, $p<0.001$; adults-normal readers: $F_{4,36}=19.8$, $p<0.001$, children-dyslexics: $F_{4,36}=18.9$, $p<0.001$; adults-dyslexics: $F_{4,36}=22.8$, $p<0.001$). The Fisher PLSD post hoc analyses of the possible pairs were significant ($p<0.05$).

According to the results illustrated in Fig. 8 and according to the previous findings, the reading time, the number of reading errors and the number of incorrect answers during the comprehension task are shown to be all directly related. As a matter of fact, the chromatic condition that needs less time to be read, also generates a smaller number of reading errors and consequently a smaller number of incorrect comprehension answers in the reading comprehension test. With these results, phonological and semantic functions look as if they are strongly related. This supports previous studies conducted by Majerus et al., (2006, 2008, 2010) which state that phonological and semantic functions are processed in close areas of the bilateral temporal lobes.

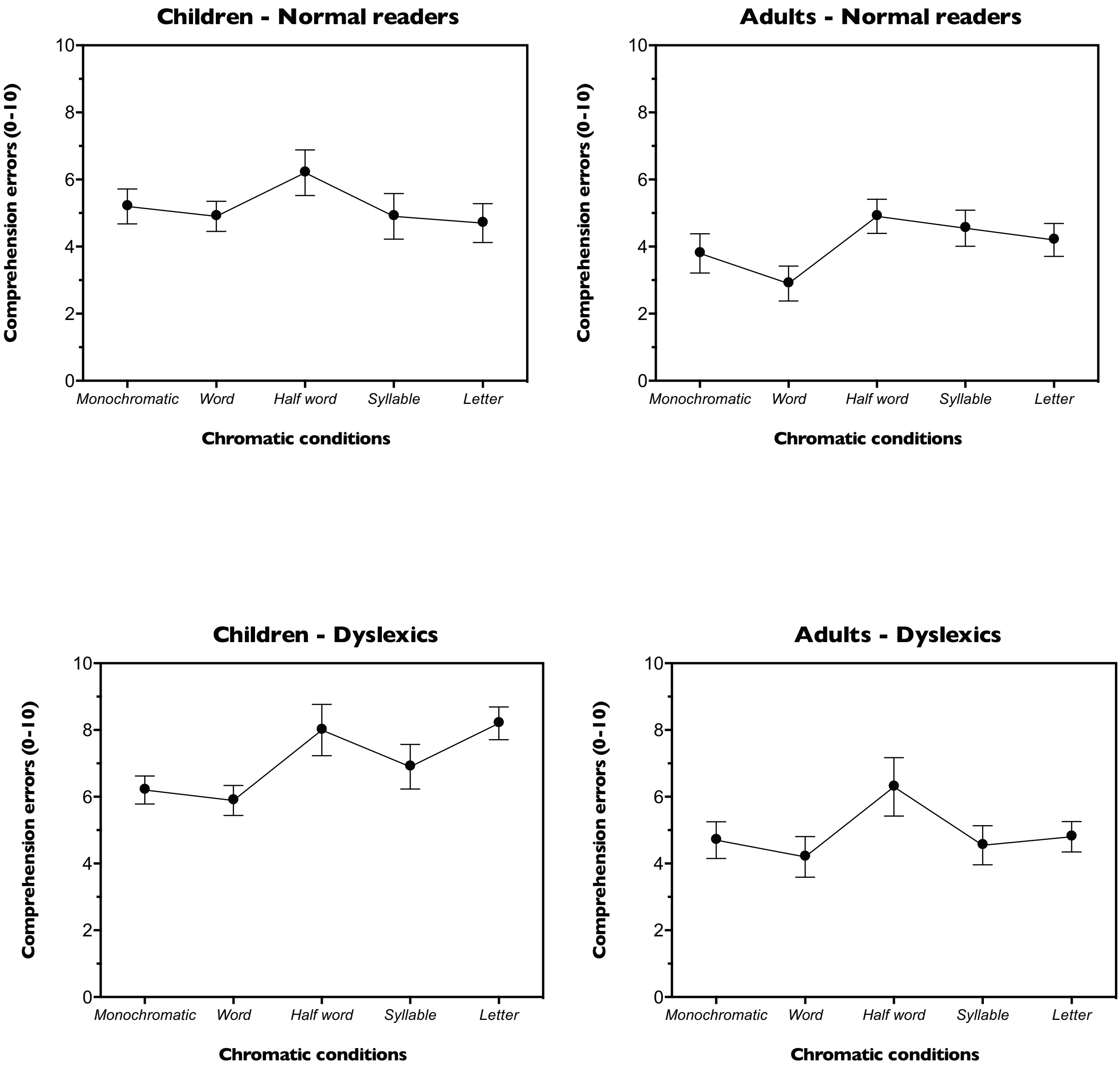

Figure 3.16. Results for the number of incorrect answers to the comprehension test as a function of the different chromatic conditions for the four groups of participants: children and adults, normal and dyslexic readers.

Reading time - attached word/non-word

The results obtained for the reading time in the attached word and non-word conditions followed a similar trend to that observed for the word condition where the words in the stimuli were naturally separated by a blank space. This time, however, what is worth to be stated is the fact that the outcomes appear all shifted upward in the graphs. This is reasonable because, due to proximity, (here the words are all joined) the reading and discrimination of meaningful units result more difficult and took subjects more time to be read, above all for dyslexic readers. This trend can be spotted at a glance from the graphs. Another trend which replicated in comparison to the results of the detached words is that concerning the half word condition, which surely came as the most complex to be read since color splits the words into two non-meaningful halves. The quickest stimulus to be read is the word stimulus (where the color enhances and makes whole words to emerge as single meaningful units). As it also happened in the detached condition, the syllable chromatic condition turned out to be a useful stimulus to improve reading time in dyslexics. Even though proximity was somehow disturbing, dyslexics found the segregation of syllable useful for their reading speed especially in young age. By observing the graphs, Fig.3.17 another peculiar result emerges. In every group of subjects, either the monochromatic condition and the letter color condition obtained the same results as already explained in the section related to the detached word stimuli. As far as the word condition of stimuli is concerned, for each group of subjects, a one way ANOVA showed significant variations within the five chromatic conditions as here reported: children-normal readers: $F_{4,36}=22.5$, $p<0.001$; adults-normal readers: $F_{4,36}=20.2$, $p<0.001$, children-dyslexics: $F_{4,36}=23.9$, $p<0.001$; adults-dyslexics: $F_{4,36}=21.1$, $p<0.001$). The Fisher PLSD post hoc analyses of the possible pairs were significant ($p<0.05$). The results can be observed in the graphs below.

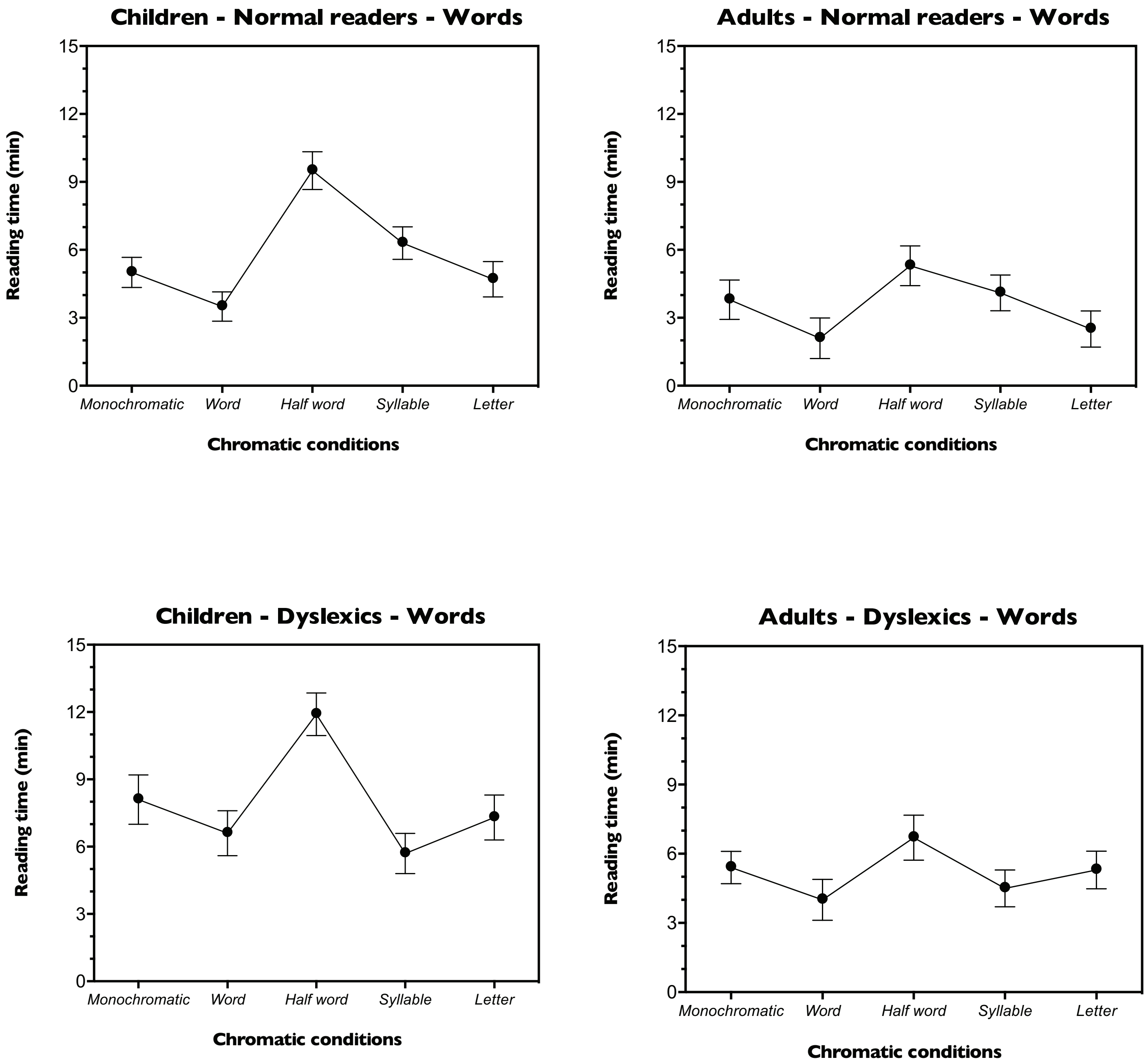

Figure 3.17. Results for the reading time in the word condition as a function of the different chromatic variations in relation to the the four groups of participants: children and adults, normal and dyslexic readers.

But, what were the results for the attached non-word condition. It was reasonable to predict that the attached non-word conditions, appearing as an agglomerate of words without any meaning, took even more time to be read and above all the reading time was especially longer for dyslexics and more precisely for dyslexic children.

As previously stated in this condition, the half word stimulus was not included among the non-word conditions.

The chromatic variations which came out to be read faster in the non-word condition are: words, syllable or letters, although the color was reported to be disturbing and made the reading harder. Nonetheless, these chromatic variations showed that subjects took less time to read them in comparison to the monochromatic color condition. Again, the syllable variation obtained the same differences previously described for normal and dyslexic readers, a part from the group of children, skilled readers, where as it can be observed from the graphs Fig. 3.18 the syllable condition took them more time to be read if compared to the other color conditions.

As far as the non-word condition is concerned, for each of the four groups who participated, a one way ANOVA illustrated the following significant variations within the four chromatic conditions used: children-normal readers: $F_{3,27}=16.7$, $p<0.001$; adults-normal readers: $F_{3,27}=22.2$, $p<0.001$; children-dyslexics: $F_{3,27}=21.6$, $p<0.001$; adults-dyslexics: $F_{3,27}=23.1$, $p<0.001$). The Fisher PLSD post hoc analyses of the main pairs were significant ($p<0.05$).

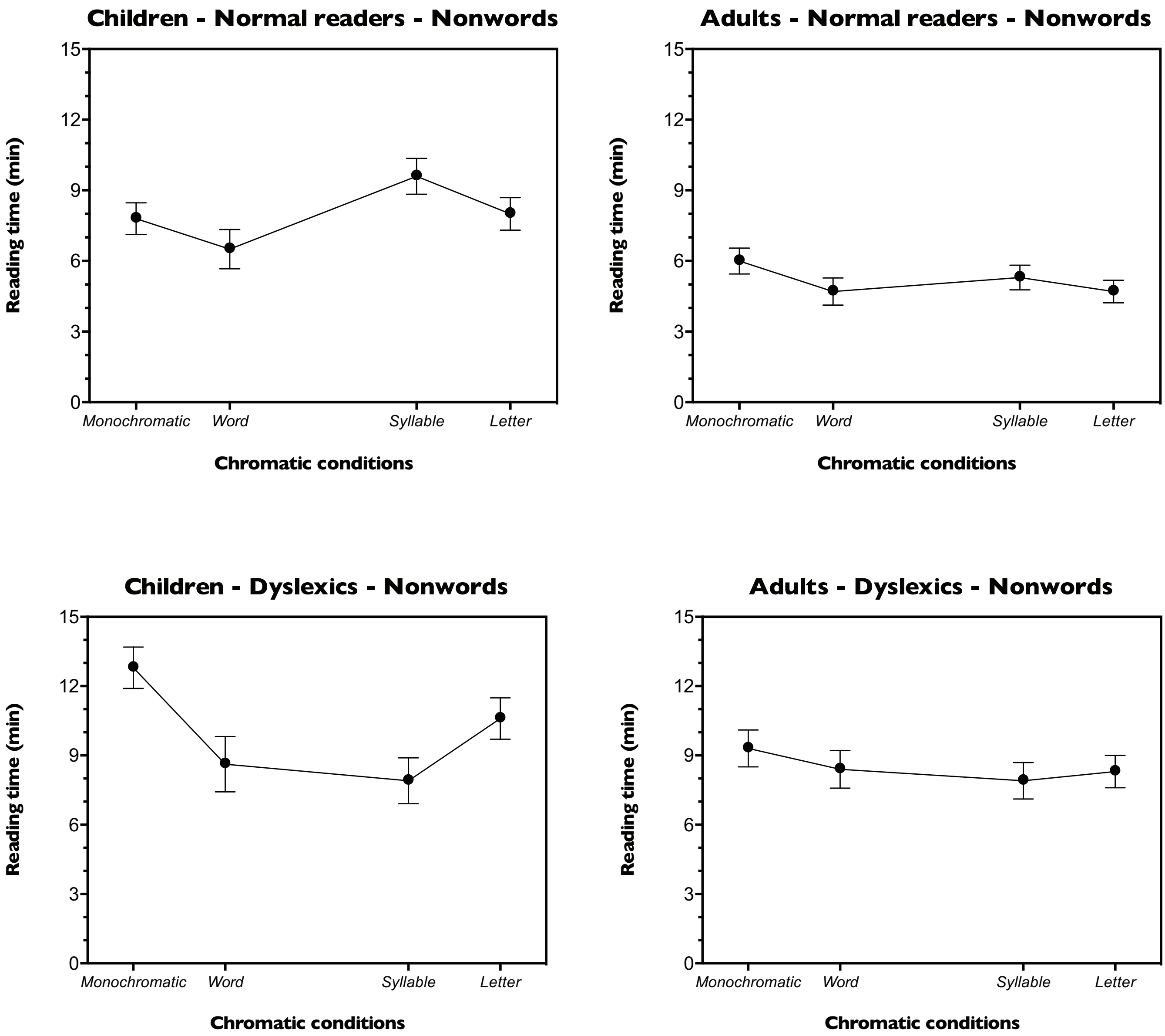

Figure 3.18. Results for the non-word reading time as a function of the different chromatic conditions referred to the four groups.

Reading errors - attached word/ non-word

Also for the reading errors, it is possible to observe a similar trend again when compared to the one reported for each of the four groups in the five word conditions previously analyzed. In this case as well, the attached words, caused the readers more problems and thus more errors were made. It was found that, the stimuli color condition which helped subjects read more accurately were the word and the syllable conditions, in every group, the great majority of subjects could benefit from these stimuli. On the contrary, In paradoxical way, the monochromatic color condition and the letter condition behave very similarly. The former, the whole green text, appeared as a sort of shapeless mass of joined words without no segregation at all, the latter, was too parceled out and again appeared as a shapeless mass of letters.

The graphs next page Fig.3.19 show the results for the five chromatic conditions.

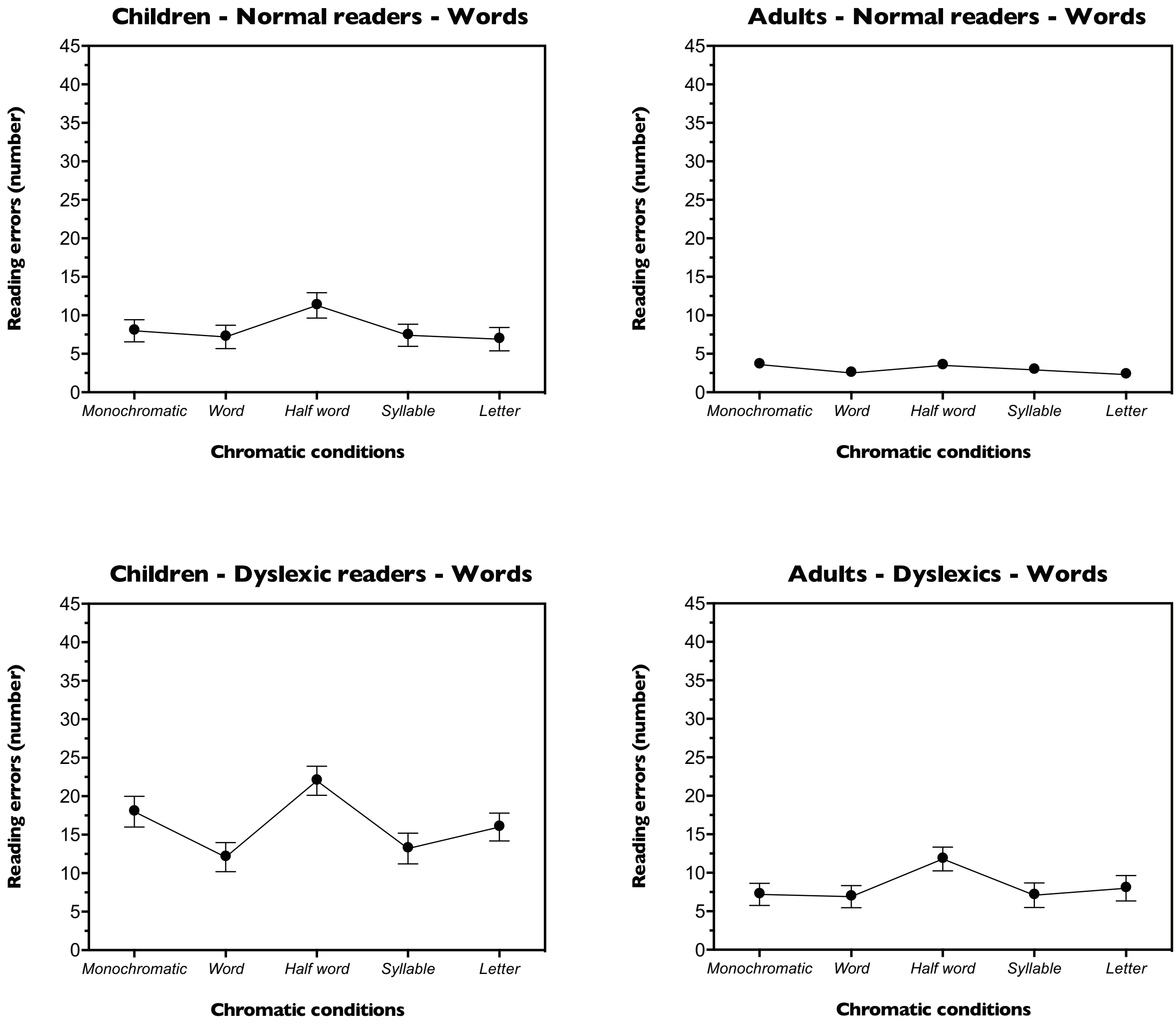

Figure 3.19. Results for the attached word reading errors as a function of the different chromatic conditions in the four groups of subjects.

The attached non-word conditions also replicated similar results if compared to the ones observed in the case of detached non-words already highlighted. The outcomes for the four chromatic conditions can be fully appreciated below in the graphs (Fig. 3.20). As can be noticed, the half word chromatic condition is left out, as previously explained and the whole data are again shifted upward. It came as no surprise that the more the stimulus came out to be difficult to be read, the more the reading errors, above all in the group of dyslexic readers.

A one-way ANOVA showed the following significant variations among the chromatic variations used: concerning the word condition and for each group they were: children-normal readers: $F_{4,36}=18.7$, $p<0.001$; adults-normal readers: $F_{4,36}=22.8$, $p<0.001$, children-dyslexics: $F_{4,36}=23.5$, $p<0.001$; adults-dyslexics: $F_{4,36}=17.8$, $p<0.001$): concerning the non-word condition and for each group they were: children-normal readers: $F_{3,27}=21.4$, $p<0.001$; adults-normal readers: $F_{3,27}=18.7$, $p<0.001$, children-dyslexics: $F_{3,27}=19.4$, $p<0.001$; adults-dyslexics: $F_{3,27}=22.6$, $p<0.001$). The Fisher PLSD post hoc analyses of the main pairs were significant ($p<0.05$).

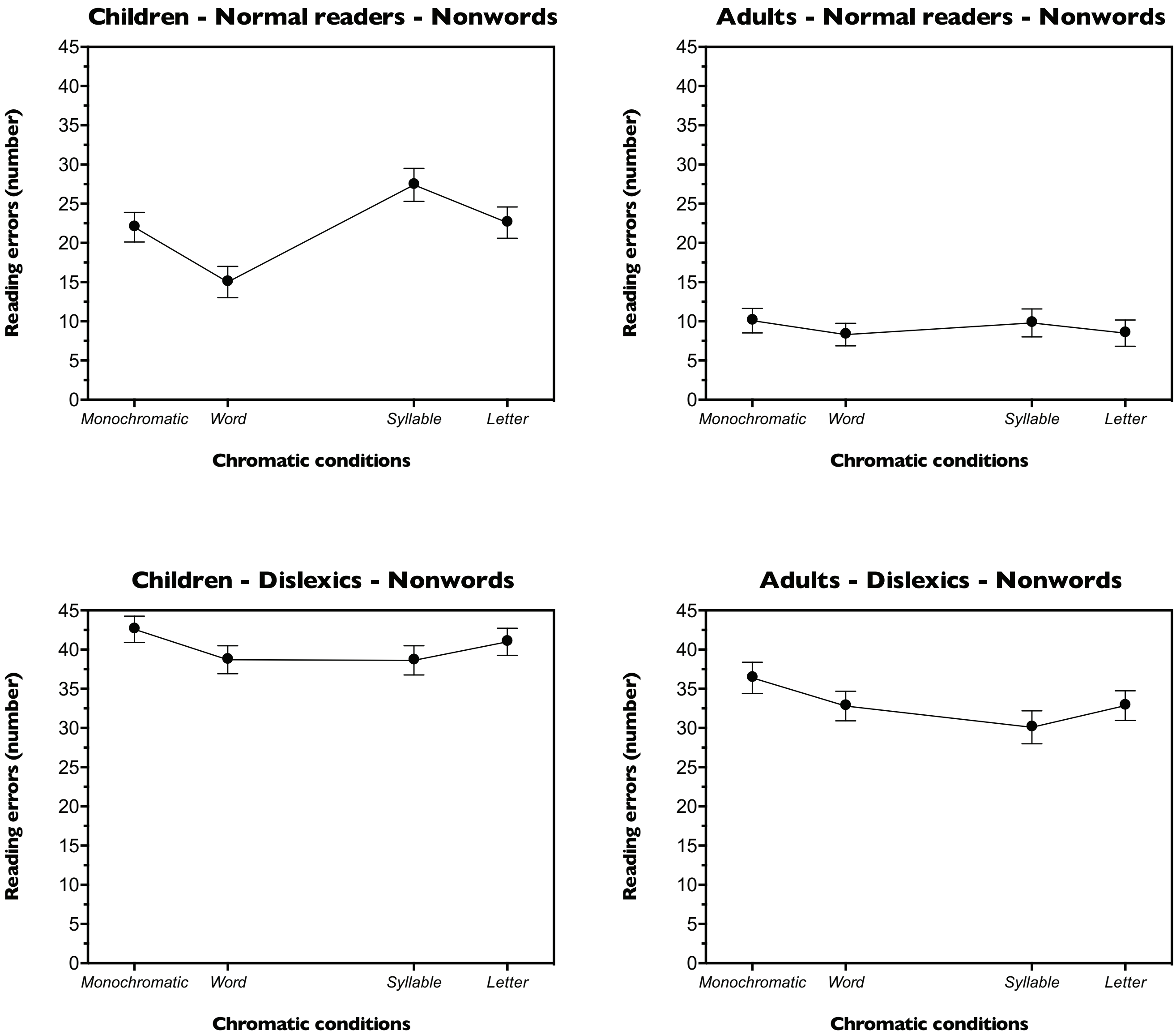

Figure 3.20. Results for the non-word reading errors as a function of the different chromatic conditions in the four different groups of participants.

Comprehension task (number of incorrect answers) - attached word

In Fig. 3.21 are illustrated the number of incorrect answers which were given during the comprehension task by all the subjects of the four groups in relation to the chromatic conditions created. Due to the nature of the task, the non-words, being nonsense words, were not followed by a comprehension reading test, and this sounds sensible. A one-way ANOVA for each group put in relief the significant variations within the five chromatic conditions: children-normal readers: $F_{4,36}=16.8$, $p<0.001$; adults-normal readers: $F_{4,36}=23.8$, $p<0.001$, children-dyslexics: $F_{4,36}=22.0$, $p<0.001$; adults-dyslexics: $F_{4,36}=19.8$, $p<0.001$). The Fisher PLSD post hoc analyses of the possible pairs were significant ($p<0.05$).

According to the previous outcomes, what is crucial to be stressed is that the reading time, the number of reading errors and the number of incorrect answers in the reading comprehension task result to be all directly related one another and again shifted upward in the graph. The more it was found difficult to read the more the time spent in reading it, less the accuracy both in the reading aloud and in the comprehension task.

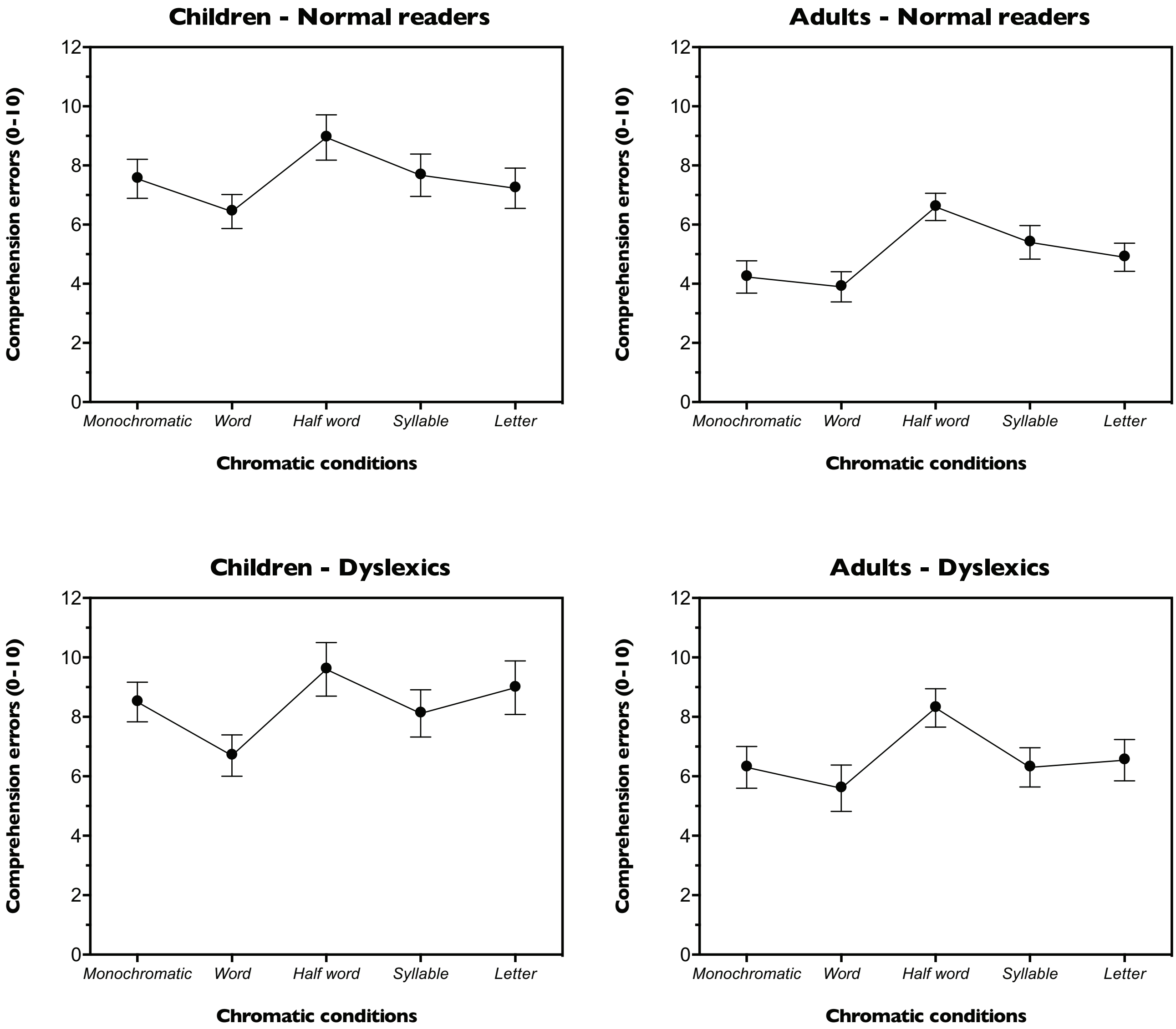

Figure 3.21. Results for the number of incorrect answers to the comprehension test as a function of the different chromatic conditions for the four different groups.

Conclusions

With this research, it are demonstrated the unique and relevant visual properties given by means of chromatic variations in children and adults either normal or dyslexic readers. In fact, this research highlights how the role of color emerged to be crucial in visual organization and segmentation of written text, affecting reading time, errors and comprehension. These results were given by pitting chromatic similarity in favor or against the Gestalt principles of grouping involved in written texts: proximity, first of all that breaks off each word adding a blank space or past experience that can be varied in word and non-word conditions.

In greater details, this study showed that color can induce wholeness, parts-whole organization and phenomenal fragmentation in words and non-words by means of several conditions which were the following: monochromatic (the whole text is colored with only one color); word (each word is colored in different colors); half word (half word is colored with a color different from the one of the second half); syllable (every syllable is colored with a different color); letter (each letter is colored with a different color). The aleatory variable considered in this study were: the reading time, the reading errors and the incorrect answers to a comprehension test. The outcomes obtained demonstrated that they are all directly related and deeply affected by the five chromatic conditions. These results were obtained measuring the aleatory variables in the four groups of readers: children and adults that could be normal or dyslexic readers. One of the main relevant difference which emerged among groups is the one found in the groups of normals and dyslexics readers where, the reading time in words and non-words composed by syllables accentuated with different colors turned out to be more effective for the dyslexic groups.

All these results are consistent with previous works carried out by Pinna & Deiana, (2014), and Pinna et al., (2010) as they demonstrate how color can affect reading in conditions different from the one here presented. The data emerged from these studies may have possible empirical implications. For example, The effect of color in reading and in spelling words and non-words could be used to facilitate and enrich standard teaching methods and it could also be employed in rehabilitation strategies in the case of learning disabilities and, more importantly, in dyslexia but also for normal readers. With this study reliable effects were found although further studies in larger populations are needed to confirm the present data and to extend the research to different conditions where color could be used in new ways in order to create wholeness, parts-whole organization and fragmentation.

An other possible way in which chromatic organization could be applied in reading is by using it according to the accentuation principle (Pinna, 2010a, 2010b, 2012a, 2012b, 2015; Pinna & Sirigu, 2011, 2016;

Pinna et al., in press) as, in these works it was demonstrated that accentuation is more effective when the accent is dissimilar in color (Pinna et al., 2016). By observing Fig. 3.22a, the Arnheim's famous quote is written and then, changed removing the blank spaces in between adjacent words (Fig. 3.22b). Later, it is presented accentuated through several chromatic conditions, for example, putting in red the first or the last letter in each word (Figs. 3.22c-d), or including a small red circle above the first letter always in each word (Fig. 3.22e). Moreover, the chromatic accentuation is again pitted against the principles of proximity and past experience making the text difficult to be read (Fig. 3.22f), or as in the case of words which are broken in the middle by a blank space, the text is made again more readable (Figs. 3.22g-h for a control), or, furthermore, accentuating each word with two different colors, one color placed in the first and another different color placed in the last letter (Fig. 3.22i).

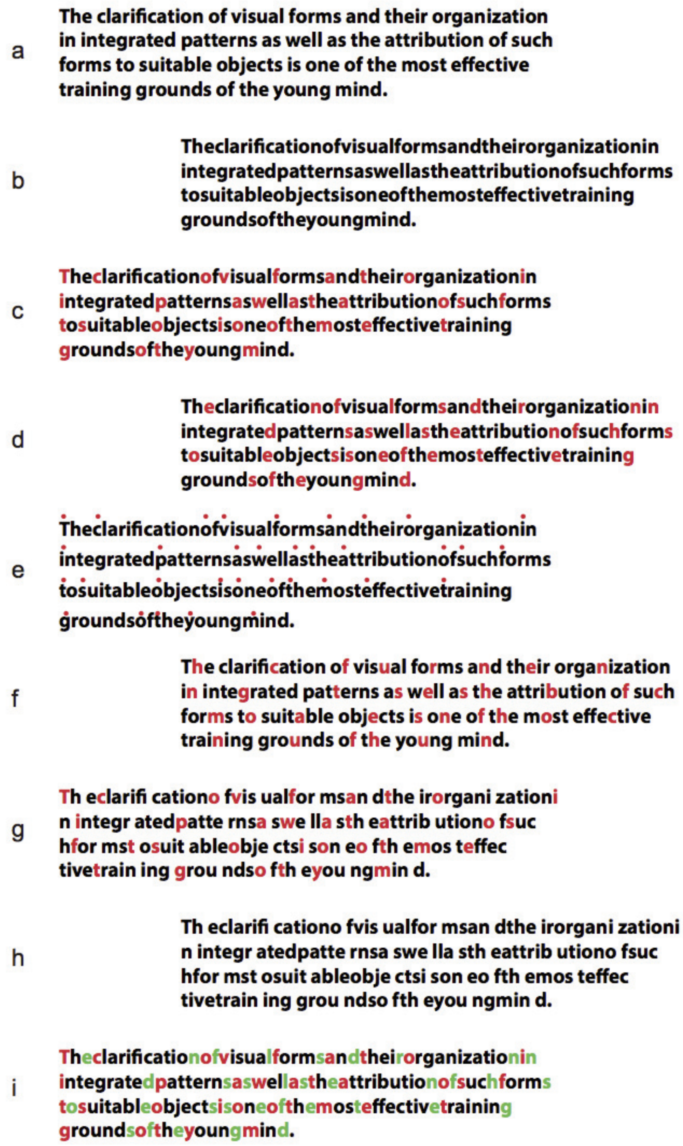

Figure 3.22. The different kinds of chromatic accentuation influencing the reading process.

To sum up, the chromatic accentuation clearly makes easier or difficult to read the quote, masking or unmasking, disrupting or highlighting. Now, if the chromatic accentuation is combined with the chromatic organization studied in this work the role of color is expected to become more and more effective.

Another possible research which may follow this study, might go in the following direction. Considering the fact that many dyslexic subjects reported that colored lenses and overlays were helpful to overcome a wide range of difficulties arising when reading, this research could well be expanded by comparing the effects of colored filters (Wilkins 2003) and of lenses and overlays, (earlier mentioned in this research as a background literature,) with those here reported when they are pitted in favor or against each other.

However, in addition to the possible applied researches or clinical applications that might follow, the main message of this research comes back to the basic questions linked to color vision and pointed out in the Introduction. In fact, these results can help to answer those questions. Indeed, they suggest that the main role of chromatic organization is that to determine a strong grouping effect on elementary components, and it results much stronger than those principles suggested by Gestalt psychologists. By observing the outcomes obtained, chromatic accentuation is especially useful as follows. Firstly, to group similar chromatic components within an object, determining the emergence of the wholeness, second to elicit a parts-whole organization, where both components are not pitted one against the other but complemented and reciprocally reinforced within the whole, and finally to accentuate fragments and to hide the whole helping the emergence of single components.

In conclusion, this triple role is considered of crucial importance not only to understand the high neural investment involved in the evolution of color systems, but also in relation to the fundamental and specialized functions of color as in nature, it provides different biological advantages and an high adaptive fitness. These results may also be useful to answer the following basic biological questions: What is the purpose of color for living beings? What are the adaptive and perceptual meanings of monochromatism and polychromatism?

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