UNIVERSITÀ DEGLI STUDI DI TRENTO

Faculty of Cognitive Sciences
Department of Cognitive and Education Sciences

Doctoral School in
Psychological Sciences and Education

The interplay between shape and colour
An experimental inquiry

Advisor:
prof. Liliana Albertazzi

Co-advisor:
prof. Luisa Canal

PhD Student:
James Dadam

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Introduction

The motivation for this study is the awareness that current perceptual science, even when it deals with qualitative aspects of experience, almost exclusively reasons in quantitative terms, i.e. in terms of primary properties or stimuli. Perceptual quality is typically considered to be an outcome of so-called top-down influences, this being the domain traditionally regarded as being the only functionally relevant qualitative component of mental states. However, perceptual qualities are in principle independent of so-called top-down or cognitive modifications due to the geographical, cultural, linguistic or social environment, to emotional and aesthetic phenomena, or to subjective preferences. Instead, they seem to be the content-bearing referents of perception. Nevertheless, mainstream science does not consider the semantic informational content of perception, and treats qualities in terms of quantities, i.e. mainly as stimuli, and considers their sensory and neurophysiologic elaboration and interpretation (Albertazzi et al., 2011, in press).

This study starts from the classical analyses of experimental phenomenology (Kanizsa, 1980, 1991; Katz, 1911, 1935; Michotte et al., 1964/1991), which produced excellent and never confuted results in vision perception, and considers them in light of more recent psychophysical and neurophysiologic research. The work deals with some perceptual aspects of shape and colour vision, and specifically with the relation between the widespread phenomenon of amodality in vision and the multifarious characteristics of colour appearances.

The study is divided into a theoretical and an experimental part, and the rationale of the two experiments is discussed within the systematic framework illustrated in Chapter 1 and Chapter 2, respectively on the topics of colour and amodality.

Specifically, the first chapter reviews several aspects of colour perception and colour theories. As to linguistics studies, it analyses how they have been developed into two different approaches, the universalistic (Berlin and Kay, 1969; Cook et al., 2005; Delgado, 2004; Drivonikou et al., 2007; Gilbert et al., 2006; Hardin, 2005; Kay, 2005; Kay and McDaniel, 1978; Kay and Regier, 2003, 2006, 2007; Kay et al., 1991, 1997; Regier and Kay, 2004; Regier et al., 2007, etc.) and the relativist ones (Agrillo and Roberson, 2007; Boroditsky, 2001; Davidoff, 1991, 2006; Davidoff and Roberson, 2004; Davidoff et al., 1999; Jameson, 2005a, b; Jameson et al., 2007; Levinson, 2000; MacKeigan and Muth, 2006; Roberson, 2005; Roberson and Davidoff, 2000; Roberson et al., 2000, 2002, 2004; etc.), and how a relatively recent study by MacLaury (1992) proposes the integration of the two approaches into an explanatory theory. These theories are contrasted with an alternative approach to colour analysis, based on Hering's theory (1878/1964), according to which colour is a purely visual phenomenon which does not need the mediation of language to be perceived.

After different theories on colour are introduced, the modes of appearance of colour are analysed (Katz, 1911, 1935). The recent literature on the different modes of colour appearance are also discussed, including simultaneous contrast, spreading, crispening, colour assimilation, etc.. Another aspect of colour study considered is colour harmony. Analysed in particular are the experimental studies of Cohn (1894), Major (1895) and Bullough (1907), essentially the founders of this type of analysis, and more recent ones like Alexander and Shansky (1976), Bailey et al. (2006), Da Pos (1999), Kimura (1950), Payne (1958, 1961), and Wright (1962).

Studies on the cold/warm (Bailey et al., 2006; Kimura, 1950; Newhall, 1941; Tinker, 1938; Wright, 1962), advancing/retiring (Chen and Lin, 2005; Goethe, 1810/1982; Luckiesh, 1918; Tornquist 1999), dark/heavy and dark/light (Bullough, 1907; DeCamp, 1917; Monroe, 1925; Taylor, 1930; Warden and Flynn, 1926) aspects of colours are also discussed, as well as their effects in depth perception. The last section of the first chapter analyses the relationship between shape and colour, considering also Kandinsky's hypothesis in the domain of art (1912), which suggested the existence of a fundamental correspondence between colour and geometrical shape. Experimental literature on the topic is discussed and analysed: for instance, Jacobsen (2002), and Albertazzi et al. (submitted), whose results, using a broader sample of colours and shapes than previous studies, have shown a significant relation whereby some colours are more frequently matched with certain shapes, whilst other colours are less frequently matched with other shapes.

The chapter on amodality considers and discusses the principal theories on amodal completion (Kanizsa, 1980, 1991; Kellman and Shipley, 1991; Nakayama et al., 1995; Takeichi et al., 1995; Tse, 1998, 1999a, b), resulting in a critical survey of the most relevant existent literature. The emphasis is placed on the local, global and internal representation theories of amodal completion, including theories about contour, surface and volumes completion. The chapter then analyses the literature on the dimensional effects of amodal completion (Kanizsa, 1980, 1991; Vezzani, 1998, 1999; Zanforlin, 1981a, b), such as the effects of expansion or shrinkage, although it is not clear whether or not these effects result from amodal completion. Finally this chapter considers an important but not yet analysed aspect of completion phenomena, i.e. colour. Unfortunately, in fact, there are few studies on the relation between colour and amodal completion (Pinna, 2005, 2006, 2008), and there are absolutely none on the effects of colour on dimensional phenomena.

The third chapter describes an experiment carried out in Italy and in Brazil in order to study the effects of colour in dimensional phenomena, seeking to answer questions like whether colour strengthens dimensional effects, whether particular colours produce specific effects when compared with other colours, whether there are differences between chromatic and achromatic colours and whether there are any effects if harmonic or disharmonic configurations of colours are introduced.

The results show that colour has an effect on amodal completion, and particularly regarding dark/light colours and harmonic and disharmonic configurations. It is seen that, for a particular group of experimental subjects, light colour always expanded, while for other groups the expansion depended on the position of the colour in the configuration.

The fourth chapter describes an experiment carried out in Germany and in Italy in order to test the existence of a perceived natural relationship between shape and colour using – differently from Albertazzi et al. (submitted) – non-geometrical figures. The figures were taken from Haeckel (2004), and consisted in drawings of microorganisms like *Spumellaria*, *Cyrtoidea* and *Diatomea*. The aim of this study was to verify whether there is a natural relation between colours and natural shapes, and which elements or parts of the shapes – like orientation, type of shape, margins, texture or dimensionality – might be responsible for that relation and explain it. The analysis also considered warm/cold colour characteristics. The first part of the experiment concerned the natural relation between colour and shape; the second part was performed using the Osgood Semantic Differential.

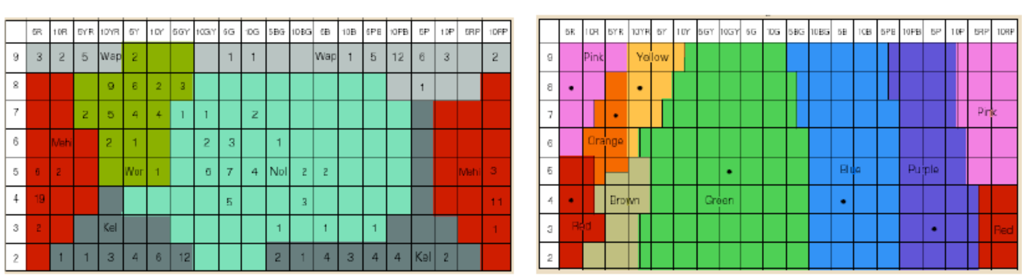
Both the experiments gave encouraging results, in some cases very significant ones, which have prompted us to develop this type of inquiry and methodology further. Some other experiments, in fact, are already in progress and others are to be designed. Overall, one of the best achievements of the research reported, has been its demonstration of the feasibility of the phenomenological methods, complementary to psychophysical methods in the scientific analysis of visual perception.

Chapter 1

Colour

The concept of colour is usually classified according to scientific definitions, linguistic categorizations and phenomenological descriptions. Scientific definitions are explicative and universal, while linguistic categorizations are partly universal (basic colour terms, see below), partly relative to the specific languages; phenomenological descriptions reflect both universal and subjective aspects of colour perception and, for this reason, the most difficult to analyse and classify.

According to a universalistic viewpoint, language does not model the reality, but only its classification in linguistic categories (Berlin and Kay, 1969). Conversely, from a relativistic viewpoint, perception of colour is influenced by language and culture (Lucy and Shweder, 1979; Whorf, 1956). Evidence for this viewpoint is, for exemple, the fact that Dani[1] (New Guinea) have only two terms for colour: *mola* for warm and light colours as red and yellow, and *mili* for cold and dark colours, as blue and green (Heider, 1972). In other words, they group all the hues under a more general category of light/dark. Roberson et al. (2000) found that in the Berinmo (Papua New Guinea) language there are five terms of colour: *wor* for some green, *wap* for almost all the light colours, *kel* for almost all the dark colours, *mehi* for red, and *nol*, which covers blue, blue/purple and most of the green (Figure 1.1).



(a) (b)

Figure 1.1 – Colour categories in (a) Berinmo and in (b) English (Davidoff et al., 1999).

[1] The Dani are a people from the Central highlands of western New Guinea, Province of Papua, Indonesia.

Berinmo's categories, then, primarily organize the colour terms according to luminosity appearances, with only 'some' hues indicated by a specific internal partition (not all nuances of red and green are items of the category, for example).

Different languages also present a different number of linguistic categories to name the nuances of the elementary colours (red, yellow, blue, green and the two achromatics). Italian and Russian, for instace, make a distinction in terms of blue. Italians have blue and *azzurro* (light blue), while Russians have *sinii* (синий) and *goluboy* (голубой) for light blue, and so on. Depending on who is the speaker, the naming of colour depends not only on how many linguistic terms of expression for colour the speaker's own language permits, but also and several other factors, among which is linguistic competence. In general, the environment seems to exercise a particular influence in the number of colour terms. For instance, because of the different types of ground, people in deserts have more names for yellow and red than people in Alaska, where there would be different names for white because of the ice and snow, or than those in a jungle, where different terms for green would be most useful.

In conclusion, according to the relativistic viewpoint, the way one names the world determines the cognitive modality in which one perceives the reality. Speakers of different languages, thus, *would perceive* the reality in a different way.

The question of the number of linguistic terms is not the only problem about colour to bring up concerning relativism. Albers (1963), for example, observed that if someone said "red", or other name of another colour, and there was a group of people listening to him/her, then for each one of them, there would be a different 'red' *in their minds*. In other words, fifty people would probably have fifty different 'reds'. Albers argues that even those fifty people who said they thought of the 'Coca-Cola red', which is the same around the world, would have thought of different reds. And even if all these people had hundreds of red samples in front of them from which to choose the Coca-Cola one, they would probably select different reds. Even if people were shown the Coca-Cola red, Albers continued, one cannot be sure that they would be having the same *subjective* perception. This occurs, argues Albers, because it is impossible to *remember* distinct colours, and *because* the nomenclature of colour is still most inadequate.

In their pioneering work, however, Berlin and Kay (1969) found and maintained that there is a universal inventory of eleven basic colour categories, and that all languages use all or fewer of these: white, black, red, green, yellow, blue, brown, purple, pink, orange and grey, in that temporal order of appearance (criticism in Delgado, 2004). A high degree of agreement on focal colours was confirmed by anthropological and psychological studies, in the sense that focal colours are named more rapidly, the given names for focal colour are shorter, and short-terms memory tasks give evidence that colour memory is aided by the existence of the relevant colour terms in one's language (Heider, 1972). Briefly, according to the universalists, a total universal inventory of basic colour categories exist.

Several studies have been carried out in support of both accounts of the main established theories. Defending the universalistic point of view, there are Berlin and Kay (1969), Cook et al. (2005), Delgado (2004), Drivonikou et al. (2007), Gilbert et al. (2006), Hardin (2005), Kay (2005), Kay and McDaniel (1978), Kay and Regier (2003, 2006, 2007), Kay et al. (1991, 1997), Regier and Kay (2004) and Regier et al. (2007). In the relativistic account there is the research of Agrillo and Roberson (2007), Boroditsky (2001), Davidoff (1991, 2006), Davidoff and Roberson (2004), Davidoff et al. (1999), Gumperz and Levinson (1996), Jameson (2005a, b), Jameson et al. (2007), Levinson (2000), Lucy (1992, 1997), Lucy and Shweder (1979), MacKeigan and Muth (2006), O'Hanlon and Roberson (2006, 2007), Pitchford and Mullen (2006), Roberson (2005), Roberson and Davidoff (2000), Roberson et al. (1999, 2000, 2002, 2004), Saunders (2000), Saunders and van Brakel (1997) and Soja (1994).

The vantage point theory on the evolution of basic colour terms of MacLaury (1992) proposed that the findings from both accounts could be integrated by an explanatory theory, preserving the debate between the two groups. This theory states that colour's categorization depends on attention; or more precisely, if it is directed more at similarity, there would be the predominance of brightness, while if the attention is directed at difference, hue would have predominance. MacLaury reached this conclusion after he had taken into consideration some changes of perspective in the analysis of colour from the study of Kay et al. (1991) on yellow-green-blue. Figure 1.2 shows the evolution of the sequence of colour categorization for hue and brightness.

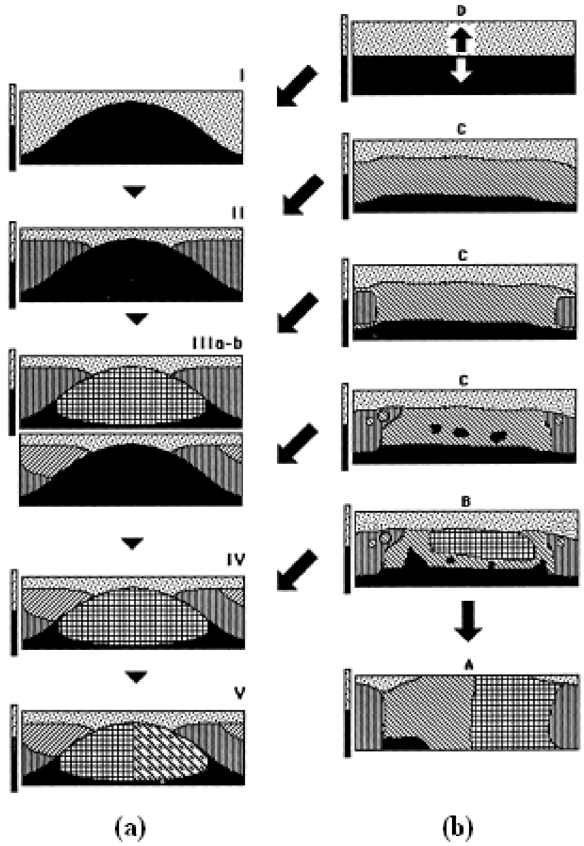


Figure 1.2 – Hue (a) and Brightness (b) sequences (MacLaury, 1992, p. 160, original drawing).

Although brightness categorizations are not as common as hue categorizations, they have a regular relationship with the second one and a strong emphasis at the first stage of colour categorization evolution. However, the more evolved the categorization of the language, the less importance is given to brightness, while hue assumes more weight. Hue sequence, in fact, not only prevails around the world, but the development of brightness categories melds into it (MacLaury, 1992, p. 159).

In comparison, if the first stage in Figure 1.2b is observed, a two-term brightness system of type D is seen (MacLaury, 1992), representing a category which has been constructed only to a level of brightness, and two cognitive coordinates, corresponding to the Stage I (Figure 1.2a) of Berlin and Kay (1969), which comprises the black and white colours, or light-warm and dark-cool categories from Rosch (Heider, 1972). The next step is comprised of three versions of type C, with and without a red category. These types merge into Stage II (white, black and red), and then into Stages IIIa (white, black, red and green) and IIIb (white, black, red and yellow). In Stage II, the light-warm category of Stage I is divided into white and a warm categories, which are comprised of red and yellow. Stage IIIa splits dark-cool into black and cool, and Stage IIIb divides warm into red and yellow.

Type B, in its turn, is characterized by a new hue category, which emerges from a weakening brightness category, and it merges into Stage IV (white, black, red, green and yellow), where both options of Stage III are present. Finally, the last type is comprised of hue categories of yellow-with-green, blue-purple, red-pink, white and black. According to MacLaury (1978, 1991), this rare type A system occurs in Salish languages and others.

Stage V (white, black, red, green, yellow and blue – see Figure 1.2 above) of Berlin and Kay (1969) is also represented in this scheme of MacLaury's (1992). Here the cool category has a new distinction between green and blue. Stages VI and VII are not listed in MacLaury scheme, but they are characterized by the addition of brown in Stage VI, and purple, pink and orange in the last Stage. A grey category can emerge at any stage.

It is important to notice that merger goes only in the hue direction. This could happen because brightness, that sweeps across the domain at large, may be a more general aspect of the perception of colour, while unique hues are located in confined areas of the colour space. Then, when attention to similarity becomes weaker and that to distinctiveness becomes stronger, it is possible that brightness appears less attractive as a reference in relation to unique hues. In this sense, when the attention to similarity is stronger, categories should be constructed on the basis of brightness. If attention is stronger than distinctiveness, then hue should be used to form the categories.

Assuming a differential attention to similarity and to distinctiveness, it would be possible to explain why individuals who speak different languages represent different stages of colour-category evolution according to the Berlin and Kay (1969) schema, despite the fact that they see the same colours from the vision point of view. It would also be possible to explain why people from small societies could represent different stages of colour-term evolution.

To sum it up, the two opposite viewpoints of relativists and universalists approach the question of colour perception in two different ways: according to the universalists, perceptual tasks are independent of language, whereas, according to the relativists, all kinds of behaviour, perception included, are culturally shaped.

However, both accounts of universalism and relativism share a common argument. Universalists argue that there are universals of colour, concerning the recognition of its focality, that derive from the universality of perception given by physiology. Relativists, on the other hand, argue that despite the universality of perception given by physiology, the differentiation of the terms and the colour conceptualization are arguments that support their position, i.e. the importance of language in discriminating the colour field (for a criticism see Da Pos and Albertazzi, 2010).

An alternative possibility in colour analysing is adopting a phenomenological approach, assuming that no matter how language influences behaviour, some universal constraints exist due to the 'natural' perceiving of colours and environment (Bergström, 2004; Da Pos, 2002; Da Pos and Albertazzi, 2010; Da Pos and Valenti, 2007; Hård and Sivik, 1981). Based on the observations on colour perception made by Hering (1878/1964), this account sees colour as a purely visual phenomena, which is organized only by using phenomenological procedures, without the mediation of language. The organization of colour in this system is done according to their judged similarity. In a task where each colour must be set near the most similar to it their representation in the space would depend on their similarity in vision: the more similar they are, the closer they would be represented.

An important aspect of Hering's considerations about colour perception is colour uniqueness. A unique hue is that without any mixed hues, thus only four of all of the hues are considered as unique: red, yellow, blue and green, plus white and black. Orange and turquoise, for this viewpoint, are mixed hues, in the sense that orange, for instance, is seen as composed by yellow and red.

Besides uniqueness of hues, a second important point in the construction of a phenomenological categorization of colour is the related concept of opponency. If one looks at all the colours between red and green, passing by yellow, any trace of blue will be found. If one passes through the blues, no yellow can be found. This means that blue is the opponent of yellow and vice-versa, as green is the opponent of red, and vice-versa. In this sense, yellow is perceived from the unique green until the unique red, which is are boundaries, while green is perceived from the unique yellow until the unique blue. For red, the boundaries are the unique yellow and unique blue, and for blue, the boundaries are the unique green and unique red. This means that some blue can be seen between the two boundaries, but not out of them, and so on for the other colours. Black and white, however, are not opponents because there is no natural boundary dividing them. Every colour can appear more or less white or black, because between them there is a continuity in which several degrees of grey can be observed, because every grey is composed, in different measures, by both black and white. Thus, every colour can appear whitish or blackish (Da Pos and Albertazzi, 2010).

To sum up, a phenomenological approach maintains that the field of phenomenal visual objects is also the primary reference of colour perception, and that, in principle, language is not necessary to categorize colour perception; that colour space is articulated by the distinction between unique and mixed colours, and by opponency; that the unique colours interrupt the chromatic continuum, creating *sharper* boundaries than the linguistic boundaries themselves, listed by Berlin and Kay (1969); that the opponent categories cannot overlap, this property being allowed only for adjacent categories; and finally, that the chromatic continuum has internal directions, and the appearance of a colour can change in one or other direction, i.e., it can increase towards an unique colour or towards the other.

The above aspects describe a natural perceptual categorization of colour, mostly independent of individual subjectivity or community of speakers, and corroborates a specific universalistic accounting of colour perception, in agreement with the perceptual 'modes of appearance' of colour (Katz, 1935, see below).

1.1 The modes of appearance of colour

Katz developed a classification of the modes of appearance of colours, in which he distinguished surface colour, film colour and volume colour (Katz, 1911, 1935). The first is present in most parts of objects people are in touch with everyday. In this case, colour is a part of the object, specifically its surface. It has a solid, compact and material aspect, like an object. Surface colours, as the surface of an object, can be smooth or wrinkled because they always follow the texture of the object's surface.

Film colour, instead, does not have a precise spatial localization because it is less dense or filmy, perfectly uniform, but without texture or heterogeneousness. An example of film colour is fog or smoke. In this appearance of colour one has the impression that the gaze can penetrate into its thickness because it seems less compact and less consistent, while in the surface colour, this does not happen because it offers resistance, forcing the gaze to stop on the external object surface. Film colour is always located in a smooth place and people never see pronounced wrinkles in it.

Both surface and film colour can be transparent. Transparent film colours are characterized by a certain degree of transparency, which allow us to see something through it. A coloured gelatine and a smoked glass are examples of this type of appearance of colour. They do not black out the background, and the objects positioned behind them can be seen, although the surface colour of these objects suffers some influence of the transparent film colours. The transparency of surface colours, on the other hand, is that which is obtained from an opaque object. If an opaque object is placed between one of the eyes and the place where the gaze is directed, one will see the colour of the opaque object become transparent.

The last way of appearance described by Katz is volume colour, characterized for filling phenomenally a three-dimensional space, such as the colour of a liquid. Here the gaze can penetrate the colour. Although a certain degree of transparency is a necessary condition to the presence of the chromatic volume, the gaze can pass completely through the object and perceive other objects behind it. It is considered as a volume colour only when it has a certain degree of transparency. For instance, if the fog is so thick and does not allow the observation of another object beyond it, then no volume is perceived and the white of the fog is perceived as a film colour. However, if people can see other objects through the fog, then its 'voluminousness' is clearly perceived.

Katz carried out a series of experiments in order to test the effects of colour in determined situations. Although the largest part of his studies regarded surface colours, that was not all he researched. In the following sections the main aspects of his theory and his experiments are summarized.

1.1.1 Film colours

One of the experiments performed by Katz using film colours regarded the subjective visual grey. Katz argued that there are no doubts about the existence of individual differences in the mode of appearance of this colour. All subjects who took part in the experiment agreed that it was definitely less localized than the other colours. Apart from the fact that it lies in front of the eyes, it was really difficult to make a more precise description of its location. Katz found that for most of the participants the subjective grey did not seem to lie in one plane. The various parts of its curved surface, indeed, seemed to appear at different distances. Observers reported that the grey 'centre' was located at circa 10-40 centimetres of distance. Its surface seemed to have a concave curvature toward subjects, described by most of them as 'funnel-shaped'. It never seemed to have the same colour. Sometimes it was the central parts, and other times it was the peripheral parts that appeared distinctly brighter. The subjective grey had something of voluminous, but it did not fill space in the same way as fog, for example. It had the mode of appearance of film colour, was very indefinitely localized, and was related to volume colour.

How about the location of the other film colours? If it was not easy to determine either the location or the apparent distance of grey, in which way could observers describe the other film colours? If closed eyes were directly illuminated, a brilliant orange was perceived. If this was done for a long time, and then the light-source was suddenly covered, greenish-blue colours, darker than subjective grey were observed, although they were not as uniform as the grey. The brighter colour seemed to be darker in its margins while the darker seemed to be bright there. The brighter colour seemed to lie at a greater distance than the subjective grey, and also appeared more voluminous and, with intense light-source, luminous. The darker colour, in its turn, appeared further than the grey, but less voluminous than it. The fact that other colours had a more defined location than the grey could be explained by the fact that the peripheral excitation produces a colour exceeding the subjective grey in insistence[2] (Katz, 1935, p. 63).

In a particular experiment, Katz used chromatic or achromatic 2.5 centimetres paper circles pasted upon achromatic cardboard in order to produce achromatic and chromatic after-images upon a lighter or darker achromatic background. In this way, he could observe the most important cases of differences in colour and brightness between after-image and ground. Observations indicated that after-images were almost always located distinctly at a distance different from that of the ground, with the following characteristics: (i) a brighter after-image always lay before a darker achromatic background; (ii) a chromatic after-image always lay before and achromatic background when this is not much brighter than the after-image; (iii) if the after-image was

[2] For insistence, Katz means that a colour has approximately the same brightness throughout its extent.

considerably darker than the achromatic ground, in most of the cases there was an impression that the after-image lay at a greater distance than the ground.

After-images, then, appear as film colours, although there are some fine differences between the modes of appearance at part of the retina with different stimulation. In the last experiment here described, the after-images that appeared nearer than the ground were characterized by a more stable structure than the ground. On the other hand, if the ground seemed to lie in front of the after-image, the effect was the opposite. The ground in this case seemed to have a greater stability than the after-image. In both cases, however, they could not be considered or seen as surface colours. One can only agree that there are different degrees of looseness of a film colour. There is always, in any case, a relationship between their positions. Despite film colours being intrinsically located indefinitely, they may be localized fairly definitely with reference to each other (Katz, 1935, p. 67).

Until now film colour had been studied as having a frontal-parallel orientation. This was the most common way to study it, but not the only possibility. Surface colours, in their turn, could appear in all possible modes of orientation. The question raised by Katz was what could be a film colour orientation when it was placed near to a surface colour. To answer this question, Katz referred to the sky as an example of film colour. The experiment conducted consisted of presenting to an observer, in a front-parallel plane orientation, a light grey cardboard with a two centimetres hole in the centre. The cardboard was held about 30 centimetres from the observer, who then had to judge where the colour film of the sky appeared while looking through the hole of the cardboard. Reports of participants show that it seemed to lie behind the hole, parallel to the cardboard, at a distance still difficult to report, yet was not very great. According to Katz, the surface of the cardboard, which was definitely localized, had the tendency to draw the film colour into its own plane. For example, if an observer looked at a film colour using a cylindrical tube, the colour seemed to lie farther than if the cardboard with a hole was used. Moreover, the orientation of film colours seemed to be influenced by a surface colour. If the aperture screen was placed in a frontal-parallel position, the film colour would appear to lie in a frontal-parallel plane. If the screen was placed in a perceptible angle, the film colour would seem to lie in the same direction.

The same effect was observed even if film colours were not completely bounded by surface colours. Looking at a portion of the sky above a distant house that stood in a frontal-parallel position from the observer, for example, the film of the sky would also appear front-parallel. But if a cardboard in a nearer position was placed in the same direction, the sky parts near to it would appear bent toward it, giving the impression of an arched film colour.

In summary, film colour has a tendency to appear in frontal-parallel orientation. It appears nearer, "the nearer the surface colour acting upon it lies to the observer" (Katz, 1935, p. 73). The more the surface colour deviates from the orientation tendency, the more the film is deviated from the frontal-parallel position. This occurs because it is easier for one to perceive both of them in a same plane than to have them in different planes. Film colour 'moves' itself toward the orientation of surface colour in order to facilitate its apprehension. The same principle, called convenient visibility, can be applied to distance. It is easier to see objects near each other in a glance when they are at the a same distance.

1.1.2 Surface colours

Achromatic colours have been aligned along a one-dimensional colour-series, where at one end there was black, at the other there was white, and between them a series of all possible degrees of darkness or brightness, producing different types of grey. However, Katz argued that if achromatic illumination varied in intensity, a bi-dimensionality of achromatic surface colours emerged. This went against a basilar principle in colour perception which states that colour remains constant despite changes in illumination. If a group of colours is observed with a determined illumination, and the same group is seen with another completely different illumination, observers simply say that they are the same. Several experiments have confirmed this result.

In an experiment about illumination perspective in artificial light (Katz, 1935, p. 79) a strong light (the amount of lux is not reported in the text) in a dark-room was used and a subject was placed seated under the light source. One metre from him, perpendicular to the light-rays, a series of eighteen achromatic papers differing in brightness was held. Five metres from the observer, papers of the same brightness of the previous ones were set up individually. The subjects' task was to compare the five metre papers with the one metre papers. If the first ones had greatest whiteness, in most of the cases a position between the second or third of the series was chosen. This permitted the researcher to have two papers at different distances from the light source equally white judged, although the nearer had a reflectance about twenty times more than the other paper. Katz said that the nearer had a white of greater "pronouncedness"[3]. Moving the white paper from the five metres position to the one metre position, there was an increase of the pronouncedness of the white, but the white was always the same. Similar results have been found with light grey, although they did not show different degrees of pronouncedness as clearly as the white ones. With the dark grey, the situation was still unclear. It was not easy to decide if the nearer or the farther member represented, in greater pronouncedness, the particular grey quality. In extreme black conditions, the opposite of the white condition was observed. There, in higher degrees of pronouncedness, the paper that showed the colour qualities was the more distant one. The different degrees of pronouncedness in which an achromatic colour appeared would demonstrate their bi-dimensionality.

Illumination could, in this sense, modify the way in which people see the colour of an object. However, the colour of the object does not change. Although one can see a black object as grey or another colour according to the changes in lighting, it is always black. Here we have an important distinction between the genuine, or real, colour of an object and its apparent colour. The latter changes due to illumination, while the former, instead, is the colour of an object and does not change. In other words, a black box is always a black box. The genuine colour is perceived only under certain illumination conditions, when the intensity of illumination is like that in the open air when the sky is lightly clouded. This intensity is called normal illumination. Under other conditions, as in direct sunlight or twilight, the real colour of an object cannot be perceived.

When objects are placed under normal illumination, the eye is able to see their particular characteristics most distinctly. The ability to recognize correctly the material from which an object is made is important in order to form the judgment about the environment in which one live. The 'reading' of the aspects of an object can only be done using the information lying on its surface when an optimal illumination condition is reached. In that condition, it is possible to perceive more details in a better way. Only when the microstructure with all the details can be perceived can one say that there is a

[3] Pronouncedness, according to Katz, is a particular type of intensity of a colour. A surface with a higher level of pronouncedness become, for example, whiter than a surface with a normal level of pronouncedness.

condition of normal illumination. Normal illumination might be the most common illumination intensity present when objects are perceived, while the genuine colours might be those which are perceived with more frequency.

1.2 Colour appearance

Two stimuli with the same characteristics can sometimes appear different if they do not share the same background or surroundings, size, shape, illumination, etc.. One case in which there are no correspondence between the same stimuli is that of simultaneous contrast. In Figure 1.3 an example of this way of colour appearance can be seen.

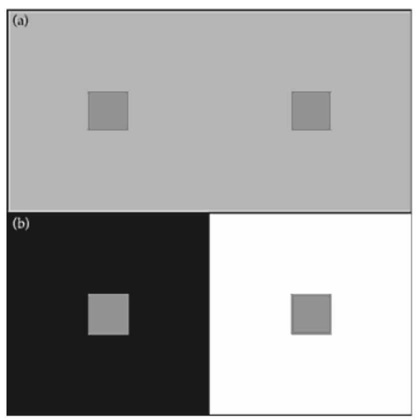


Figure 1.3a,b – An example of simultaneous contrast. The small grey squares used on the grey background are the same as those used in the black and white background (Fairchild, 2005, p. 112).

The small greys used in the figure are always the same, although our perception seems to say something different about their appearances in the squares in Figure 1.3a and in Figure 1.3b. The different backgrounds give a different perceptual rendering. With the black background, the small grey square appears lighter, while with the white background it appears darker. Simultaneous contrast or induction is only one of the many colour appearance phenomena that can be observed. The colour shifts follow the opponent theory of colour vision in a contrasting sense along the opponent dimensions: a light background induces a stimulus to appear darker, a dark background induces it to appear lighter, red induces green, green induces red, yellow induces blue and blue induces yellow.

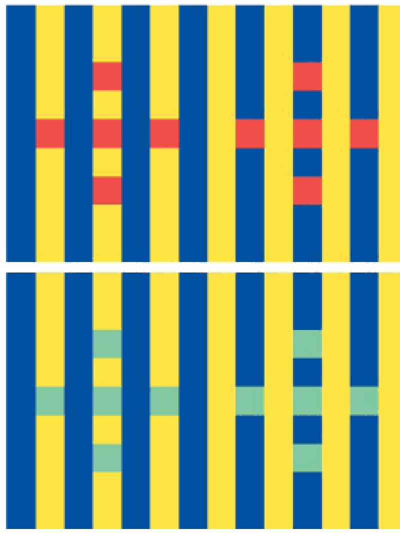


Figure 1.4 – Although all the squares have the same edges, they appear different. Squares in the yellow stripes appear darker and bluer, while squares in blue stripes appear lighter and yellower (Robertson, 1996).

Figure 1.4 is another example of simultaneous contrast, which shows the complexity of this phenomenon. All the red or cyan squares in the figure are surrounded by the same chromatic edges. Every square has two yellow and two blue edges. Since the output is not the same for the squares, and consequently they do not appear similar, the idea that chromatic induction is determined only by edges can be rejected. Squares in the yellow stripes appear darker and bluer, while squares in the blue stripes appear lighter and yellower.

Simultaneous contrast is directly related to other two colour appearance phenomena: spreading and crispening. When the stimulus becomes smaller or increases in frequency, the simultaneous contrast disappears and is replaced by spreading, which is the apparent mixture of a colour stimulus and its surroundings. Crispening, on the other hand, is the increase in perceived magnitude of colour differences when the background on which the two stimuli are compared is similar in colour to the stimuli (Mandic et al., 2002).

Figure 1.5 presents both simultaneous contrast and spreading. On the red background, achromatic stimuli of different frequencies are presented. At higher spatial frequencies (small patches on the right), the occurrence of spreading is observed, and the patches appear pinkish. At lower frequencies (large patches on the left), patches appear greenish and simultaneous contrast is observed.

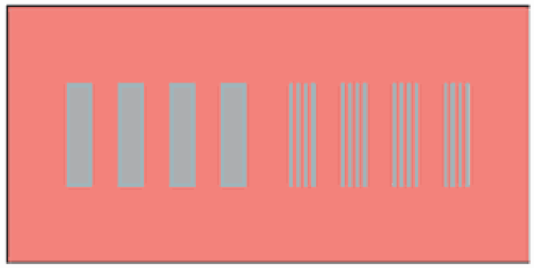


Figure 1.5 – On the left simultaneous contrast and on the right spreading. The grey areas are physically identical, but the spatial scale with the red background makes them appear different (Fairchild, 2005, p. 116).

The opposite of colour contrast is colour assimilation, also called Bezold-Brücke effect (Purdy, 1931). In this case, colour appears different due to the relation with the adjacent colours. The red lines in the black background appear darker while those in the white background seem lighter (see Figure 1.6). This occurs when one observes the hue of a monochromatic stimulus in situations with changes in luminance because there is a mixing of the colours with the surrounding. Thus, the hue does not remain constant. The brightness changes, however, are exactly the opposite to what would be predicted from the knowledge of simultaneous contrast. Effects seem to be related to size, shape and position of the borders (Burnham, 1953).

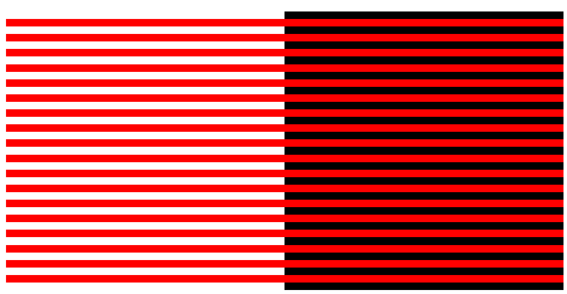


Figure 1.6 – Red lines seem lighter with the white background and darker with the black background.

The Abney effect, or effect of purity in hue, is the effect in which a shift in the hue is observed when white light is added to a monochromatic light source, causing the desaturation of the light source (Pridmore, 2007). In Figure 1.7 it is possible to observe the effect of the addition of white light on the hues. The first line presents the original hues, and the following lines show the effect of desaturation by the addition of white light.

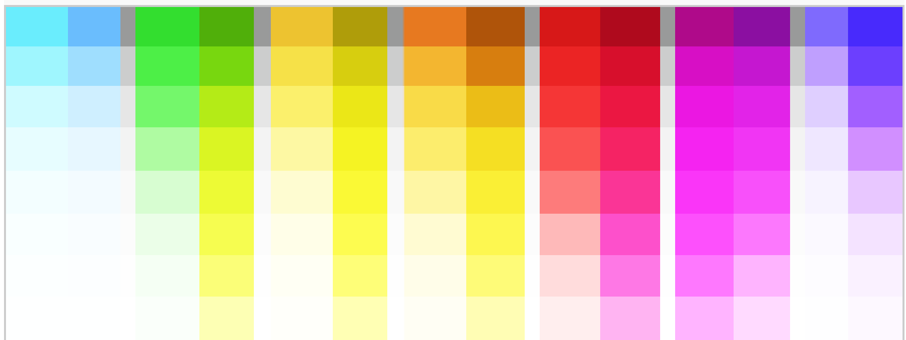


Figure 1.7 – In the Abney effect, the addition of white light changes perception of the original hues (Philip Greenspun illustration project, available on http://en.wikipedia.org/wiki/File:Abney-effect-animation.gif, 2008).

The Helmholtz-Kohlrausch effect, also called the brightness/luminance or the lightness/luminance-factor ratio effect (Nayatani, 1997), is defined by the CIE International Lighting Vocabulary as the "change in brightness of the perceived colour produced by increasing the purity of a colour stimulus while keeping its luminance constant within the range of photopic vision. For related perceived colours, a change in lightness can also occur when the purity is increased while keeping the luminance factor of the colour stimulus constant" (CIE Publication 17.4, 1988, p. 50). A chromatic stimulus with the same luminance as the white reference stimulus appears brighter than the reference stimulus. For many observers it appears to glow (Wyszecki and Stiles, 1982, p. 410). In this sense, at constant luminance, increasing the saturation also increases the perceived brightness. This effect is believed to be caused by a contribution of chromatic component in a chromatic colour stimulus to its perceived lightness. However, this contribution to brightness (or perceived lightness) is different for different hues of chromatic colour stimuli (Nayatani, 1997, p. 385). The Helmholtz-Kohlrausch effect shows that perceived brightness cannot be considered as a one-dimensional function of stimulus luminance. A stimulus appears brighter as it becomes more chromatic at constant luminance (Fairchild, 2005, p. 120).

If there are changes in the overall luminance level, there are also significant changes in the colour appearance of objects. They appear more vivid and contrasty in a bright summer afternoon than at dusk. This is the so-called Hunt effect (Hunt, 1952), which predicts the increase of colourfulness with increased levels of luminance. When an image is seen under a low level of illumination, the colourfulness of the various elements present in the image is low. A similar effect is the Stevens effect (Stevens and

Stevens, 1963), in which instead of the colourfulness increase, the contrast increases with luminance.

The work of Bartleson and Breneman (1967), which is diverse to the Stevens effect, was centred in understanding the perceived contrast in images and its variation with the luminance level and surroundings, and they obtained interesting results about changes in the relative luminance of the image surrounding. Their study found an increase in the perceived contrast of images when the surroundings of an image were changed from dark to dim to light. The dark surroundings of an image made dark areas appear lighter while the results on light areas were not as consistent. Despite the changes in the surroundings, they still appeared white. This created a resultant change in the perceived contrast, since there was more perceived changes in dark areas than in light areas.

Another effect on colour appearance is the Helson-Judd effect (Helson, 1938). These authors found that bright objects continue to appear in the same chromatic hue as the illuminant, and dark objects appear to have a hue complementary to the illuminant, when the objects are under highly chromatic illuminants. Under tungsten light, for instance, white papers continue to have an orange-yellow appearance, while dark grey papers appear more bluish. In a normal illuminant this effect cannot be observed (Lee, 2005, p. 336). These results were found in an experimental study in which subjects, under monochromatic illumination, chose Munsell designations to non-selective samples composed by neutral Munsell patches. The samples which were lighter than the background had the same chroma of the source, while those that were darker than the background, had the chroma of the source's complement hue.

Another phenomenon related to the colour appearance is the constancy of colour. Figure 1.8 shows the checkerboard illusion of Adelson (1995). In the figure on the left, the two squares marked with the letters A and B have the same shade of grey, although people see them completely different. If both squares are joined with a stripe of the same shade, it is possible to see that they are identical. This occurs because visual system calculates that in a shadowed area like that of square B, the grey must belong to a white surface, while in the lighted area the grey must belong to a dark surface.

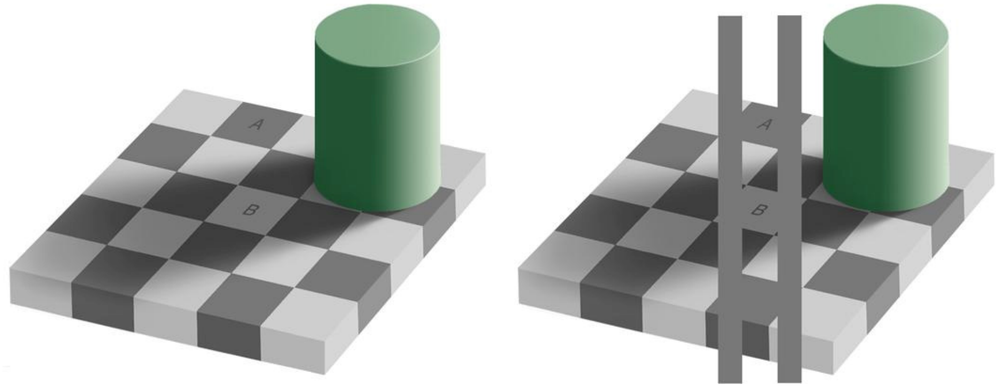


Figure 1.8 – The squares marked with A and B have the same shade of grey, although they appear different (Edward H. Adelson checkerboard illusion, 1995, available on http://web.mit.edu/persci/people/adelson/checkershadow_illusion.html).

Colour constancy is defined as the apparent invariance of a colour object's appearance upon changes in illumination. Foster et al. (1997) define colour constancy as the constancy of the perceived colours of surfaces despite the changes in the intensity and the spectral composition of illumination. Human colour vision, however, does not display constancy for every possible scene in every possible illumination, but it does for some scenes in some illumination conditions (Hilbert, 2005). Some authors do not agree with the existence of colour constancy. Fairchild (2005), for example, argued that it does not exist in humans (p. 132). He argued that if colour constancy existed, it would not be necessary to measure the illumination of the light source in colorimetric calculations in the prevision of colour matches. Since the information which reaches the eyes was the result of both illuminant and spectral reflectance of the surface object, any change in the illuminant would correspond in a change in the colour signal, and thus, because of the constant changes in illumination, colour constancy would be impossible to observe (Hilbert, 2005).

However, there is some degree of colour constancy. A white page under artificial illumination or under sunlight remains always white, despite the different illumination, although in the last condition the white will appear whiter than in the first one. The possibility to 'see' the same colour in different conditions indicates that the perception of colour is not exclusively a question of local signal.

An explanation for the constancy of colour is that while on one hand there is a sensory change, on the other hand there is an inference or judgment. The constant element, in this case, would be a product of a cognitive interpretation of the sensorial data and not a product of the senses. This approach has, however, several problems. The first is the over-intellectualizing of an automatic and independent cognitive ability (Hilbert, 2005), since some animals and small children have shown some degree of colour constancy, too. In human infants, colour constancy emerges in the first few months (Dannemiller, 1998). The second problem is the absence of the necessary inferences since just because people see colour instead to think that they are in front of colours, and because these inferences do not seem to be important for colour constancy. Even if the conclusion of the inference is incorrect, the phenomenon does not change and persists.

Another account suggests that perceptual constancies are the result of unconscious processes that are independent of higher cognition. According to Helmholtz (1867/1924), light on the eye produces a reaction in the nervous system and then a sensation, which is the beginning of an unconscious inference process. Although Helmholtz could account for several unexplained points of previous theories, some problems still remained. He spoke in terms of two objects of awareness: the illumination-dependent sensation and the external property of the object. Both were external, and Helmholtz used the term colour for both. This suggests that only one property was involved, and not two.

The fundamental Helmholtz's idea is that perceptual processing recovers information about the distal causes of proximal stimuli. This idea is embodied in the most influential theories that currently explain colour constancy (Hilbert, 2005). The basic differences between the current theory and that of Helmholtz' consist of the description of the unconscious process in computational terms rather than in terms of a logical inferencial process and in the nature of the inputs for these computations, which regard external objects, considered to be not accessible to cognition and consciousness, and not sensations. For computational theories of colour constancy, inputs and processes responsible for the production of outputs are not available to conscious awareness. However, computational theories cannot account for the question of colour constancy from a phenomenological point of view because they cannot account for aspects of colour appearance which depend on illuminants, such as the perception of shadow. The problems in computational theories, observed Hilbert (2005), could be solved by supposing that the visual system not only delivers information on the reflecting properties of objects, but also on the way objects are illuminated.

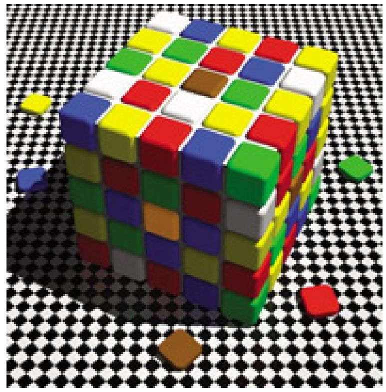


Figure 1.9 – Another example of colour constancy: the central brown square on the top and the central orange square on the side facing slightly to the left are, actually, the same colour (R. Beau Lotto cube illusion, available in http://www.lottolab.org/).

In most cases, theories that have tried to predict colour constancy or to explain it have failed because they have not taken into consideration the fact that, in phenomenological terms, what changes is not the light source, but the aspect of the illumination of the object. People do not see the illumination, but they see objects that are illuminated and the changes in their appearance due to the changes of the illumination. Consequently, the colour appearance of an object must have more than the three traditional dimensions of variation, and this must be taken into consideration in order to develop a more consistent theory of colour constancy.

1.3 Colour harmony

In discussing the harmonic aspects of colour, Da Pos (1999) suggests that a very important distinction is that between object property and subject characteristics. According to Da Pos, a particular combination of colours can or cannot be considered pleasant according to some relations among the different aspects of the colours, such as tone, saturation, lightness, etc., or according to the subjects' personality, e.g. introvert or extrovert, and the mental state in the moment of the observation. If the subject is happy or sad, this aspect can have some influence in the harmony perception. The analysis of colour characteristics has an objective aspect, because it regards the object, while the analysis of subjects' aspects is thought to be a subjective analysis. However, according to Da Pos, if both elements are analysed by a scientific method, the results of the latter can also be considered as objective, verifiable and reproducible. They will not only be considered as 'opinion' or common sense information, but also as scientific data. The experimental aesthetic, for example, does not deny the existence of subjective or cultural differences, but takes as its task to distinguish which of them comes from external or internal variables (Da Pos, 1999). By adopting a proper scientific method, it will be possible to control the variables and obtain a result in order to explain which elements have a stronger impact in determining what can be considered harmonic and what can not. In this respect, Da Pos points out an important fact, i.e. that colour is a relational phenomenon, being the result of a complex interaction among several components. In this sense, there is not a 'coloured stimulus' or a 'coloured radiation'. Perceived colour is determined by the relations between different stimulation in time and space in the visual field. Understanding the chromatic phenomena, affirms Da Pos, means having the competence to accurately formulate all the important relations that determine or accompany them.

In the research history of colour harmony, there have been several studies that have described regularities and relations between colour characteristics and pleasantness, and other studies that have suggested the opposite. Da Pos cited two studies particularly interesting because of their completely opposite results. The first was Cohn's (1894) study. This author found regularities among his subjects in the judgment of colours and their association with pleasantness and wrote rules about the characteristics of preferred and non preferred colours. The study of Major (1895), however, did not confirm Cohn's results. Major found that there was no constancy in the results, but strong individual differences. In fact, his study did not observe any relations between chromatic characteristics (saturation, lightness, grey scale, background contrast, etc.) and pleasantness. Several studies have been conducted on the subject, with results sometimes in favour of regularities and relations between colour characteristics and pleasantness, sometimes not. According to Da Pos, none of them reached a definitive conclusion in any of the aspects involved. For Da Pos, one of the most interesting questions in the field of colour harmony is if to verify whether the pleasantness for a *combination* of colours is the result of the pleasantness of the *single* colours present in the whole combination. On the one hand there is the atomistic/associationist account, which defends the idea that the beauty of a composition can be explained by the properties of each part. On the other hand, there is the Gestalt account, in which the explanation is found in the relations among the parts, which are necessary and sufficient for the pleasantness of the configuration.

In the aesthetic researches, it was common to relate harmony with balance (Da Pos, 1999). Bullough (1907) did it in the gravitational sense. In order to have a balanced configuration, according to him, the heavier colour must stay below the lighter colour. For example, if one paints a wall with two different nuances of the same colour, say pink and red, in such a way that both the same proportions, pink occupying the lower and red the upper half of the wall, this configuration would give to most of the people an "uncomfortable feeling of top-heaviness, instability and lack of balance, which would be absent from the reverse arrangement of the colours" (Bullough, 1907, p. 112).

In order to have a more balanced effect, without changing the positions of colours, an alternative would be to give a wider area to pink, and a narrower area to red. Bullough explained that the apparent differences in weight of these two shades were responsible for this effect. There would be no problem if the pink were painted in the upper half of the wall, because red, as a stronger and heavier colour, could support the weight of pink, which is lighter. He explained that dark tints, since they were seen as heavier, should stay below the light ones. When working with shades of the same colour, this rule seemed not to be a problem, but when dealing with two different colour-tones, as blue and red, then there could exist some difficulty in determining which is the darkest one.

To verify this rule, and whether it could be used not only for shade-differences, but also for tone-differences, and in order to discover the principles behind it, Bullough carried out an experiment using plates containing two geometrical figures of identical shape, each one composed of two colours, one above the other (see Figure 1.10).

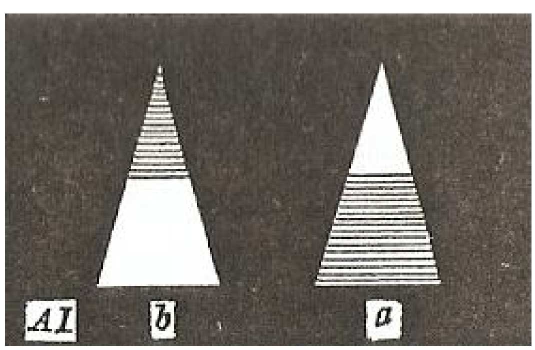


Figure 1.10 – Configuration used by Bullough to test if dark colours must stay below light colours (Bullough, 1907, p. 116).

Bullough used 30 shades and tested 50 subjects from eight to 50 years old, most of them undergraduate or graduate students. He found that the rule works very well, almost without exceptions, in the shade-differences, but that it could also be used in cases of tone-differences. In this second case, there was however the introduction of an element of uncertainty and hesitation in the selections made by the subjects. However, the hesitation, uncertainty or indifference of some subjects did not constitute a problem, because results seemed to be consistent enough to affirm that luminosity-differences could afford a criterion.

Testimonials of many subjects suggested that dark colours are heavier. They seemed to be more 'substantial', more 'solid', more able to give a better 'support' or a better 'balance' to the whole configuration.

In the few cases when people did not use, or did not agree that they were using the weight-principle, but a different one, they basically described their choices in terms of three alternative principles. The first was that of landscapes-associations. In this case, subjects made an association with the perceived figure and a previously perceived sea- or landscape visual image and interpreted the stimulus as if it were a land- or a seascape. These associations occurred most frequently when the stimulus was a circle with a colour configuration made by a dark and a light blue, which formed a circular picture of the sea with a pale-blue sky above: the line contrast between both coloured areas worked as the horizon. With other figures, such as squares and triangles, the use of landscape-association was limited to one and four cases respectively. The square case occurred with the shades dark and light green, when the subject reported seeing these configurations (normal and inverted) as the slope of a hill with a dark or light sky behind it, according to the position of colours. With triangles, subjects reported that they seemed to look perspectives and, in these cases, the subjects' attention went from the base to the apex of the triangles and from the fore-ground to the background of the landscape. However, among most of the subjects who made associations with circles, there were no associations with triangles, which suggested that it was an individual characteristic of these few subjects and not a rule.

The second alternative principle used was the selection of a colour according to the subject preference. More common was the rejection of a colour because of the size of the coloured area of an unpleasant colour. This happened only in the triangle case, because of the difference in the dimension of the areas. The colour on the bottom part always occupied a bigger area, while the colour on the apex had a smaller area. There were, however, two possibilities of exclusion. The first was the rejection of an unpleasant colour because it occupied the larger area. Subjects justified their rejection using the expression: “there was more of it” (Bullough, 1907, p. 145). The second was the selection of the preferred colour when it was on the apex of the triangle. The author explained that although a colour on the apex occupied a smaller area than the other one, it was felt to have a special prominence by occupying the top of the triangle, its most characteristic feature. In this principle, beyond the mere quantitative criterion of the size of an area, there was also a second qualitative criterion, which gave importance to the position of a colour and a sense of its application in the space.

The third and last alternative principle used by subjects in cases of failure of the weigh-principle were the apparent differences in identical colours according to their positions in the figure, or the apparent differences in the shape of identical figures according to colour position. These two illusions were largely used in doubtful cases. One subject of Bullough’s study said that in a certain stimulus composed by a square and the colours red and blue, the latter appeared less dazzling in one position than in the other (in relation to the lower/upper position), while another subject reported that the blue was the less glaring colour. These differences, however, could not occur since the reds and the blues in the lower and upper positions were the same. Similarly, two subjects affirmed that they perceived the dark green of a stimulus darker in one position than in the other. There are other examples of this illusion, which was mostly found in the squares and circles.

The second illusion regards cases in which circles were seen as ellipses, sometimes more rounded in the image on the left, sometimes in that on the right. Another variation was the apparent dimension of the stimuli. Sometimes the figure on the left seemed larger and sometimes the other one appeared larger. Sometimes circles also appeared as a flat disk on one side and as a sphere on the other side and vice-versa, but in most of the cases these illusions were observed when the dark colour was above the light colour. Bullough, however, had no explanation for this effect.

The author tried to find an explanation as to why dark colours must stay below by asking participants their justifications for why they thought that. Most of them answered that they did it by association with the environment. According to them, people live surrounded by natural objects, which usually present darker colours below than lighter colours, and this was the reason why people have the idea that this configuration was a typical case. Thus, the association of visual memory-images of natural objects with the perceived colour-arrangements would be responsible for producing the weight-effect of darker colour. The idea that darker colours should stay below lighter ones was bred in people by custom and habit, and inference has impressed upon people that the lower part of an object is heavier to preserve its stability.

Bullough contested the justification of the participants, arguing that there are not so many natural objects that are darker below and lighter above. He argued that colour-arrangements in nature seem quite accidental and did not believe that the subjects' association was due to a habit contracted from the environment. The second criticism to those justifications came from the experimental data. The same subjects never used the weight-principle and landscape-associations in the same figures (in the few exceptions where this occurred, it always produced opposite effects). This meant that the two processes were completely different, one regarding the apperception of a geometrical figure as a figure, the other regarding the interpretation of a figure as having meaning, as something more than a figure. Both principles, from the data point of view, seemed to be irreconcilable.

The reason why dark colours stay below and why they seem heavier was due to their appearance of 'heaviness'. Bullough explained that when something has more volume or substance than an other thing, it looks heavier. This occurs because there is "more of it" (Bullough, 1907, p. 150). A stone with the double size of another stone, he argued, is perceived as heavier because it has more volume, more substance. In the same sense, a weak mixture of water and a coloured substance is seen as lighter than if the mixture was done with more substance, given a stronger colour effect to the water, because in the second case it would have more substance. The author recalled that this would not mean that the darker 'is' heavier, but that it appears heavier. Following this train of thought, red will be heavier than pink, because in the first one there is more red than in the second, not in the sense of the extension of an area, but in the sense that the mixture or the perceived 'quantity' of that colour is bigger than the other. If more pink is added to pink, it will become red, and then, will be perceived heavier because it would have a bigger 'quantity' of it. Adding more and more colour, luminosity decreases and the colour become darker. The increased darkness, then, seems to appear the result of pigment addiction. If some black is added to red, luminosity can decrease beyond the saturation point and a darker red than the saturated one is obtained. This dark red, when compared with the saturated one, has more substance, appearing heavier. This shows that it is not saturation that is index of colour weight, but luminosity.

The attribution of weight to a colour is a non-reflective and immediate process. Colours simply look heavier. This idea is clearer when two colours are compared, but it is also possible to think about the weight of only one colour. Bullough (1907) explained that saturated colours have different luminosity, and since green and yellow have higher luminosity than blue and violet, consequently green and yellow appear lighter than blue and violet when seen separately.

Other studies have confirmed the assumption that dark colours are seen as heavier than light colours (DeCamp, 1917; Monroe, 1925; Payne, 1958, 1961; Taylor, 1930; Warden and Flynn, 1926). These last authors found that white, grey and black had a consistent increasing series of weight. White would be the lightest one, while black would be the heaviest. Among chromatic colours, yellow and green were lighter than blue, purple and red, although the last three colours did not have marked differences. Payne (1958) found that red and blue seemed heavier than yellow, and that brightness was the major cue for apparent weight, although hue had a smaller effect (Payne, 1961). Monroe (1925) found that the apparent weight had an inverse variation with brightness. According to the experimental research carried out by this author, blue was heavier than red, which was heavier than green, which was heavier than yellow. However, there was a high variation in the subjects' judgments of the saturation effect. Increased saturation made colours appear lighter than the less saturated colours.

Monroe has also noticed that the contrast with the background could influence the apparent weight of colour. Increasing the background brightness decreased the apparent heaviness of dark red and increased that of dark yellow. The background, however, did not affect the apparent weight of colours that differed in chroma or saturation. Alexander and Shansky (1976) found that the apparent weight was a decreasing function of lightness and an increasing function of saturation. Hue, instead, was a minor determinant. Wright (1962) used the differential semantic of Osgood to test subjects' judgments in terms of surface colours' weights which were present in a matte square with a neutral background in daylight condition. Wright found a well-defined lightness effect and a saturation effect of a smaller magnitude. The saturation effect relative to the lightness of colour reported in the study of Wright was of the order of 10%, while that of Monroe (1925) was of 40%.

Wright also asked his subjects to say if a colour was warm or cold. This classification was well-known, and people used to speak of the warm red, orange and yellow, and the cold or cool violet, blue or green. Several studies were been carried out asking subjects to judge the warmth of a colour. Lewinski (1938), Ross (1938) and Stefanescu-Goanga (1911) found that red was warmer than blue in projected colours. The same was found in surface colours by Allesch (1925), Bullough (1908), Collins (1924), Kimura (1950), Newhall (1941), Tatibana (1937) and Tinker (1938). Ross concluded that temperature had a relation with brightness and saturation of colour. The increase in warmth ratings meant an increase in brightness and in saturation. There was, however, a correlation effect between hue and brightness. Wright (1962), while reviewing Ross' data and analysing separately the red and blue regions, found that there was no evidence for a relation between brightness or saturation in the blue region and warmth, and that the relation between warmth and brightness was the reverse of the correlation presented by Ross. According to Wright, the data of Ross showed that increasing warmth corresponded to an increase in brightness.

Newhall asked almost 300 subjects divided into two groups to list warm and cool objects and to assign colours to the objects. Each group performed only one task. Red was considered the warmest. Blue was the coldest, followed by green and yellow-green. Tinker and Kimura found that all the colours they used were seen as warmer than black, white or grey. Wright, using the same procedure as the previous one with the weight of colours, found a well-defined effect of the hue on apparent warmth, independent of lightness or saturation. There were also effects of lightness and saturation in accordance with the other studies, but Wright results showed that these effects were less definitive than hue effect. Increasing warmth corresponded to increasing saturation.

Other studies focused in the apparent nearer depth perception of warm colours. Bailey et al. (2006) argued that the colour of an object affects the judgment of its apparent depth. This effect is related to the references of advancing and retiring colours, in which oranges and reds are seen as advancing colours and seem nearer than to the retiring colours, such as blues, which seem farther (Goethe, 1810/1982; Luckiesh, 1918). Experimental literature of this effect relates that results were obtained using simple stimuli as coloured lines, colour patches, point light sources, etc., normally with saturated colours. Bailey et al., indeed, observed the effect on a real object, a teapot (see Figure 1.11 below).

Figure 1.11 – Teapots with the same luminance used in the experiment (Bailey et al., 2006).

In the experiment, participants were asked to select the closest teapot in a paired comparison test. There were seven different coloured teapots with equal luminance and four grey backgrounds differing in intensity. The test also used uniform colour patches. Results showed that there was a relationship between warm-cold colours and perceived depth for the colour patches. The warmer coloured patches were seen as closer than the cooler patches. With the teapots this was not observed. With complex images colour was not necessarily an overriding cue of depth.

1.4 The relation between colour and shape

In the field of art studies, Kandinsky (1912) suggested the existence of a fundamental correspondence between colour and shape, and specifically, geometric shapes. According to him, there would be a relation between triangles and yellow, squares and red, and circles and blue. This correspondence would be due to the relation between colours and angles (Kandinsky 1926/1979). Acute angles would show the characteristic of being 'active' and 'aggressive', as the colour yellow, the obtuse angle would be similar to blue, and the right angle would be red in character. In 1923, Kandinsky asked the participants of his painting course to match yellow, red and blue to triangle, square and circle, and the results were in accordance with his theory. However, it was most probable that participants in this course were already involved in the practise, influenced by his teaching and with some knowledge about his theories (Jacobsen, 2002).

To test Kandinsky's theory, 200 non-artist university students of the University of Leipzig were tested in two different conditions (Jacobsen, 2002). One group was asked to assign the colours to the forms, as in Kandinsky's test. The other group was told to search the most beautiful assignment of colours to forms, in order to compare situation one (mere-correspondence instruction) to an aesthetic-correspondence instruction. Participants of both groups were asked to give an explanation of their choice, when possible.

Results showed no differences between the two instructions conditions, and Kandinsky's relation hypothesis was clearly the less chosen between the six possible combinations. Only 10 subjects chose a yellow triangle, a red square and a blue circle. Almost half of the participants (92) preferred a configuration with a red triangle, a blue square and a yellow circle. In their rationale, 51 of the participants who chose this last combination mentioned both the traffic sign of warning triangle and the sun, and a large part of the rest of these participants also mentioned at least one of these two associations. There was, however, a significant difference in the number of subjects who gave a justification of the associations motivating their choices between the two instruction conditions. It seems that people in the aesthetic condition were more reluctant in giving an association rationale (17), than people in the other instruction condition (34). A contingent of 58 participants were resubmitted to the experiment some months later, and similar results were found. Again, Kandinsky's assignment was the less preferred.

Jacobsen made two hypotheses to explain why both instructions had the same results. One hypothesis could be that although one group was not told to make an aesthetic combination, participants spontaneously used this principle in their choice. A second possibility could be a result from the employment of common informational basis by the participants, who used world-knowledge associations to justify their choices. The warning triangle and the sun were very often associations used by subjects in both instruction conditions, even if they could not be considered aesthetic criterion.

World-knowledge associations, however, have different variability according to the different variables used. Some of them can depend on and change according to the evolution of conventions in history, or some can be culturally dependent, as the traffic signs. Others can seem more constant, like the sun, although this does not mean that it can not be ambiguous. Sun colour, for example, can vary according to the period of the day or to the context of its pictorial representation. In sunset, for example, it can be more represented as red than yellow. In the same sense, a circle can have different meanings, not only that of the sun. It can be associated with a flower, a ball or even a clock in front of a train station (as the case of Rovereto's train station). Thus, the associations based on world-knowledge can depend on the cultural environment where participants live, the historical period in which they are and, of course, the influence of the social and commercial relations among people and societies. Results of Jacobsen's experiment, however, did not present prevalent cultural or fashion justifications made by the subjects, but only everyday associations.

Kandinsky's results could depend on some artistic training. People with artistic experience could show a different result from non-artistic people because of artistic knowledge and practise, as painting techniques or mixing of colours, for instance. Lupton and Miller (1991), however, reported results from a group of designers who answered Kandinsky's questionnaire. Two out of eight produced the same configuration as Kandinsky, but gave different explanations for their choice. The other six produced different configurations. For Jacobsen, these data indicated a strong influence due to education and experience and, consequently, the assignment of colour to shapes would depend on culture or on subculturally prevalent conditions (on the Bauhaus 'spirit', in the present case). The author argued that the correspondence was conditioned by cultural relativity.

A more recent study (Albertazzi et al., submitted) also tried to analyse a possible correspondence between colours and shapes, but used a broader sample of colours and forms, than that used in the previous studies. Authors used 40 different hues, displayed in a circle, including the four unique hues: yellow, red, green and blue, separated by 90 degrees from each other. Twelve geometrical forms were tested, bi-dimensional and three-dimensional.

Results showed a significant relation between shapes and colour. In this study it was demonstrated that some colours are more frequently matched with certain shapes, whilst other colours are less frequently matched with other shapes. A correspondence analysis of data demonstrated some relations between shapes and colour characteristics (warm/cold and light/dark hues), too.

Preliminary results indicated a partial confirmation of Kandisnsky's hypothesis, with matches between yellow and triangles, and between red and squares. The mismatch between circles and blue could be, according to the authors, due to the lack of sharp corners, which could exclude circles from the forms on which Kandinsky's hypothesis is based. According to Kandinsky, an effect from more or less acute angles could determine the colour of a shape. Since circles do not have angles, they should not be included in the tests of this theory.

A second experiment was carried out in order to control size, perimeter, orientation and modes of appearance of shapes, using 70 subjects that did not participated in the first experiment. These results also demonstrated a significant connection between shape and colour.

Authors concluded that hues were differently related to different geometrical shapes, and factors such as orientation, size and others seemed to not have a particular influence in the matches between form and colour. The relation between some shapes and colour characteristics also became clear. Some of them were more related with cool colours, such as blue and green, while others were related more frequently with warm colours, such as red and yellow, and some of them could be considered neutral from the point of view of the 'temperature'. Shapes could, despite the sharing of the same 'temperature' conditions, differ in the dimension of light/dark condition. Circles, for instance, could be matched with a dark hue, and triangles with a light one, although both of them could be considered as warm shapes.

Correspondence analysis showed the organization of form in colour space according to two bipolar scales that characterize chromatic systems. They are the division in cold and warm and in dark and light. The first dimension is the well known subdivision of hues in warm and cold, while the second is due to the fact that different hues have different natural lightness. Black and white do not have boundaries, and they can be observed in every colour. When a specific hue is accompanied by more white, it becomes lighter; when it has more black it is seen as darker.

Natural lightness seems to be a significant aspect of colours. According to Spillmann (1985), when observed, all colours reveal a relation with the natural lightness of their hue in a way that observers can directly see if hues appear with their level of lightness or not, i.e., if they are seen as too light or too dark. As it is known, the darkest shade of all colours is purple, while yellow seems to be the lightest one. Green is darker than yellow, but lighter than red and blue, when the hues are considered at their maximum chroma for surface colour. In this sense, blue, red and purple naturally belong to the darker hues, while yellow and green to the lighter. Albertazzi et al. (submitted) suggest their study be verified with researches using colours which can vary in other dimensions, such as chroma, and not only in hue and lightness.

Concluding, recent experimental results seems to favour the existence of functional relations between items in the visual field in the Koffka's sense (Koffka, 1935), while Kandinsky's hypothesis is partially confirmed and partially refused. Finally, some characteristics of shapes, such as size, orientation and perimeter, seem not to have influence in the dimensions studied.

1.5 Summary

In this chapter several aspects of colour perception and colour theories were reviewed. As to the linguistic studies, it was mentioned how they developed two different approaches: the universalistic and the relativist. The latter defends the idea that language shapes reality and the way people see the world, and also that language and culture will influence the perception of colour. The universalistic approach, conversely, affirms that perception of colour is mostly independent of cultural or linguistic influence. Several studies have been carried out in both approaches, and a relatively recent study of MacLaury (1992) proposed the integration of the two approaches in an explanatory theory. According to this theory, colour categorization would depend on attention. If the attention was directed more at the similarity of colours, there would be a predominance of the brightness, while if the attention was directed towards the differences of colours, then hue would predominate.

An alternative approach to colour analysis is phenomenological, based on Hering's theory (1878/1964). In this account, colour is seen as a purely visual phenomenon, which does not need the mediation of language to be perceived. The organization of colours is accomplished according to their similarity, each colour being set near the most similar to it.

After introducing the different ways to study colour, and a clarification of the phenomenological approach, the ways of appearance of colour (Katz, 1911, 1935), i.e., surface colour, film colour and volume colour were mentioned. The main experiments carried out by Katz were considered as well as recent literature regarding simultaneous contrast, where the elements suffer the effects of the background, and also spreading, crispening, and colour assimilation, which is the opposite of colour contrast. Another effect in colour appearance is the Abney effect (Pridmore, 2007), which consists of an effect caused by the level of hue purity. Adding white light to a monochromatic light source causes the desaturation of the light source, changing the perceived colour.

The brightness/luminance or lightness/luminance-factor ratio effect is a change in brightness caused by increasing the hue purity. The Hunt effect (Hunt, 1952), in its turn, is an effect caused by changes in the overall luminance, increasing colourfulness. Similar to Hunt's effect is Steven's effect (Stevens and Stevens, 1963), but here, instead of an increase in colourfulness, an increase in the contrast is observed. Bartleson and Breneman (1967) found an increase in the perceived contrast of images when the surroundings of an image were changed from dark to dim to light. The dark surroundings make the dark areas appear lighter, while light areas do not have a consistent change and appear white.

The constancy of colour is a phenomenon defined as the apparent invariance of the colour objects appearance upon changes in illumination. It is a controversial effect and there are a great number of divergences among scientists about this phenomenon. Most who failed to explain colour constancy did not used a phenomenological approach, which is very important because what changes in this effect is the aspect of the illumination of the object, and not the illumination itself. The use of the three traditional colour measurements (hue, brightness and saturation) is not enough to explain the variations. This can be a sign that there are more elements which are not taken into consideration by traditional theories yet to be introduced in the discussion of colour constancy.

Another aspect in the study of colour taken into consideration is colour harmony. Colour harmony can be analysed with scientific methods and can give answers about the general preferences of individuals. Cohn (1894) found regularities in the judgement of colours and their association with pleasantness, and wrote the rules of the characteristics of preferences in colours. One year later, Major found no consistent results to support Cohn's research. Other studies have followed the two pioneering ones, some of them in accordance with Cohn, some of them with Major (1895). Most of the studies in the aesthetic field associated harmony with the idea of balance. Bullough (1907) applied this association in terms of weight and found that dark colours are heavier than lighter colours and, therefore, are better placed in the lower part of a configuration. When they are placed in the upper part, they should have a smaller area than the lighter colours in order to maintain the equilibrium in the configuration. The studies of DeCamp (1917), Monroe (1925), Payne (1958, 1961), Taylor (1930) and Warden and Flynn (1926) also found that dark colours appear heavier than light colours.

There are also several studies on the relation cold-warm colours, such as that of Allesch (1925), Bullough (1908), Collins (1924), Kimura (1950), Lewinski (1938), Newhall (1941), Stefanescu-Goanga (1911), Ross (1938), Tatibana (1937) and Tinker (1938). These authors found that red is warmer than blue, for instance.

Other studies focused in the apparent nearer depth perception of warm colours. Bailey et al. (2006) argued that the colour of an object affects the judgement of its apparent depth. This effect is related to the phenomenon of advancing and retiring colours, in which oranges and reds are seen as advancing and nearer than the retiring colours, such as blues, which appear farther (Goethe, 1810/1982; Luckiesh, 1918).

The last section of this chapter analysed the relationship between shape and colour. It starts with the study of Kandinsky (1912), who suggested the existence of a fundamental correspondence between colour and geometrical shape. According to him, there was a natural relation between triangles and yellow, squares and red, and circles and blue, in the function of the angles of the figures (Kandinsky 1926/1979). Acute angles would be active and 'aggressive', as in the colour yellow, the obtuse angle would be similar to blue, and the right angle, would be red in character.

Jacobsen (2002) tested 200 non-artist university students in order to verify Kandisnky hypothesis, and found different results. The combination of colours suggested by Kandinsky was the less chosen among participants, who preferred a red triangle, a blue square and a yellow circle, making associations with the traffic red sign of warning triangle and the yellow sun. Albertazzi et al. (submitted) used a broader sample of colours and shapes than the previous studies. Subjects were also advised to avoid associations with past experiences and make their judgement only based on the perception of which colour would better and most naturally match a shape. Results showed a significant relation, demonstrating that some colours are more frequently matched with certain shapes whilst other colours are less frequently matched with other shapes, indicating a partial confirmation of Kandinsky's hypothesis (yellow/triangle and red/square). Relations between shapes and colour-characteristics (warm/cold and light/dark hues) were also found. Albertazzi et al. concluded that hues are differently related to different geometrical shapes, and factors as orientation, size and others seem not to have a particular influence in the matches between form and colour. The relation between some shapes and colour characteristics was also made clear.

As a follow up to Albertazzi et al.'s research, in Chapter 4 an experiment carried out in Germany and in Italy in order to test the natural relationship between shape and colour using *non*-geometrical images is described. The images used were taken from Haeckel (2004), and consist in images from the groups of *Spumellaria*, *Cyrtoidea* and *Diatomea*.

Chapter 2

Visual Completion
Theories, experiments and critics.

One might say that people see what is present in the sensorial stimulation, hence they do not see things when they are not present in the stimuli. Although this statement seems logical, it is not coherent with a phenomenological view, because people see much more than what is present in the stimulation (Massironi, 1998). When people look at something, they see that object in its unity, as complete, and do not consider an objet to be incomplete just because they cannot see its back or other parts of it. Rather, people are able to see it as complete, and they are surprised if discover that it is actually not so. In this sense, the existence of a certain property at the physical level is not a sufficient condition for the same property to exist at the phenomenal level and vice versa.

Consequently, one cannot consider perception to be a mere 'take act' or an accurate recorder of objects that constitute the external physical world. This entails that the phenomenal world, which consists of the objects and events that people experience as present around us, is not directly a copy of the physical environment, but rather the result of a series of mediations. Perceptive activity gives a mediated and indirect knowledge of physical objects and events. In this sense, people sometimes see more than there is in the physical stimulus; sometimes they perceive less than there is in the stimulus; and sometimes they see 'distortedly' what is physically present in the stimulus.

In the first case we have situations like the one in which some parts of an object are hidden by another object or by a screen. Even if people are not shown all the properties of the hidden object, they are able to see it in its entirety. In Figure 2.1a below, most of the subjects tested stated that it was composed of two squares, one over the other.

In the experiment described in chapter 3, when a group of 60 subjects were shown this image, 58 of them described it as two squares, and the other two as a box, i.e., they had seen it three-dimensionally. However, only one square can be seen with all the stimuli, because the second one is partially occluded, and the borders in its bottom right part cannot be seen. It is thus not possible to affirm one hundred percent that it is really a complete square, suggest instead that it is ‘L-shaped’ (Figure 2.1b) or something like Figure 2.1c; this is one case in which people are induced to see more than there is in the physical stimulus by subjective completion.

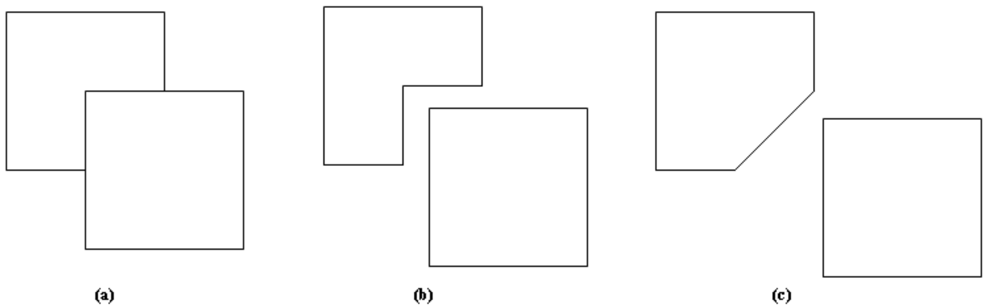


Figure 2.1 – People prefer to say that Figure 2.1a is composed of two squares, instead of choosing a solution like 2.1b or 2.1c.

There are various situations in which people perceive less than what is present in the stimulus. This normally occurs when they are confronted by something full of details or elements, and they simplify it in order to recognise what is really important or necessary to understand what they have in front of them. On observing Figure 2.2a below, it is most probable that people see a configuration as in Figure 2.2b: a black cross and a white square. It is harder to see four small white squares and a cross, like Figure 2.2c, or either the four white squares or four black segments. Although it is possible to give several solutions for Figure 2.2a, people normally prefer a simpler one, where the completion of the white square behind the black cross can be observed. The white square acts as background to the cross, which becomes the figure and remains in front of the white square. This occurs because in the majority of situations, the visual field presents many different objects at the same time, and the laws of organization allow a hierarchical distribution of the highlights (Koffka, 1935; Metzger, 1941; Rubin, 1915/1958).

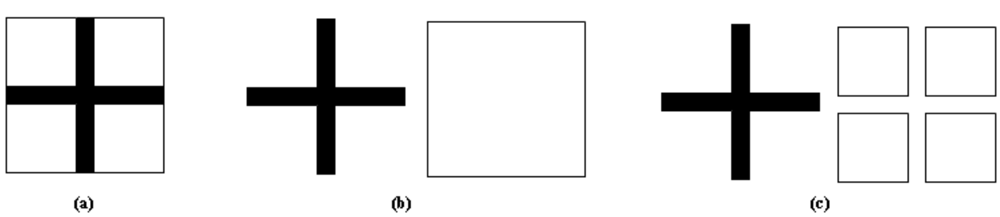


Figure 2.2 – The configuration in 2.2b is preferred to 2.2c as a solution for figure 2.2a

The last case is the one in which people see ‘distortedly’ what is present in the stimulus. This is the case of the optical illusions. Figure 2.3 shows the Müller-Lyer illusion, in which the two horizontal lines have the same extension, even though they seem to be of different lengths. This illusion is a classic example of stimulus distortion, but there are several other examples of this in the literature. Nor should people forget figures that are ambiguous and constantly reverse figure and background (as exemplified by Rubin’s vase-profile illusion), meaning (Jastrow’s duck-rabbit illusion), and position (Necker’s cube) or have whole-part ambiguity (Arcimboldi’s paintings).

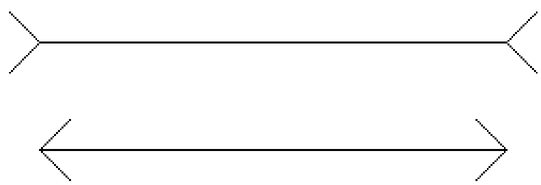


Figure 2.3 – In the Müller-Lyer illusion, the two horizontal lines seem to have different lengths.

These examples corroborate the assertion that there are differences between what is present in the physical stimulus and what people perceive; and situations of completion have provided good occasions to observe such differences. But what is completion? Visual completion is the ability to perceive something, like an object, in its entirety, although one or some of its parts are not present in the stimuli.

In most cases, completion occurs because of occlusion, when an object is partially hidden by another object. But this is not always so. In some cases (see Figure 2.4 below) the phenomena of contour interposition, apparent transparency (Metelli, 1974; Ware, 1980) or spontaneous splitting (Kanizsa, 1979; Koffka, 1935; Parks, 1986) can be observed. The feature shared by these different phenomena is the perception of depth.

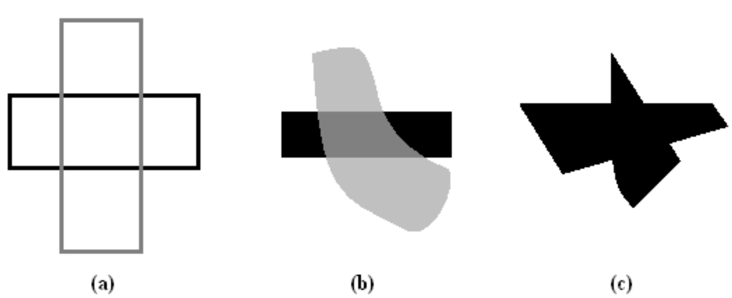


Figure 2.4 – Contour interposition (a), apparent transparency (b), spontaneous splitting (c)

2.1 Types of completion

We have already seen that objects can be presented in such a way that some of them completely or partially occlude others. This involves processes of perceptual interpolation, characterized by the completion, aggregation, integration and filling of gaps. These processes can occur in different modes, namely: visual (when the interpolated parts are modally present), perceptual or in amodal presence (when the parts are not modally present), or mental (in thought mode).

Among these processes, amodal completion is the most common form of visual completion. It occurs, as said, when an object is partially hidden behind another object (Michotte, 1964/1991). The hidden object continues behind the occluder, owing to the presence of the margin common to both objects. Because a margin can usually only belong to one object (Rubin, 1915/1958), the object occluded continues amodally and completes itself behind the occluding object, which assumes the common margin as its margin. The concept of 'border ownership' is fundamental in theories of completion, and it is one of the reasons why people do not prefer a solution like Figure 2.1b. The object in front 'owns' the border, and the object behind can continue behind the other one and link with other parts in the occluded zone.

The integration of the hidden part of an object has long been considered a mental integration; a kind of contribution from knowledge and past experience of how things are to construction of the visual world (Kanizsa, 1991). This conception, however, at least with respect to the completion of forms or objects, has been questioned by Kanizsa in light of the difference between mental representation and perceptual presence. Although the chromatic attributes of the visual mode do not occur, the continuation is amodal because it is genuinely perceptual, or, in Kanizsa's words, "it imposes itself coercive and cannot be modified at will as a presence just thought" (Kanizsa, 1980, 1991). It is therefore a real phenomenal presence (Metzger, 1941), and not a mental representation.

In order to clarify the difference among the three types of completion, one can draw a line which extends from point 'A' to point 'B' without interruption: we thus have an object that can be seen completely because it presents all the perceptual stimuli, without occluded parts. It is present in the visual mode.

Figure 2.5 – Modal presence

If the line is interrupted between the points ‘A’ and ‘B’ by a blank segment, so that the line begins at point ‘A’, then disappears, and reappears before reaching point ‘B’, we no longer have the same situation as in Figure 2.5. In this case, a part of the line is not present in the visible mode, but it is possible to interpolate this missing piece with the other two visible parts. Nevertheless, this happens only at a mental representation level, without perceived effects, because the ‘empty’ blank space between the two visible parts continues to exist. While the first example consists in a ‘viewed’ line, the second one refers to a ‘thought’ line, because one can only see the two segments of the line.

Figure 2.6 – Mental representation

If the same line is occluded by an object, and consequently the occluded part is no longer modally visible, we have a situation of amodal completion.

Figure 2.7 – Amodal presence

The line in Figure 2.7 does not need to be represented as continuous because the two segments naturally tend to continue behind the object. In this case, it is a ‘genuine phenomenal presence’, which is termed ‘amodal completion’. Unlike the represented datum, the perceived datum is an objective one, phenomenally given independently of our will.

The term ‘amodal’ completion was proposed by Michotte to distinguish it from modal completion (Michotte et al., 1964/1991). In modal completion, observers add parts to the figure, processing alterations as the prolongation of the figure lines, changing their directions and filling the gaps with the same visual qualities as the rest of the configuration, i.e., in the presence of luminance and colour. Amodal completion, in fact, is characterized by the absence of visual qualities like luminance and colour. The part modally not present, i.e. occluded, is not seen as a gap. In a situation where an object is partially hidden by another one, people normally do not mention the gap, but report seeing the whole object despite the absence of visual qualities in that region. The gaps in the stimulation are in some way inoperative. In this sense, the term 'amodal' originally indicated the absence of visual qualities, in contrast with a 'modal' situation, where these qualities (luminance and colour) are present.

A particular and interesting case of completion is that of Kanizsa's triangle (Figure 2.8). If it is considered only the physical stimulus, one has three couples of black lines, each forming a 'V', and three circular black shapes similar to those in the *Pac-Man* arcade game. If it is instead considered the perceived image, one has two white triangles, one with a black margin partially occluded by the other without margin-gradient, and three black circles or disks. According to Kanizsa (1955, 1980), this latter configuration has advantages in terms of simplicity and stability. The lines in V become a triangle and the disks are seen as circles, but this is only possible because there is a matt triangular surface in front of the other figures and the background. Since a surface cannot exist without borders, Kanizsa maintains that these emerge in the absence of the gradient in the stimulation as a result of stratification of the parts, which in its turn is a consequence of amodal completion. These borders, however, are not the same as thought borders or virtual ones, because they have a more intense degree of perceptive presence. The almost-perceptive character of the illusory contours is possible, says Kanizsa, because there are some intense transformations of colour and clarity in the surface concerned.

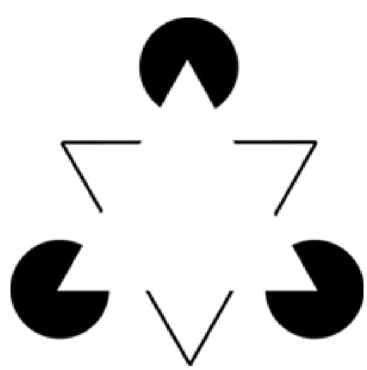


Figure 2.8 – Kanizsa's triangle

This means that these borders appear, and the completion of the three black circles and the white triangle with black borders occurs precisely because a segregation of the central white area from the white background forms a white triangle with illusory contours. This triangle appears to be in front of the other figures and its surface appears to be whiter than the white of the background, despite the fact that there are no differences between the whiteness of both areas from the point of view of the stimuli.

Kanizsa (1955, 1980) explains that when the borders of this kind are formed, certain phenomenal characteristics are commonly observed, such as transformation of the clarity and the mode of appearance in a certain part of the visual field that phenomenally distinguishes it from the other parts, although the stimulation conditions are the same. The region which undergoes this transformation also suffers an apparent phenomenal three-dimensional dislocation and appears to be in front of the other parts. This region has borders that separate it from the contiguous parts, even though there is neither a qualitative nor a quantitative difference in the stimulation that justifies the existence of borders. In optimal conditions, all of these three events impose themselves coercively and have a modal character which distinguishes them from the virtual lines.

The segregation of this central white area occurs because the configuration comprises some elements that are not perfectly regular, and which in order to become more regular, simpler, more symmetrical and stable, need a completion. In this way, the three black disks and the three ‘V’ lines complete themselves amodally behind the white triangle, becoming three black circles and one white triangle with black borders partially occluded by the white triangle, which emerges by segregating itself from the rest of the configuration, changing in appearance and clarity. The white triangle in front of the others is, according to Kanizsa, modally present.

2.2 Amodal completion

A number of theories have sought to explain the way in which the visual system bridges the gaps generated by partially occluded objects. Tse (1999a) has grouped these theories into three groups: the first group comprises theories that use local image cues. According to these theories, completion occurs because of good continuation, contour orientation and T-junction (Kellman and Shipley, 1991; Takeichi et al., 1995; Wertheimer, 1923; Wouterlood and Boselie, 1992).

The second group emphasizes the importance of global factors. In these theories, symmetry, regularity and simplicity of form or pattern are the cues used by the visual system to amodally complete occluded objects (Buffart et al., 1981; Hochberg and Brooks, 1960; Moravec and Beck, 1986; Sekuler, 1994; Sekuler et al., 1994; van Lier et al., 1994, 1995).

Finally, the last group includes theories about internal representations, these being traditionally surfaces (Nakayama and Shimojo, 1992; Nakayama et al., 1989, 1995), or more recently volumes (Tse, 1998, 1999b; Tse and Albert, 1998; van Lier, 1999; van Lier and Wagemans, 1999). In this last group, a recent approach proposed by Tse emphasizes the role of volume completion, in particular with regard to the concept of mergeability. With the term 'complete mergeability' Tse means that the "unbounded surface and inside of a volume can be extended into occluded space along the trajectory defined by its visible surfaces as they head under the occluder such that this unbounded volume extension merges entirely with other unbounded volume extensions" (Tse, 1999a, p. 170).

2.2.1 Theories of local type

Local amodal completion theories rely mainly on the principles of figural organization and other aspects of Gestalt psychology. The main feature of this theoretical account is the importance that it gives to direct experience. According to the Gestaltists, before constructing a theory which explains the processes by which visible objects are formed, it is necessary to describe the visual world and the objects of which it is made using the phenomenological method for the purpose (Kanizsa, 1980).

This approach is very different from the atomistic and associationist theories of perception. The essential incoherence of postulating an inferential or inductive process that *generates* information content was long ago pointed out in Hume's treatise, with its distinction between the stimulus set used to make the inference and the perceptual product of that inference. Hume showed that this distinction is eliminated by the very inferential process that defined it; an argument that has been validated in every possible computational rendering of ‘inference’, whether in machine learning, AI approaches to visual perception, or probabilistic models. In all these cases, the inevitable outcome is an inferential model plus some sort of uniformity, regularity or genericity assumption which is encoded in the inferential apparatus as an inductive bias, regularization, or Bayesian prior (Albertazzi et al, 2011, in press; Vishwanath, 2005).

As to criticism of the atomistic viewpoint, Gestalt theory showed that the context in which the stimulation occurs has an important role in perception. Although it is possible to break stimulation down into its atomic parts or individual components, our experience is always composed of a limited number of objects, not of innumerable single elements isolated and independent of each other. What people see are organized objects, delineated shapes, colours, not stimuli, wavelengths or radiations. Wertheimer (1923) argued that when people look out of the window, they see a house, trees and the sky. Although theoretically they might say that there are 327 nuances of brightness and colour, they do not do so. People only say that there is a house, trees and the sky outside the window, because these organized things are what they really see. Or when people hear a melody, they do not hear a group of notes, or a single note preceded and followed by other notes, and obviously not frequencies. They hear the entire melody, which is not the sum of its individual parts.

Physical objects or events are only parts of complex chains of processes, which, in the case of visual perception, can be described as follows: the physical object or visual event which is the ‘source of the stimuli’ emits or reflects light radiations of different intensity and frequency. After these radiations, which are called ‘distal stimuli’, propagate themselves in the visual field into the eyes, they create in the observer’s retina an area of stimulation, called ‘proximal stimuli’, that corresponds to the optical projection of the object. This area varies in size according to the distance between object and organism, while its shape varies according to the object’s inclination with respect to the observer. The retinal stimulation starts a chain of physiological processes, with photochemical reactions at the level of the receptors (rods, with low sensitivity to chromatic colours, but much more sensitive in situations with low illumination than are cones, which are responsible for colour sensitivity), triggering and conveying nerve impulses along the optical afferent pathways which modify the physiological state or the cortical area. The resulting cortical processes constitute the physiological substrate of perceptual experience at the psychophysical level. Since the organism of each single observer has a distinct cortical process, the phenomenal object or perceptual datum is a private experience of each observer (Kanizsa, 1980; Massironi, 1998). Along this route, from the beginning to the end of this process, the unity of physical objects is lost, and the information that reaches the subject consists of a huge quantity of isolated and independent elements.

However, because of the principles of perceptual organization, the perceptual system is able to group all these single elements to produce an organized and senseful world. The principles of grouping have been studied by Wertheimer, and they are an important contribution to the analysis and explanation of the perceptual processes that start from the materials found directly in immediate experience, free of interpretations and rationalizations. The perceptual units depend on certain factors that promote the grouping of elements into a whole. The main factors in the organization and unification of the visual field are proximity, similarity, continuity of direction, directionality, common fate, closure, *Prägnanz*, and past experience. These factors can act in the same direction, and thus reinforce themselves, or in opposite directions and cancel each other out. The organization of visual space is the result of the combination of these factors (Kaniza, 1980, 1991; Massironi, 1998; Wertheimer, 1923).

In proximity, the closer elements tend to form units more than do the more distant ones. In Figure 2.9 below it is seen a set of 25 dots which could at least theoretically, be organized in several ways. Nevertheless, there is one pattern predominant in function of the distance among the dots.

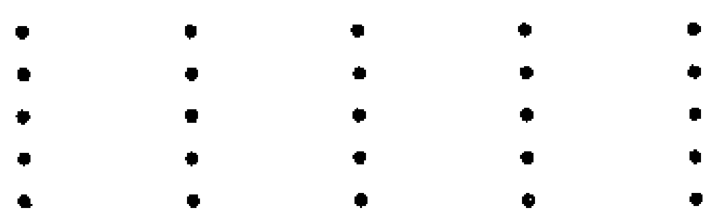


Figure 2.9 – Dots tend to group in columns because vertical distances are shorter than horizontal ones. (Wertheimer, 1923, original drawing)

Since the vertical distances are shorter, they tend to be grouped in columns, and not in rows or in other kinds of configuration. A horizontal arrangement is possible, but it is harder to see than the vertical one. People ‘think’ of an organization in rows rather than ‘see’ it.

The second principle of figural organization is similarity. Elements with some kind of similarity tend to form units. In Figure 2.10, the dots are separated by equal distances. In terms of proximity they would form one single group organized in a horizontal line.

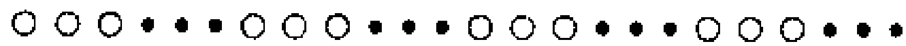


Figure 2.10 – Dots tend to group according to size and colour similarities. (Wertheimer, 1923, original drawing)

However, half of the dots are bigger than the other half, and half of them are white, while the others are black. These differences segregate the dots according to the similarity of colour and size. The perceptual result is groups of three dots (proximity) that are white coloured (similarity), and groups of three dots (proximity) that are black coloured (similarity).

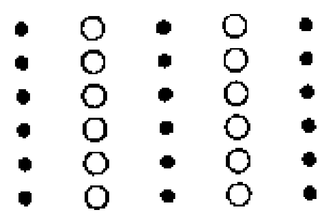


Figure 2.11 – When both factors cooperate, there is an effect reinforcement. (Wertheimer, 1923, original drawing)

Both principles – proximity and similarity – can cooperate together to strengthen the effect, which in the case of Figure 2.11 is the verticality of the configuration; or they can compete against each other, as in Figure 2.12, where the dots tend to align themselves in oblique lines, according to similarity, which prevails over proximity.

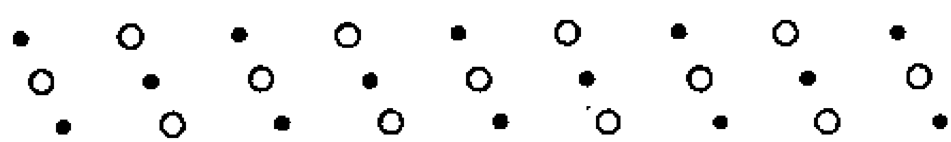


Figure 2.12 – Oblique lines of black dots and oblique lines of white dots are preferred to diagonal lines of black and white alternating dots (Wertheimer, 1923, original drawing).

Common fate is a kind of similarity principle. It states that elements with the same orientation or with similarities in their behaviour tend to aggregate. In a situation where some elements of the configuration are moving in the same direction or at the same speed, even if they are located in different regions among static elements, they tend to be considered as a group, while the static elements are considered as another group.

Another principle is that of continuity of direction. It states that a segment preferentially unifies itself with another segment which continues in the same direction. In Figure 2.13a, people normally see a horizontal line from which branches an oblique segment. The configurations in 2.13b and 2.13c are possible, but they are unnatural. A solution like 2.13b and 2.13c can only happen when thought, but not when seen.

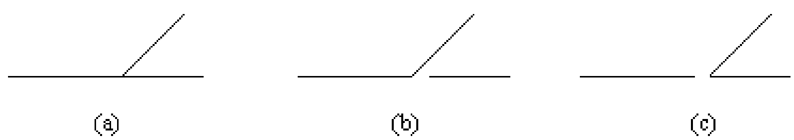


Figure 2.13 – Although (b) and (c) are two possibilities of grouping for (a), a configuration with a horizontal line, and an oblique segment is preferred (Kanizsa, 1980).

Directionality is a principle studied by Bozzi (1969) and it is different from continuity of direction. This principle states that the directionality of a figure affects its internal organization. Figure 2.14 shows how the organization of the small squares indicates a direction, from left to right, then downwards, and then to the right again. Another factor close to the directionality and continuity of direction is the orientation of the elements in the visual space.

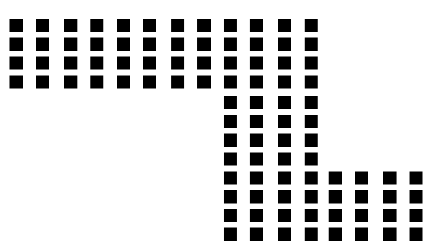


Figure 2.14 – Grouping according to directionality (Bozzi, 1969).

Elements with the same orientation tend to aggregate themselves in the same group. In Figure 2.15, elements oriented to the right (central and right arrows) go together, despite the similarities between left and central arrows.

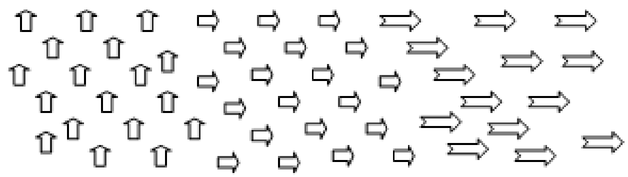


Figure 2.15 – In this particular case, orientation predominates over similarity.

Closure is a strong principle of figural organization. Shapes that tend to close prevail over continuity of direction and proximity. In Figure 2.16, this principle exercises a strong power in the structures presented, closing the more distant elements into three spheres, despite the proximity of the arcs or the similarity of the three elements with an opening to the right (C), and the three elements with an opening to the left (⊃). Here another principle exerts a particular influence: areas with convex margins tend to become a figure more than areas with concave margins.

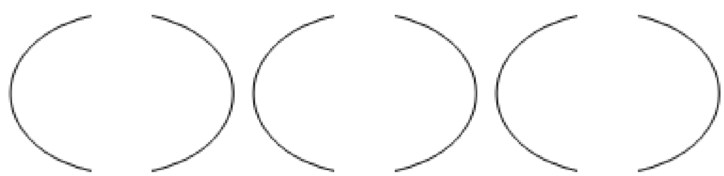


Figure 2.16 – Elements that if combined could close an area tend to group.

Prägnanz, also called simplicity, is a controversial principle. Forms that are simpler, ordered, symmetrical, regular, structurally coherent are preferred because they form balanced and harmonized objects. *Prägnanz* is the good gestalt, although defining what is good gestalt is not as simple as one might think. It is controversial because it has sometimes been used arbitrarily when explanation is not possible. By *Prägnanz* we understand the principle whereby the perceptual field is organized so that elements are present in balanced and harmonious units, and their parts complement each other to construct a perfect whole without non-belonging parts.

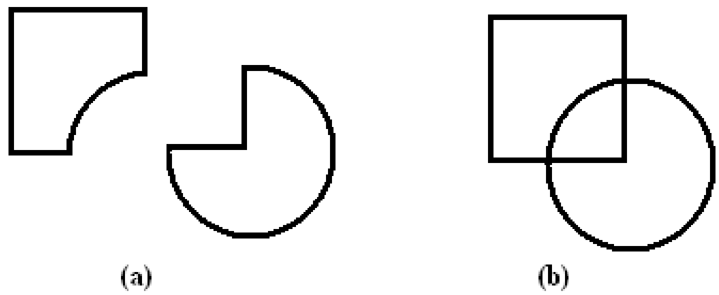


Figure 2.17 – The two figures in (a) unify themselves in (b), producing more balanced figures (based on Massironi, 1998, p. 69).

In Figure 2.17a there are two distinct figures, each one with a well-defined shape. They are closed and stable figures, but when they are placed together, as in 2.17b, the original figures can no longer be seen. They have been transformed into a square and a circle, which are simpler than the previous shapes, in a way that makes them practically impossible to see. Curved lines go together, as well as the line segments, which when unified produce a square. Figures became more regular and structurally more coherent.

Last but not least, past experience is also a principle of figural organization. It favours the formation of objects with which people are familiar, rather than unknown forms. In Figure 2.18 below, when the line segments are turned 90° clockwise, they become a letter 'E', but normally only for people who know the Latin alphabet. People who use other kinds of script will probably see only lines, not a letter.

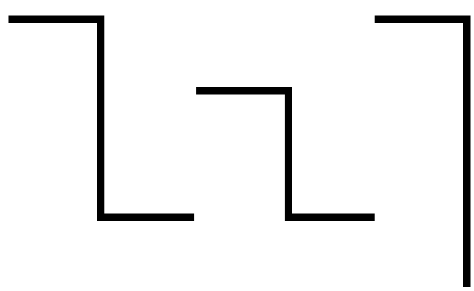


Figure 2.18 – When turned 90° clockwise, an 'E' is seen (Kanizsa, 1980, p. 68).

According to Kanizsa (1980), this principle applies only when it is not in competition with other factors and is not intense. The other principles can neutralize the action of past experience, demonstrating that the segmentation of the visual field is not a result of learning, as one might think. It normally occurs only when there is equality of conditions. In this case, a familiar output is preferred.

All the principles of figural organization presented can act in the same direction, thereby reinforcing themselves, or in opposite directions, thereby cancelling themselves. The organization of visual space is the result of the combination of these factors (Kaniza, 1980, 1991; Massironi, 1998; Wertheimer, 1923).

Amodal completion and these principles are closely interrelated. The principles act in order to produce more balanced figures, and parts of figures may group behind other parts to produce amodal completion. The upper part of Figure 2.19 shows black rectangles and triangles grouped by proximity. In the lower part, white rectangles have been placed between the black ones, producing a new figure. Closure and continuity of direction produce the effect of a black hexagon partially occluded behind the white rectangles.

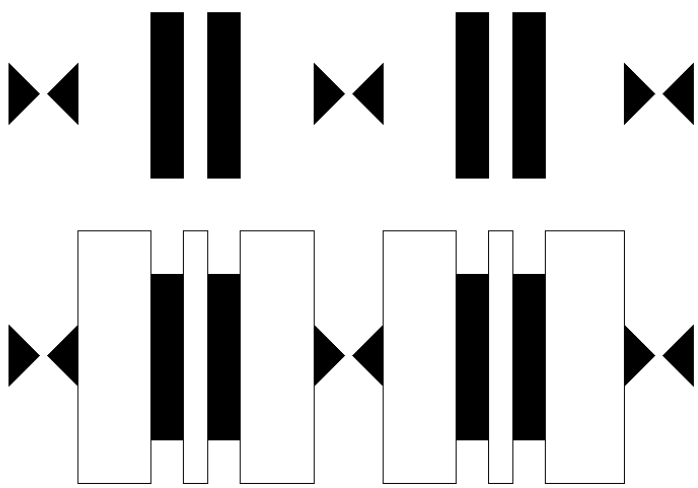


Figure 2.19 – An amodally completed hexagon emerges behind the white rectangles (Kanizsa, 1980, p. 56).

Amodal completion, according to this account, is the result of local conditions rather than the regularity of the global structure. In Figure 2.20, global structure should produce the amodal completion of a black square behind the grey circle on the left, and a white square behind the grey circle on the right. Nevertheless, most people say that what they see is a white cross on the left, and a black cross on the right, indicating that local cues are responsible for the amodal completion, and not the global cues.

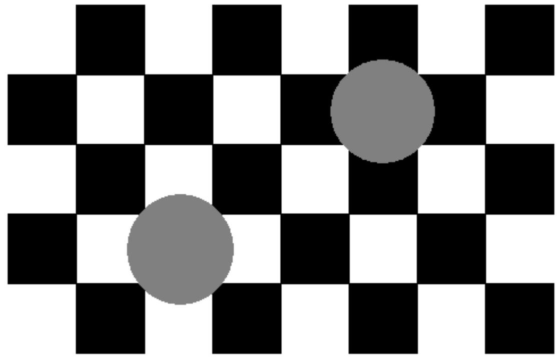


Figure 2.20 –There are a white and a black cross behind the grey circles (Kanizsa, 1991, p. 70).

Also Wouterlood and Boselie (1992) support the idea that local cues favour an occlusion interpretation. They have developed a model of perceptual organization which is a specification of the Gestalt principle of continuity of direction or good continuation. This model assumes the existence of a tendency to describe a pattern with the smallest number of contour elements and changes of direction. Specifically, Wouterlood and Boselie have studied the effects of different types of junctions combined in situations where surface contours are closed or not closed (in the sense that the contours end abruptly in a juxtaposed surface), and they have concluded that the junctions alone cannot accurately predict the interpretations of stimuli with T-junctions in an occlusion context; it also depends on the possibility of the closure of a region behind an occluder. These criteria are the two basic conditions for the model that Wouterlood and Boselie present based on good continuation. In this way, contours which 'end' in another contour, when possible, continue behind the surface, following the same direction as their modal part, trying to close its surface by meeting another contour.

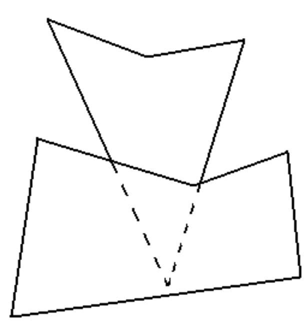


Figure 2.21 – In this model, the contours of the higher figure continue behind the lower figure until the closure of the surface when the contours join (Wouterlood and Boselie, 1992, p. 273).

The model consist in a first stage where a figure-ground segregation occurs, followed by a three-line junctions grouping where a completely bounded region emerges (the lower Figure in 2.21), and a region with two open-ended contours (the higher figure in 2.21). In the last stage, the open segments are eliminated by linear continuation within the boundaries of the occluder, until the joint with another line segment, when the occluded opened region becomes a closed area.

Kellman and Shipley (1991) present another point of view. According to these authors, the perception of amodal completion derives from the interpolation process of a single boundary. They have developed a theory of unit formation unifying perception under occlusion and illusory figure perception, based on three theoretical postulates: (i) the perception of the unity and boundaries of partly occluded objects and the perception of illusory figures are the results of an identical unit formation process (p. 159) – one interpolated edge stays in front or behind another surface according to the depth information; (ii) static and kinematic perception of hidden object boundaries may depend on a single process (p. 166); (iii) and the mechanisms of unit formation incorporate basic ecological constraints, specifically utilizing the information provided by spatial and spatiotemporal discontinuities in projected edges (p. 167). The aim of Kellman and Shipley's theory is to explain how partially hidden objects are perceived as units.

The first necessary condition for visual interpolation, according to Kellman and Shipley, is the presence of an abrupt change in the boundary's direction; in other words, a spatial discontinuity is necessary. Kellman and Shipley have found that people report seeing an illusory figure when there are discontinuities at the ends of the interpolated contours more frequently than when there are no such discontinuities. However, spatial discontinuity is not a sufficient condition for unit formation, which is fulfilled when other conditions are present.

Figure 2.22 – The discontinuity of the elements produces an illusory white circle (Kellmann and Shipley, 1991, original drawing, p. 172).

A notion reciprocal to discontinuity is relatability. When two discontinuous edges can be connected without interruption, they are said to be relatable. It is important that relatability respects the monotonicity constraint, i.e., the connection must go from one edge to the other continuously, without return or doubling back on itself. Even small misalignments may block unit formation.

Relatability is, according to Kellman and Shipley, an important factor in determining which discontinuities in the optic array derive from occlusion and which from abrupt changes in the outer boundaries of an object. If the edges are relatable, the discontinuity derives from occlusion. Relatability has been experimentally demonstrated able to predict unit formation under occlusion. When the connected edges completely enclose an area, then a new unit is formed, and the enclosed area will normally appear as an object, although it may appear as a hole depending on the depth information.

Depth information determines the depth placement of units. It is not part of the unit formation process, but it determines whether the units are modal or amodal. In spontaneous splitting figures, for example, there is no depth information, and the depth relations between the two areas reverse. Depth placement is also responsible for boundary assignment. In this sense, completion results from discontinuities of the relatable edges in the visual field which enclose an area, and depth information determines whether a completion is modal or amodal.

For Takeichi et al. (1995), amodal completion is an estimation problem, i.e., one of estimating the shape, colour and other visual attributes of occluded parts. The highly arbitrary nature of the occlusion of surfaces is the difficulty to resolve. They consider their theory of the curvature-constraint an extension of Kellman and Shipley's (1991) theory with the addition of curvature.

According to Takeichi et al., amodal completion consists in the subproblems of representation, parsing, correspondence and interpolation, which can be solved on the generic-viewpoint assumption. The latter states that the observer is not in a special position with relation to the scene. This prevents the occurrence of an abrupt change in an object's contour properties at the point of occlusion; what occurs when objects are seen from an accidental vantage point (Nakayama and Shimojo, 1992).

In this model, the qualitative shape of a contour is described by the number of inflections, and the junction is considered a sufficient condition for occlusion. These two aspects are related, because if contours at a junction share the same geometrical property, they will belong to the same object. The terminators of the junctions are connected according to the solution of the interpolation problem, preferring the simplest interpolation.

The interpolated contour, in its turn, must be continuous, smooth and contain the minimum number of inflections. It is thus one of the simplest possible solutions to the problem of interpolation. A terminator cannot be considered an inflection, and the presence of an inflection in the interpolated contour is possible only when its attendance is necessary to give continuity to the whole contour. There is here an important assumption of this theory. The minimum possible number of inflections is the estimated number of inflections, called the ‘curvature-consistency assumption’.

When the contour of an object is partially hidden by another object and forms a junction where the contour is interpolated by the occluder, the tangent of the contour in this point divides the occluded region into two subregions. The division line is called the ‘curvature-constraint line’. If the contour continues in the same subregion as the visible contour, the sign of the curvature does not change. If the contour goes to the other subregion, there is a change in the sign and an inflection is formed. The solution with the smallest number of inflections is the strongest one and is preferred to the other possibilities; and the number of inflections depends on the side of the curvature-constraint line to which the opposite endpoint of the interpolated contour belongs.

2.2.2 Theories of global type

This group of theories supports the idea that global processes dominate perceptual completion, while local processes play a minor role. On this account, the entire scene is important for perceptual completion, while in the local theories only the local region around the points of occlusion is important.

The first attempts to explain completion with global cues dealt with another problem: how to create quantitative methods to study the complexity of shapes. The research by Hochberg and Brooks (1960) was an important step in this direction. They analysed two-dimensional line drawings in order to create a psychophysical equation that could predict the depth-responses of subjects to non-perspective projection-drawings of three-dimensional objects. Eighteen measurements of the figures were used, such as the total number of interior angles, total number of line segments, number of line segments that formed the perimeter and number of internal line segments, number of different angles, and total number of subfigures.

Of these 18 factors, three emerged as predominant: number of angles, asymmetry, and number of line segments. Hochberg and Brooks suggested that these three factors are identifiable as approximations to the Gestalt principles of figural organization. The number of angles would be equivalent to complexity, or conversely, a small number of angles would be the equivalent of simplicity. The second factor, the number of continuous line-segments, would be the equivalent to continuation. A smaller number of segments would indicate a better continuation, and its inverse would be good continuation. The last factor, the number of different angles, divided by the total number of angles, would be the inverse of symmetry. If the angles are not different, a symmetrical configuration is likely.

These three factors together compose an equation, developed by Hochberg and Brooks, able to predict the three-dimensionality of the members of a group of reversible-perspective projections. The mechanisms behind the equation would work according to the magnitudes of the complexity, asymmetry and discontinuity. The greater these magnitudes, the more three-dimensional the object will appear.

Other studies have been conducted in order to determine the necessary and sufficient conditions for figural completion, such as the so-called ‘Coding Theory’. According to the latter, when something is shown to a person, interpretations are made of it. Since what is shown may be ambiguous, several interpretations are possible, and each of them corresponds to a ‘primitive code’ (Buffart et al., 1981). A primitive code is a sequence of symbols characterized by a detailed description of the stimulus. It consists of a starting location, direction, and a sequence of lengths and angles that describe the contours.

The primitive code is reduced by coding theory, producing an end code. Regularities in the figure lead to simplifications in the primitive code. This happens when present in a code is a sub-sequence which repeats *n* times without variation or interruption (iteration); when the same sub-sequence repeats itself to a natural ending, as in the case of a square where a right angle and a side are repeated four times (continuation). Reducing by continuation can also be used in cases where a uniform curve continues until the intersection of a line that has already been drawn, or when a line continues to an intersection or endpoint of an already existing line.

Other possibilities of reduction arise when there is an inversion in the order (reversal); when spatial symmetry is present (symmetry); when the elements can use a different way to state the same thing (distribution); when the substring of a code appears more than once in a string and iteration or distribution is not allowed, and the following strings can be replaced by a new symbol (symbolization). A last possibility is the use of subcodes for all the previous possibilities.

After simplification of the primitive code the end code is obtained, which in its turn is evaluated according to the number of independent parameters that it requires (number of angles, line lengths, numbers and symbols). This number is called the 'structural information load'. According to an ordinary selective information theory, information is what one does not know previously but can find out when a message is received (Garner, 1962).

In this sense, the information load is reduced by the perceptual system, and the interpretation reached is the one with the lowest information load generating the simplest interpretation. This is what the simplicity law in coding theory predicts: perceptual systems tend to use the code with the minimum information load.

When applied to experimental research, coding theory has shown that the familiarity of completed figures is not a necessary condition for a completion or mosaic interpretation; and local cues, like T-shapes, are not a sufficient condition. As regards symmetry, understood as the number of axes of symmetry, on average it can be considered a good predictor for mosaic interpretation or completion, but it cannot be taken as the main factor. In terms of continuation, people tend to see a mosaic configuration when the edges of the front figure, i.e. the possible occluder, continue straight out to make edges of the partially occluded figures. However, it has been shown experimentally that continuation is not a necessary condition to produce a mosaic interpretation. Some figures with these characteristics, used in the experiment by Buffart et al. (1981), were infrequently seen as mosaic while figures in which the edges did not continue straight out to make edges of the occluded figure were seen as mosaic.

Furthermore, the subjects of Buffart et al.'s experiment confirmed that the solutions with lower information load were preferred to the others. For the 25 figures used, a mosaic interpretation and one or more completion interpretations were made. In 16 cases, the solutions for completion had lower information loads than the solution for mosaic, seven had equal information loads, and two of them had mosaic interpretation as the lowest information load. The results showed that 96% of the subjects preferred a completion solution when it had less information than the mosaic solution; 45% chose completion when both had the same level of information; and only 10% preferred completion when mosaic had the lower information loads. For all the 25 figures, coding theory made the correct prediction. In this sense, the subjects tended to see a more economical solution. Symmetrical variations would be chosen if it was the simplest option, but also an asymmetrical or irregular configuration could take place if it was simpler than the other possibilities.

The coding model has also demonstrated its capacity to capture the overall organizational power of symmetrically arranged figures. In Figure 2.23, two configurations with similar parts are shown. The first of them, 2.23a, has a smaller information load when it is seen as a square behind another square than when it is seen as a mosaic, so that completion would be preferred as a solution. In figure 2.23b, the mosaic configuration has a lower information load than the completion solution, and is consequently preferred. Coding theory therefore predicts that configurations like those shown below can in a certain sense capture a subfigure and completely change its appearance. This is an important demonstration of the role of overall figural goodness, which is the reverse of the interpretation for figure 2.23a when shown in a more complex context of L-shaped figures, and of the coding model's adequacy for situations like this one.

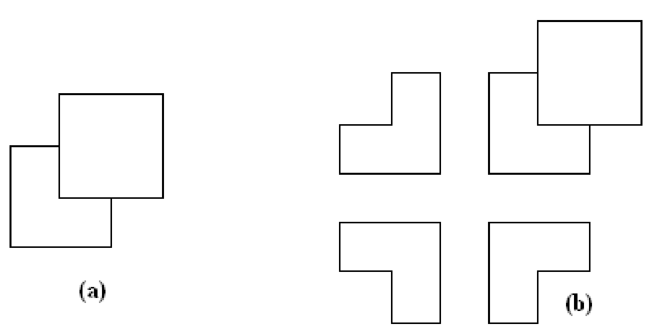


Figure 2.23 – In (a) the lower information load is for a completion solution, while in (b) it is for a mosaic configuration (2.23b was originally drawn in Dinnerstein and Wertheimer, 1957).

The general idea behind coding theory is the simplification of the code which translates the structure of an object or figure taking account of regularities in the configurations, such as the presence of the same angle more than once. However, the simplification made by coding theory does not mean that it assumes that perceptual systems perform simplification by leaving details out of the figure. Instead, it assumes that, when possible, perceptual systems use a more complex structural representation which uses less arbitrary information, replacing accidental or arbitrary information.

However, simplicity does not seem to explain why completion take place, at least when one considers the simplicity of a shape (Moravec and Beck, 1986). In Moravec and Beck's study, the type of completion seems to depend on the time exposure of the stimulus. With a presentation of only one second, good continuation was used in 74.6% of the trials. With a longer exposure time, good continuation was used in 37% and symmetry in 53.2% of the trials.

Since continuation is a local factor in which completion occurs when only the two line segments at an intersection are processed, the observer's attention does not need to concentrate on the whole figure. Symmetry, as a global factor, seems to require more time to process all the figural information. Thus, symmetry depends on a longer exposure time, and if the perceptual system does not have sufficient time to process all accessible information, it uses what is possible during the time available. The longer the exposure time, the greater the possibility that completion will be constructed by subjects.

In another experiment, only some parts of the stimuli were shown through holes in a mask. These parts suggested different kinds of completion, and although several answers were possible, the subjects did not choose the simplest possible shape. With the symmetrically biased stimuli, 85% of the trials were completed symmetrically. When the stimuli were biased according to good continuation, 67% of the trials presented continuation characteristics.

Sekuler et al. (1994) have also found that time influences the perception of completion. In their opinion, there may be a series of perceptual representations beginning with a mosaic representation which, with a longer time, continues through a local completion, and ends with a predominantly global completion. In an experiment conducted by these authors, participants were shown a priming stimulus (symmetric, occluded or asymmetric) with different time exposures. Then, after an interval of 15ms, they were shown a combination of three separate figures as test stimuli, two side by side in the lower part of the screen (half of the figures were symmetric, and half asymmetric). The subject's tasks was to state if these two figures were the same or different from each another. All figures were line drawings.

The results showed that after a symmetric or occluded prime, responses were more rapid to symmetric than to asymmetric objects. Following asymmetric primes, the responses were more rapid to asymmetric than to symmetric objects. According to the global theory of completion, there should be no difference between the priming patterns for symmetric and occluded primes, but a slight difference was found. Although similar, the results were not completely consistent with a purely global theory process. The local theory of completion, in its turn, predicts no differences between the priming pattern for occluded and asymmetric primes, but the results obtained by this experiment were inconsistent with predictions. It seems that completion is dominated by global processes with durations of 300ms and 150ms, although the results in the former case were not consistent with predictions of a purely global theory of completion. Evidence of an initial local completion was not found even for the short prime duration test.

In a second experiment, this time with filled figures, no evidences of a dominating local process was found. The results for both situations were predicted by the global theory of completion, even for the shortest one of 150ms. In this case, there was a difference in the priming effect between occluded and symmetric objects, but both had positive levels of priming consistent with global processes.

Regarding the initial question about the influence of time exposure in completion, the results of research by Sekular et al. (1994) reveal that global factors apply early in the completion process. In this sense, it seems that global processes dominate the perception of completion, although a relatively minor role of the local processes cannot be ruled out, mainly in early perception.

To test whether stimulus orientation influences the completion of partly occluded objects, Sekuler (1994) carried out a new set of experiments using stimuli with horizontal, vertical and diagonal orientation. Previous studies had suggested that good continuation was consistent with vertical symmetry. If this was correct, local processes would dominate in cases where a local solution produces vertical symmetry, rather than horizontal or diagonal symmetry.

The results showed that local processes never dominate completion, and that they are incompatible with a dominating local process, even with vertical symmetry. On the other hand, the results were consistent with a dominating global process, although they were inconsistent with a purely global one. Subjects' responses in 69% of the cases showed priming consistent with global processing in the diagonal and horizontal situations, and 56% in the vertical one, which was in accordance with predictions. Object perception, however, is co-determined by global regularities detected by the visual system. Orientation and good continuation may interact with one another, but in Sekuler's experiment the stimulus had a strong symmetry configuration, which may have prevented the influence of local cues.

It seems that the degree of symmetry in a figure is an important cue for the domination of local or global processes. With a stronger symmetrical configuration, global processes dominate, but with a weaker symmetry, local processes have greater importance in determining completion. A second experiment carried out by Sekuler using a weaker symmetrical configuration yielded results different from those of the previous experiment. In this case, vertical and diagonal configurations were more consistent with a dominating local process. For horizontal symmetry, 75% of the subjects preferred global priming effects, while for diagonal and vertical symmetries, the rates were 31% and 35%. This confirmed a previous prediction about vertical symmetry, but it also furnished a new finding: the diagonal symmetry had revealed differences between diagonal and horizontal configurations, although this result was not predicted. A subsequent experiment showed that vertical and diagonal stimuli were detected more rapidly than stimuli with a horizontal configuration.

The outcome of Sekuler's experiments seems to confirm previous assumptions that local cues dominate completion, especially when the figures are irregular, until global elements impose themselves more coercively. When more regularities are present in the figure, the more likely it becomes that global processes will take place in the completion. However, Sekuler's research did not consider other local or global factors besides good continuation and symmetry which may have exerted an influence.

Van Lier et al. (1994) proposed an alternative model using a combination of the coding theory and the global-minimum principle which states that the simplest interpretation is preferred. The combination of these two elements is called 'structural information theory', and it enables prediction of the preferred interpretations on the basis of the perceptual complexity of a figure. Unlike in previous researches with structural information theory, van Lier et al.'s approach assumed that the perceptual complexity of an interpretation must consider the internal structure, the external structure, and the virtual structure of the configuration in order to analyse shape, position and occlusion. The sum of these three structures determines complexity. Then, using the global-minimum principle, the interpretation with the lowest perceptual complexity is preferred.

The global-minimum principle, however, failed to predict certain choices by observers, who preferred a configuration different from that one indicated by the principle as the optimal one, as in the case of Figure 2.24. Although the information load is lower in 2.24a than in 2.24b, the subjects preferred the latter. According to van Lier et al., the problem is that codification of the structures was performed only in function of the internal structure of the objects, without considering the external and virtual structures.

The internal structure is determined according to the number of elements (contours, lines, angles, etc.) codified in symbols. The sum of the complexities of all figures in the interpretation is the total complexity of the internal structure. The external structure regards the relative positions of the objects and how they affect visual perception. It concerns regularities among the shapes, and these regularities bind pattern elements. If the binding occurs in the internal structure, it can strengthen the interpretation. If it occurs in the external structure, the interpretation may be weakened.

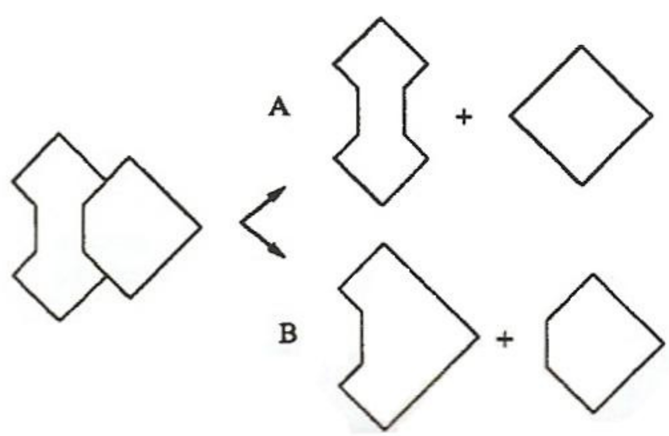


Figure 2.24 – Interpretation 2.24B is preferred although its information load is 13, higher than that from interpretation 2.24A, which is 10 (van Lier et al., 1994, original drawing, p. 885).

The last structure considered is the virtual structure. Virtual elements can be added in order to complete an occluded shape, and they increase the complexity of an interpretation by adding of new lines and angles. The difference between the number of visible elements of the partly occluded shape and its total number of elements defines the number of virtual elements.

Authors have tested this theory using stimuli from three different articles, totalizing 144 patterns. The selected articles have in common the applicability of the structural information theory, with results which confirm or reject it. In these articles, the patterns indicated by the observers as preferred were predicted in 52% of cases by the internal structure, 65% by the external structure, and 49% by the virtual structures. If the three structures are summed, it is possible to predict a higher number of patterns. In fact, 95% of the cases indicated by subjects as the preferred configuration were correctly predicted when this new criterion for the global-minimum principle was adopted.

The simple summation of these three structures is a good indicator of the perceptual complexity of an interpretation, which is much more effective than if the structures demonstrated to have equal effectiveness are used separately. According to van Lier et al., the three structures correspond to the principle of *Prägnanz* (in the sense of the simplicity of the shapes), to the coincidence-explanation principle, and to the principle of good continuation. A solution for the problem of amodal completion would thus be formulation of a theory able to encompass both local and global theories.

Only a model which quantifies both global and local aspects can predict the preferences for one or the other type of completion, and because both these aspects are relevant in pattern completion, theories which emphasize either global or local simplicity will fail (van Lier et al., 1995). The preference for one or the other aspect results from competition between these two completions. Local completion is characterized by a simple amodal part of a shape but with a more complex completed shape than with a global completion, which has as its characteristics the simplicity of the completed shape, but a complex amodal part of the shape. Van Lier et al. assume that the perceptual complexity of both interpretations should be considered in order to make predictions about the output of which kind of completion would win. Theories which consider only local cues or global cues have failed to explain a wide range of completion situations that have instead been explained by a theory which combines both aspects.

2.2.3 Theories of internal representation

This group of theories consists of those that consider the occurrence of amodal completion as resulting from compliance with certain conditions (inferred from image cues) among internal representations (traditionally surfaces but also volumes). Completion thus occurs, because the surface completes itself on a common depth plane. Nakayama et al. (1995) maintain that the encoding of surfaces is indispensable for perception. Surface representation is an important intermediate stage of vision between the acquisition of information and later steps like object recognition. It provides an appropriate basis for particular visual functions, such as object recognition, object manipulation, and locomotion.

In the case of completion, when regions are partially hidden, we have two types of contour: one inherent to the object itself, or intrinsic, and another defined by occlusion or extrinsic (Nakayama et al. 1989). The former provides information about the object's shape, while the latter one is formed by the interposition of another object without an intrinsic relation with the object itself. It varies in position according to the location of the object, the observer, and any other occluding objects.

An occluding object thus not only hides information about the occluded object, but also adds extrinsic edge information, potentially degrading the recognition of patterns. To avoid this problem, the visual system must distinguish the two types of contour present in completion situations and which are classified on the basis of depth, according to the following rules: (i) when image regions of different surfaces meet, the border between them can belong to only one of them; (ii) in conditions of surface opacity, the surface coded as being in the front-ground owns the border; and (iii) regions that do not own a border are said to be 'unbounded', and an unbounded region can connect itself with other unbounded regions which form larger surfaces by completing themselves behind the occluder.

In surface representation theory, depth information is fundamental for the categorization of edges, which in its turn is responsible to determine the grouping and segmentation of image fragments, determining what object is recognized. Alternatively to the surface representation, Nakayama et al. proposed that information could be reached in a more efficient and shorter way, through the encoding of relative depth contour representation.

In this group of theories, a more recent type of research has been conducted by introducing a new element: the use of three-dimensional stimuli. Until ten years ago, studies on amodal completion did not consider objects with their volumetric characteristics. The majority of studies were conducted using flat bi-dimensional stimuli, and in this case, the discussion between global and local cues were plausible. Since the introduction of the third dimension, the question of which kind of cue is more important or explains the higher number of completion cases has lost its relevance because of the need to introduce a new element: the global object's interpretation based on its figural properties. Of course, local and global cues still play an important role in the completion of 3-D objects, but they alone cannot hold completion. The object should assume its own nature as a shape, a 3-D object, a volume, etc., then to yield possible interpretations. In this case, intrinsic regularities appear to perform the most important role in the completion of objects. As the regularities grow numerically, become more complex and elaborated, the simpler become the interpretations. Van Lier and Wagemans (1999) have shown that the simplest interpretation was increasingly preferred, the greater the differences in object regularities between alternative completions.

Figure 2.25 depicts a curved object with its lower part hidden by another object. If the curvature is interpreted as frontwards, the output is as in 2.25B2. If the interpretation produces a solution like that in 2.25C2, the curvature is seen as downwards. Essentiality, these are two different objects in competition that cannot be derived from local cues. Figural properties, however, could give rise to a global object representation.

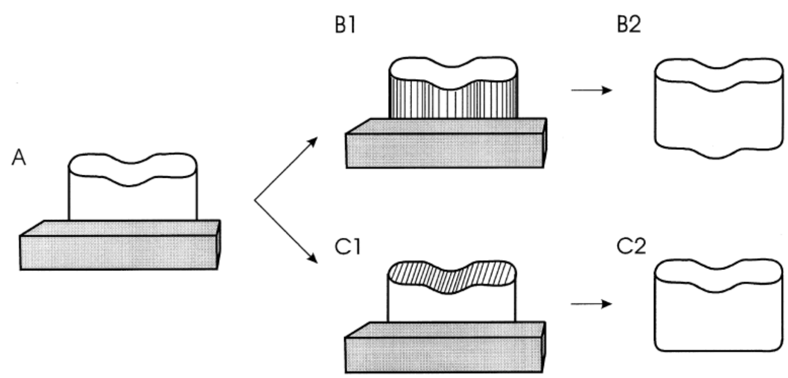


Figure 2.25 – The solution for A depends on the interpretation given to the curvature of the object (van Lier, 1999, original drawing, p. 216).

Van Lier and Wagemans (1999) carried out a series of experiments in order to understand the amodal completion of solid objects. They started by comparing local and global solutions, as had been done for 2-D surfaces, and found that, although these solutions were still valid for 3-D objects, a strong influence was exerted by structural object aspects. They showed subjects basic cubes with one or more indentations in two different sizes. Stimuli were shown in pairs and subjects were asked to say if the two objects could be two views of the same object, since one of them was rotated 90° in relation to the other. The results showed that both global and local tendencies played a role, and when both converged on the same completion this solution was preferred to others. The experiments were repeated twice with some variations, and the results were basically the same. Some effects were observed when a new stimulus were used, suggesting that global completions could well be generated by the visual system, but it seemed that they needed more configural support.

On analysing the experimental data, van Lier and Wagemans found a tendency towards more symmetrical objects, although symmetry alone could not be responsible for subjects' preferences. On considering only the top surface of each cube, this tendency became stronger. This may have indicated an overall tendency towards simple and regular shapes, and according to the authors, because the structural information theory incorporates the tendency of the visual system towards simplicity, it could be used to explain 3-D, as in the case of 2-D surface completion.

For Tse (1999b), contour-based and surface-based theories of completion are limited and cannot explain several cases which instead are explained on a volume-based account. Tse pointed out that, although our lives are full of volumetric partially occluded objects, most of the research on amodal completion has only used 2-D stimuli. A volume-based theory, added Tse, is necessary to understand the role played by spaces enclosed by visible surfaces in completion. Tse used the word 'volume' to denote a 3-D enclosure, and extended the surface-based theory of Nakayama et al. (see above) by stressing the way in which surfaces interact in occluded and self-occluded spaces, and analysing the role played by volume in the completion. On this new account, surfaces are special cases of 'degenerate' volumes which do not have 'insides' like normal volumes.

Before explaining the details of his theory, Tse cited several examples demonstrating the inefficiency of certain theories in predicting amodal completion. Situations in which relatable contours are present do not produce completion, while in other cases amodal completion is present even in the absence of relatable contours. The relatability of contours is thus neither a necessary nor a sufficient condition for the occurrence of amodal completion. Moreover, objects with self-occlusion can complete themselves without relatable contours being necessary.

Nor can the surface completion view explain situations involving volumes. Unbounded surfaces should meet behind the occluder when in a common depth plane, but this is not the case in Figure 2.26.

Here the surfaces of the two cubes are relatable as their contours, and they lie on a common depth plane. However, they are not complete, probably because the common surface appears to be part of both cubes, and a surface can only belong to one volume at a time. Another plausible explanation would be that the inside of one object surface cannot link with the outside of the other one in order to constitute a single closed surface. However, Tse points out that the assignment of roles for inside or outside in amodal completion constrains change in the perceptual level of surfaces to that of volumes, because surfaces cannot have an inside or an outside.

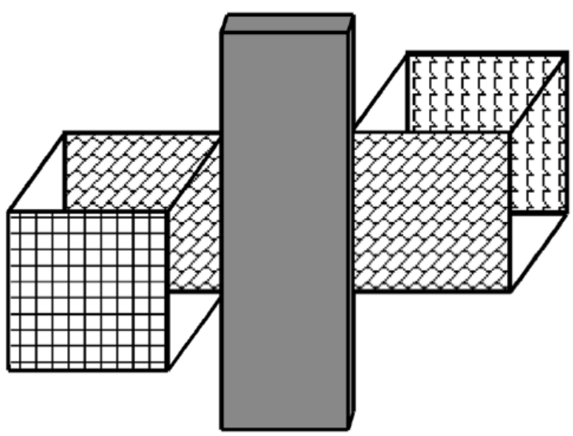


Figure 2.26 – The presence of relatable contours and relatable surfaces does not produce amodal completion (Tse, 1999b, original drawing, p. 45).

A crucial aspect of the volume account of completion is that the visible surface region of an object can relate to another region behind the visible surface of the object to form a volume: i.e., in the self-occluded space, the two regions can complete themselves and produce a volume. The exact form of an occluded region does not seem to be a necessary condition. According to Tse, the visual system may determine completion without interpolating the precise output of the completed area. This would not inhibit a good description of the structures. Another assumption relates to the smoothness of surfaces without visible contours projected from their interior. In this case, the absence of information is a cue for the formation of a particular configuration, so that this assumption implies a surface connectedness, even when the closure of the surfaces is not feasible. Completion has been observed even in the non-attendance of occluding contours, closed surfaces, and surface occlusions. These events can be explained on the assumption that the contours of an image "may be less cues of permission than cues of denial" (Tse, 1999b, p. 52). Images connect because there is nothing to say that they cannot connect. Surface connectedness acts by default, except when nonrelatable surfaces are indicated by image contours.

If surface relatability and contour relatability cannot explain amodal completion, although they play an important role, what can explain completion? The answer may be that the insides or the substances of the visible parts can merge behind or through the occluder, even if visible surfaces are not relatable. The concept of mergeability would mean that "the inside of one unbounded volume can join the inside of another unbounded volume to create a larger unbounded or bounded volume" (Tse, 1999b, p. 53).

According to this research, the role of contours should be conceived in a different way. They are no longer seen as cues to occlusion, but as cues to the formation of volumes. Also border ownership, always seen as something given in the beginning as a primary process, is here considered only after the determination of the occlusion relationships among volumes. Volumes, at this point, should no longer be understood as having a surface-bound enclosure, but as being occupied, filled or enclosed space bounded or otherwise by a surface.

It is important to note that a distinction between surfaces and volumes could be considered a false dichotomy if we are thinking about the natural world, because an object always has a surface, and all surfaces have an inside, since surfaces are the outermost parts of everything. An inside is, in its turn, everything that is under the visible surface. What is still not clear is whether they are separate or independent types of mind representation, or whether they constitute a single process also in the brain. Tse prefers to think that they are only one, because "volume subsumes the representation of a surface" (Tse, 1999b, p. 64). Several factors contribute to the view that volume mergeability and surface relatability are aspects of the same unique process of volume completion. For example, the visual system cannot analyse volume mergeability without analysing the layout of the surface, because this latter specifies the insides of a volume. Moreover, says Tse, surface orientation is specified together with the direction of the inside. Surface layout can then provide information about the direction of the inside because it is always found behind or under the visible bounding surface. Unbounded surfaces may implicate the merging of unbounded insides, but also the opposite: unbounded insides may imply unbounded surfaces. Moreover, outputs of volume completion could be used as inputs for processes of object recognition which need a match of form to memory, or in motor processes involving grasping or handling in 3-D.

The example of the "sea monster" can summarize volume completion. The presence of contours of penetration works as a strong cue to surface occlusion and surface penetration. Contours of penetration are a special kind of surface conformation in which a penetrated surface conforms around the penetrating surface. Conformation, in its turn, is a cue to the recovery of the curvature of a surface from images that are ambiguous (Tse, 1998). In conformation, the surface of a volume conforms to the curvature of its neighbouring supporting surface, when no cues to the contrary are present.

When shown Figure 2.27 below, all of the ten subjects asked by Tse reported seeing a "sea monster". Each segment of the figure, if taken alone, does not have the power to induce a strong volume perception or an illusory surface in the role of water, but when taken as a whole, the three segments can produce an illusory water surface and a volumetric perception of the segments. All of these effects can be perceived despite the absence of: (i) traditional cues for amodal completion; (ii) surface-based cues indicating that the visible parts could link up under the illusory surface; (iii) good continuation or relatability; (iv) and an occluding surface in order to create unbounded surfaces. The three parts, however, are seen as a single volume.

Figure 2.27 – The "sea monster" (Tse, 1998, original drawing, p. 985).

The three parts of the "sea monster" could not complete if they were considered as flat surfaces, because none of the traditional surfaces cues necessary to produce completion are present. The water surface, instead, could occlude the black segments only if the contours of penetration were taken in consideration as cues to discontinuities. However, illusory contours are neither necessary nor sufficient for the formation of volume and vice-versa. They are independent (Tse, 1998).

A volume can also be reversible, and this is a proof that a three-dimensional figure does not belong to the group of flat surfaces which can own their edges. They are volumes that possess all their surfaces. The reversal of the figure-ground relationship implicates changes in the shapes of the completed volumes, but also in the occlusion relationships. The borders of the image which have an ambiguous character belong to the shape which is expected. The case which dominates the mental set at that time wins the border ownership. In this way, amodal completion and volume formation are, says Tse, "not entirely preattentive or cognitively impenetrable processes".

2.3 Amodal completion and dimensional phenomena

In concomitance with the amodal completion, it is common to observe effects of expansion and shrinkage in which an object or a surface seems to be perceptually bigger or smaller than it is metrically. Normally, an occluded object that tends to complete or to continue itself behind another object appears smaller than it is metrically (Figure 2.28). 'Empty' spaces or backgrounds can also shrink if they are behind a figure (Kanizsa, 1972, 1975, 1980), as can be seen in Figure 2.29.

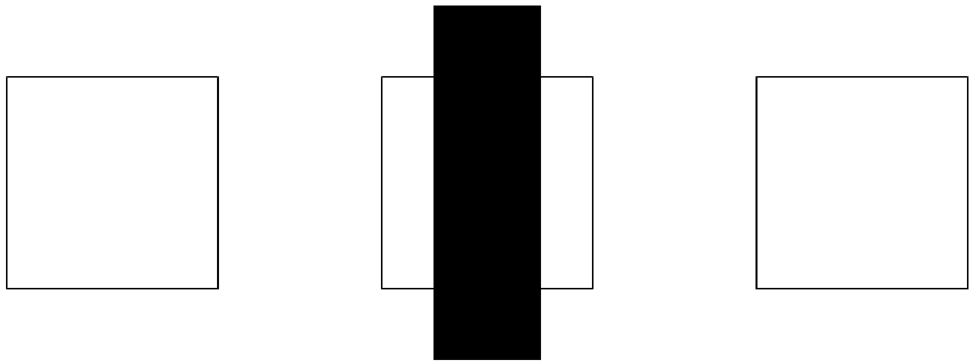


Figure 2.28 – The central square seems to be narrower than the others. (Kanizsa, 1980, p. 310).

While the shrinkage of occluded parts oscillates between 2% and 9% and seems to be proportional to the occluded area (Kanizsa, 1975; Tampieri, 1979; Vicario and Tomat, 1991a), shrinkage of empty spaces is bigger and can reach 18% (Vicario and Tomat, 1991a). According to a study by Luccio and Edile (1981), figures with physical borders shrink much less than figures with illusory or non-evident borders, while the 'empty' space, because it does not have borders, is the greatest shrinkage case.

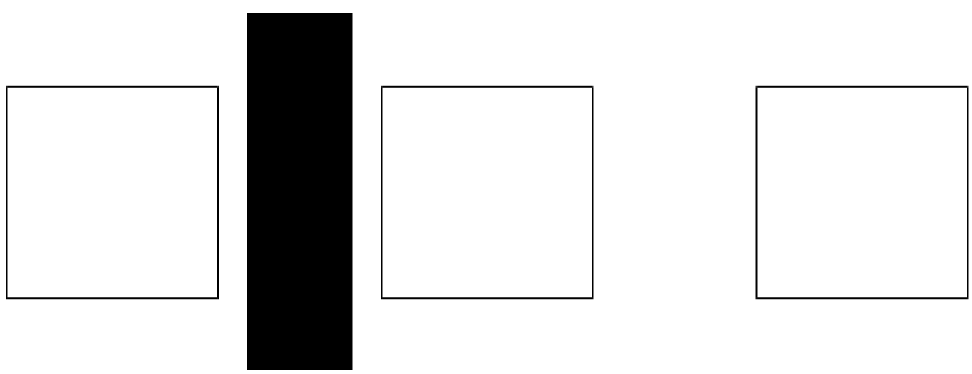


Figure 2.29 – The background between the left and the central squares seems to be narrower than the background between the right and the central squares, demonstrating that also empty spaces shrink (Kanizsa, 1980, p. 310).

Even if these shrinkage phenomena are observed in the presence of amodal completion, there are different opinions on whether amodal completion is the cause of these dimensional effects. The explanation proposed by Kanizsa (1972, 1975, 1979, 1980) is based on Metzger's research into the *Ganzfeld* (1930), in which the amplitude and the articulation of the phenomenal space are determined by the distribution of energy originated by the stimulation. In this way, when the stimulation has a low intensity, the visual space shrinks and tends to assume the smallest amplitude. Thus, the configuration in output responds to the "principle of minimum", which states that a perceiver sees the simplest interpretation of a pattern (Koffka, 1935), and the apparent size is proportional to the quantity of the energy. According to Kanizsa (1972, 1975, 1980), amodal completion is a case in which the external forces are reduced to the minimum level because the object, figure or surface which completed itself behind an occluder has little energy available, since the energy produced by the stimulation is almost entirely used to form the surface that stays in front of the configuration, i.e., the surface modally presented.

This statement is consonant with the traditional theory of Gestalt psychology where the perceived shape is not an amount of places and geometrical relations, but a distribution of forces. Drawing on Koffka's theories, Kanizsa conceived object formation as a de-formation and counterbalance of the internal resistance process powered by external forces from the stimulation. The power of the stimulation, however, does not derive from the absolute intensity, but from the level of figural articulation and inhomogeneity (Gerbino, 1993).

The results of research conducted by Gerbino (1975) go in the same direction as Kanizsa's energetic theory. When the occluder of Figure 2.30 was made to look transparent, the occluded surface appeared to be longer because it had a bigger modal area, and consequently, more energy had been used to produce it.

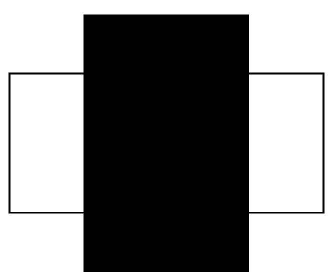


Figure 2.30 – When the occluder is made to look transparent, the occluded rectangle appears longer.

On the order hand, there are several authors who do not agree with Kanizsa's explanation. Zanforlin (1981a) argues that shrinkage does not depend on amodal completion but results from the division of the space into three parts, while the division into more than three parts would produce an expansion. Zanforlin was the first to maintain that phenomenal constriction does not result from amodal completion (Vezzani, 1998, 1999) but is a limit case of Oppel-Kundt's illusion (Kundt, 1863).

According to Gerbino (1993), the contour is the place where the balance between internal and external forces is determined. Therefore, the dimensional phenomena of shrinkage will depend on the proportion of the occluded contour, and not on the occluded area. Gerbino found a shrinkage of 5% in both cases, with amodal completion and with only the amodal completion of the upper and lower contours (Figure 2.31a).

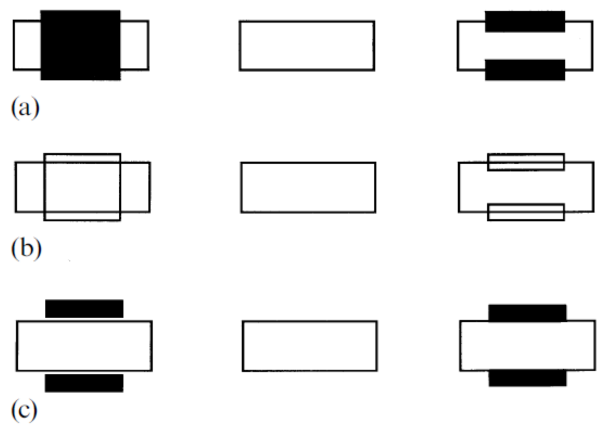


Figure 2.31 – Vezzani (1999).

In light of these results, Vezzani (1998, 1999) operated a variation in the stimuli using only contour interposition (Figure 2.31b) and found that effects could be also observed in this condition where only the contours were left. In a second stimuli alteration, small rectangles were placed near the large rectangle in order to avoid occlusion, and shrinkage was also verified. These results go against the theory that dimensional phenomena are due to amodal completion because they demonstrate that amodal completion is not a necessary condition for shrinkage.

Another finding contrary to amodal completion theory is provided by Vezzani (1994a), who proposed a figure with a much narrower occluder, which, according to him, was too small to explain dimensional phenomena. In Figure 2.32, only one line is placed in front of a horizontal rectangle. However, not only constriction was observed, but also expansion. For Vezzani, a minimal completion like that by a line, which cannot occlude more than a small part of the rectangle, cannot explain the presence of either shrinkage or expansion: their presence in this results from other factors, not from amodal completion. If, therefore, amodal completion is not the cause of shrinkage in Figure 2.32, the same is true for other cases. An explanation for these effects, says Vezzani, would be the division into parts as reported by Zanforlin (1981b).

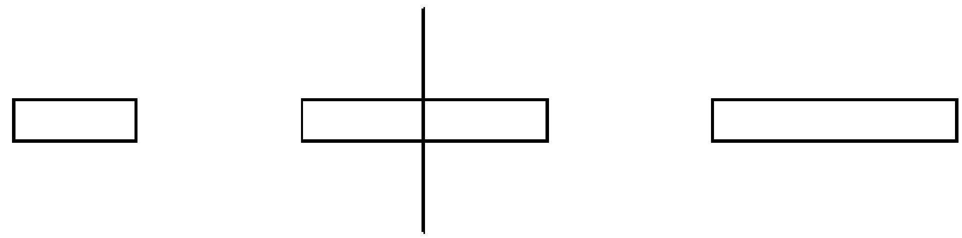


Figure 2.32 – The dimensional phenomena are also present if it is only a line that occludes the object (Vezzani, 1994a).

The constriction of empty or homogeneous spaces seems to play an important role, but contrary to Kanizsa's hypothesis, which states that empty spaces shrink because they do not have much energy, Vezzani assumes that completion is not important at all, because the phenomena can also be observed in the absence of amodal completion. For Vezzani, several factors support the hypothesis that phenomenal shrinkage depends on two optical-geometrical illusions: the first illusion consists in the constriction of spaces divided into a few parts – mostly if figures that cause division are higher than the divided figures – while the second illusion consists in the constriction of empty or homogeneous spaces, even if it is not still well known how these two illusions are related.

The relation between the height of the occluder and that of the occluded parts seems to be very important for dimensional phenomena. While in most of the examples occluders were higher and shrinkage was observed, Vezzani (1994b, 1998, 1999) obtained different results when using occluders with different heights. In fact, when the occluded surface is shorter than the occluder's, it is possible to obtain a constriction even if there are many divisions, although it has been known that a surface divided into more than three parts expands (Zanforlin, 1981a). It seems that this occurs when the occluder is taller than the occluded surfaces and when the occlusion is due to several homogeneous spaces. Nevertheless, if shorter homogeneous spaces are used as occluders, an expansion is obtained. This occurs also with a background occluded only by one figure, since it is shorter than the other figures, as can be observed in Figure 2.33 below.

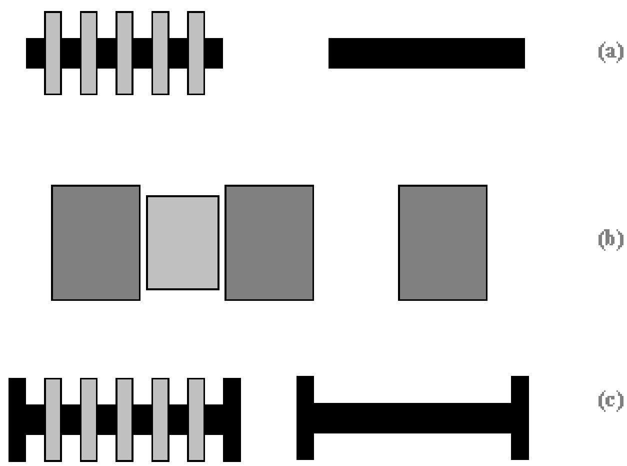


Figure 2.33 – In (a) shrinkage of the occluded black area is observed. In (b) and in (c), because the occluder is not taller than the occluded, an expansion is verified.

Vezzani (1998, 1999) considers this to be another finding against Kanizsa's theory that dimensional phenomena are a consequence of amodal completion, because expansion can be obtained also in conditions of occlusion, when surfaces, in theory, must shrink. He also considers the constriction of occluding surfaces to be an important point against amodal completion. This occurs because the occluder is virtually divided by the occluded surface. Vezzani (1994a, 1998) and Purghé and Olivero (1998) have found not only the shrinkage of the occluder, but also the expansion of the occluded surface.

Expansion is a dimensional phenomenon which was initially considered to be shrinkage due to amodal completion. The first to notice this phenomena were Kanizsa and Luccio (1978), who found that partially occluded objects appear bigger than they are metrically, and that the effect of this expansion is about 8%, while Gerbino (1979) and Vicario and Tomat (1991b) found that expansion covaries with shrinkage. In Figure 2.34, the black rectangle adjacent to the white rectangle appears bigger than it is metrically because it seems to continue behind the horizontal rectangle. Amodal continuation would be the factor responsible for the expansion. According to Gerbino (1993), this is a local effect, and amodal completion is not necessary because amodal continuation is sufficient for expansion. Other experiments carried out by different researchers have demonstrated a relation between expansion and amodal continuation (Micali et al., 1978; Luccio, 1980).

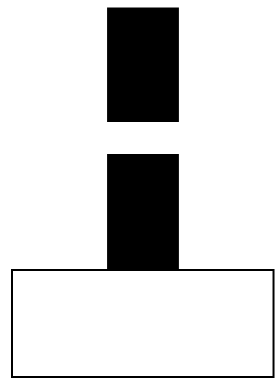


Figure 2.34 – The rectangle adjacent to the white surface is perceived to be about 8% bigger than it is metrically (Kanizsa and Luccio, 1978).

As for shrinkage, the Kanizsa's energetic theory was originally used to explain the phenomena of expansion. The critical point in this case concerns the internal forces in the occlusion area. The internal forces of restraint would be weaker than those in the non-occluded areas of the visual space. Because figures that continue amodally behind an occluder do not have a modal contour on one of the sides, i.e., they are not closed, their energy tends to overflow in the direction of the occluder, expanding the figure (Gerbino, 1993). In this sense, both phenomena have the same explanation.

However, some results pointing in a direction different from amodal continuation have been obtained. Vezzani (1993) conducted an experiment comparing two situations (see Figure 2.35 below).

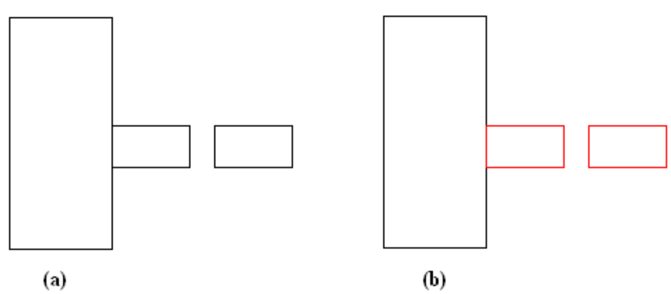


Figure 2.35 – In (b) an expansion was not expected but proved to have the same effect as (a). (Vezzani, 1993).

In one of them, the adjacent rectangle had all contours visible and in a different colour from the bigger rectangle, which had a small part of its contour occluded by the differently coloured contour of the adjacent rectangle (Figure 2.35b). In the other situation, both rectangles had the same colour. The common contour appeared to belong to the bigger rectangle, and the smaller one, since it had no visible contour on the adjacent side, seemed to continue behind the bigger one (2.35a).

Although Vezzani expected different results in the two cases (expansion in 2.35a and no effect in 2.35b), he found an effect of about 5% in both situations. Parlangeli and Roncato (1994) obtained results similar to Vezzani's. In a first experiment, they tested subjects by showing them four different situations (see Figure 2.36 below). In each situation there were two vertical rectangles, one constant and the other variable, always positioned with 30mm of distance. The constant rectangle was positioned 10mm higher than the variable rectangle. The constant rectangle could have a length of 40mm or 50mm and a width of 10mm, while the variable rectangle had a width of 10mm and its length was variable, with a difference of 1mm in a range between -5mm and +5mm in relation to the length of the constant rectangle. Furthermore, in three situations, a horizontal rectangle of 90mm per 20mm was shown under the two vertical rectangles. In one situation the variable rectangle touched the horizontal rectangle; in another the distance between both was 1mm, and in another situation the distance was 0.5mm. On comparing the condition with amodal continuation and that without the horizontal rectangle, a significant expansion of 2.7% was found. A significant expansion of 2.4% was also found in the comparison with the situation in which the distance between the horizontal and the variable rectangle was 0.5mm, in which the expansion was not expected because the necessary conditions for amodal continuation were not present. Parlangeli and Roncato concluded that adjacent contours seem to have no influence on the dimensional phenomenon of expansion, since it is considered a necessary condition together with the presence of an occluder for observation of expansion.

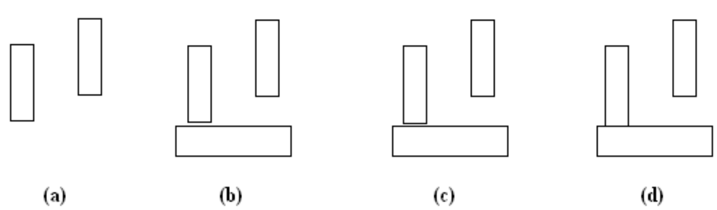


Figure 2.36 – A significant expansion was found in (c), although the vertical rectangle does not go behind the horizontal one (Parlangeli and Roncato, 1994, p. 65).

In a second experiment, Parlangeli and Roncato tested the necessity of an occluder for the perceived effect of expansion. Stimuli were very similar to those in the previous experiment. This time, because the length variation of the constant rectangle had not been significant in the first experiment, the authors decided to keep it fixed at 50mm of length. The length of the variable rectangle this time could vary between 45 and 55mm.

The horizontal rectangle was replaced by a horizontal line in order for it not to be an occluder. Finally, five situations were shown to subjects: a control situation without the horizontal line, a situation in which the variable rectangle touched the horizontal line, and situations where the distance between the line and the rectangle were 0.5mm, 1mm and 1.5mm. The results showed a significant expansion of 2.16% in the condition where the horizontal line and the variable rectangle were in touch, in comparison with the control situation. Moreover, there were no significant differences between the three situations without adjacent position and that the one with the adjacent position. In conclusion, Parlangeli and Roncato's data reveal an expansion even though the necessary conditions of the presence of an occluder and figure adjacency are not present, and consequently call the relation between amodal continuation and expansion into question.

Several other studies have sought to demonstrate that dimensional phenomena are a result of amodal completion, while others have sought to prove the opposite and propose alternative explanations. The findings of the above-mentioned studies still cannot clearly and fully explain the mechanisms responsible for those phenomena, even if they potentially provide an explanation for the effects of shrinkage and expansion. Moreover, they cannot exclude that amodal completion may be responsible for them. Nevertheless, regardless of the real causes of those effects, a factor which must however be explained, expansion and shrinkage are two phenomena frequently observed simultaneously in situations of amodal completion, which are excellent occasions to analyse both phenomena.

2.4 The completion of colour

A large body of literature has been developed on several aspects of amodal completion, particularly in regard to dimensional effects and their possible causes. However, colour has been rarely considered. Only recently have some studies been conducted on this subject, and they have shown that colours, in the same way as objects or shapes, can complete amodally. This happens, for instance, when the colour of an object is hidden by another colour or by lighting. There are, according to recent studies, four possible phenomenal combinations: amodal or modal coloration and amodal or modal discoloration (Pinna, 2008). The first two cases are situations in which a colour completes itself behind lighting, while in the last two there is completion in which a colour is completed behind another colour. Pinna converts the concept of 'amodal', which originally referred to a perception of completeness and object unity despite the modal absence of a border, into a concept in which the perceived completeness and unity refers to a colour completeness and unity despite the absence of a colour within the entire object.

Pinna has called the completion of a colour behind lighting 'coloration'. This happens when, for example, in an object composed of more than one colour, only one of them is considered its own colour, while the others assume a different role. Figure 2.37 for instance, presents the lighting illusion (Pinna, 2006, 2008). It consists of six adjacent blue contours with different luminance arranged in order of luminance. The image is perceived as a volumetric object illuminated by light.

Figure 2.37 – The lighting illusion is an example of amodal coloration (Pinna, 2008, p. 416).

The inner region appears whiter than the background – as brighter and fuzzier. It is seen as the surface colour of the object and contemporaneously as the reflected light. This means that this region is perceived as simultaneously an object and an illuminated region. According to Pinna, the blue colour of the boundaries completes itself behind the illumination, becoming the colour of the object, and the white of the inner region assumes the role of lighting. The blue colour spreads itself and fills the inner region of the object behind the white colour. This process is called ‘amodal coloration’.

Different degrees of amodal coloration can be observed by decreasing the number of adjacent contours. In this way, there is an increase in the modal coloration and a decrease in the figural, volumetric and lighting effects. The watercolour illusion (Pinna, 2005; Pinna and Reeves, 2006) is an example of how the decrease in the number of adjacent contours can produce a different effect. Figure 2.38 shows a surface coloured with a veil of light blue which spreads from the contour with a solid figural appearance segregated in depth. It is considered a quasi-modal coloration, because the light blue in the inner region appears brighter than the light blue colour on the contours.

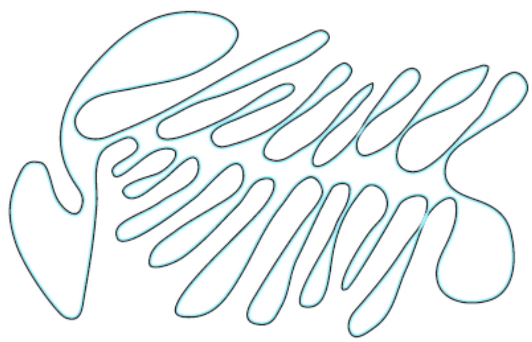


Figure 2.38 – In the watercolour illusion the colour of the borders spreads across the entire surface. (Pinna, 2008, p. 416).

The last two cases refer to the amodal completion of a colour behind another colour creating two different types of discoloration, one modal and the other amodal. In the modal discoloration, one colour can discolour another in a way that the discoloured colour appears as illumination, while the other colour assumes the role of the colour of the surface, completing itself behind the discoloured one. In Figure 2.39, the inner region was filled with a light red colour, but despite the changes, the perceived result is basically the same as in the lighting illusion: the figure appears illuminated by a bright light and the inner region appears white instead of red, because of the discolouration of the red.

Pinna (2008) stresses that although this last illusion and the lighting illusion have similar structures, they show phenomenological and theoretical differences. The first difference is between the conditions where both illusions can be perceived. The discoloration illusion cannot be observed in achromatic conditions, while lighting can be seen in chromatic and achromatic situations. The second difference regards the fact that discoloration is related to the colour that discolours itself, while the lighting illusion concerns the perceived illumination of the object.

Figure 2.39 – The light red in the inner region discolours and appears white (Pinna, 2006, p. 585).

The last case of the four possible combinations is amodal discoloration. This is obtained by increasing the luminance of the colour in the inner region of the object until it no longer appears as lighting but as a second surface colour. This second surface colour, however, does not assume the role of object's colour. It is perceived as another colour covering the real colour of the object. The perceived colour of the object is that from the borders, which completes itself behind the second surface colour.

Since discoloration cannot be observed under achromatic conditions, it is likely that perceptual mechanisms are responsible for this difference. In fact, Pinna (2008) found that subjects gave different descriptions of the stimulus when it was presented in chromatic or achromatic conditions. When a blue gradient was used, the different colours in the inner regions of the object discoloured, and the blue completed itself behind them, while with a grey gradient, the opposite occurred: the colours in the central region became the colour of the object, completing itself behind the grey contour. This means that chromatic and achromatic colours have different roles in an amodal completion situation. Chromatic colours determine chromatic salience and the segregation strength of the entire object from the background. Achromatic colours, on the other hand, determine the strength of figure-ground segregation along the boundaries of the object.

2.5 Summary

This chapter has reviewed, from a phenomenological perspective, the main findings in the experimental literature on visual completion. Based on the most important research developed by some of the principal exponents in the perception field, it has analysed the theoretical aspects of completion.

Having seen that the physical and phenomenal levels do not always correspond, and that what people perceive is different from what is present in the stimulus – as in illusion or occlusion situations – the concept of completion becomes clear: it is the ability to perceive something in its entirety although a part or parts of it are not present in the stimulus.

Completion can come about in three ways: modal, amodal and mental. Amodal completion, characterized by the absence of visual qualities like colour and luminance, has been the main focus of this chapter. First examined have been theories of recent decades which have sought to explain amodal completion. These theories can be classified among theories of local type, theories of global type, and theories of internal representation.

Theories of local type use local cues, like good continuation, T-junctions, closure or contour relatability, to explain completion. Theories of global type explain completion with symmetry, which can be quantified using Coding Theory. This theory 'translates' qualitative aspects in terms of symbolic codes, which have proved to be a good predictors if, in situations of occlusion, one object is better seen as amodally completed, or as a mosaic configuration.

The proponents of these two groups of theories have dominated the discussion, each defending their own point of view. The former proposed that the time exposure of the stimulus may be a decisive element in explaining amodal completion. Global cues seem to need longer exposure than local cues. If subjects were exposed to the stimulus only for a short time, local configurations predominated, while if the exposure time was longer, global configuration was preferred. However, other studies demonstrated that in some cases global factors prevail even in short time exposure.

Structural information theory, which considers the internal, external and virtual structures of the configuration in order to analyse shape, position and occlusion, was then applied to predict the preferred interpretations on the basis of the perceptual complexity of a figure. It was very successful in predicting the outcome of a higher number of situations where previous theories had failed. The difference of this approach resided in its combination of both local and global elements. At that time, researchers were already aware that theories which considered only one type of local or global cue had failed to explain a wide range of completion situations that were instead explainable by a theory combining both aspects.

The last group comprises more recent theories using three-dimensional elements, such as volumes or even flat elements like surfaces. They defend the idea that local and global cues cannot predict preferences for one or another type of configuration if they do not take account of the internal representations of the stimuli.

This group divides into two subgroups. The first consists of traditional theories of surface completion. These state that surface completes itself on a common depth plane, and the main elements are depth information and border ownership. More recent theories belong to the second group. They analyse stimuli as volumes because visual world is full of 3-D objects and is not composed solely of flat surfaces – the subject which has received most attention in this research area.

According to this last account, images connect and are seen as volumes when there is nothing to say the opposite. Surface connectedness happens by default when the surfaces are mergeable, i.e., when their insides can join the inside of another volume to create a larger volume. The volume-based theory is promising, and it has yielded good results, better than those of theories where only local or global cues are considered. Only approaches where both aspects have been taken into consideration have demonstrated a wider action field.

After reviewing theories that have sought to explain completion, the chapter has analysed the literature on the dimensional effects of amodal completion. Effects of expansion or shrinkage are commonly observed in concomitance with amodal completion, although it is not clear whether or not these effects result from amodal completion. Objects and surfaces are seen as bigger or smaller than they are metrically, but research to date has not been able to explain why this happens.

The final aspect considered in this chapter has been the amodal completion of colour. Interest in the study of the amodal completion of colour is recent and the literature on this phenomena is still very limited. However, colours can also complete themselves, as shapes do. A colour hidden by illumination or by another colour can complete itself in different ways, by coloration or discoloration. This new branch of research has introduced an interesting and largely undeveloped subject into studies on amodal completion: colour. There are few studies in the literature on the relation between colour and completion, and there are absolutely none on the effects of colour on the dimensional phenomena. This is a gap in the theory that should be filled.

The next chapter describes an experiment carried out in Italy and in Brazil in order to study the effects of colour in dimensional phenomena. As we have seen, two accounts have tried to explain expansion and shrinkage in amodal completion. Kanizsa argued that they result from completion, while others, for instance Vezzani and Zanforlin, have disagreed with Kanizsa and put forward a different explanation. However, the concern here is not to determine whether these phenomena are a result of amodal completion, or why completion occurs. Instead, the interest is in the effects of the introduction of colour into situations where amodal completion is present. Does colour strengthen the dimensional effects? Do particular colours have special compared with other colours? Are there differences between chromatic and achromatic colours? Are there effects if harmonic or disharmonic configurations of colours are introduced? An attempt is made to answer all these questions in the next chapter.

Chapter 3

The amodal completion of boundaries

Completion is a widespread phenomenon in vision: it is the ability to perceive something, e.g. an object, in its entirety even though a part or some parts of it are perceived in the absence of the corresponding stimuli (Michotte et al., 1964/1991, p. 144). In some cases the parts of the object are hidden by another entity, as in the case of occlusion, but observers are able to perceive the whole object, completing it amodally (Kanizsa, 1979, 1980, 1991; Koffka, 1935; Michotte et al., 1964/1991). In the context of natural selection, the phenomenon contributes to the simplicity and unity of visual objects, and therefore to the observer's biological survival (Ramachandran, 1987).

The pervasiveness of the phenomenon is also evidenced by the presence of the perception of amodality in non-humans, which confirms that it is a phenomenon which occurs at the primary process level (Aust and Huber, 2006; Bakin et al., 2000; Deruelle et al., 2000; Fagot et al., 2006; Kanizsa et al., 1993; Kovàcs et al., 1995; Miller et al., 2001; Nagasaka et al., 2007; Regolin and Vallortigara, 1995; Regolin et al., 2004; Sovrano and Bisazza, 2008; Tvardìkova and Fuchs, 2010).

Given the pervasiveness of amodality in perception, its various aspects have been of constant interest to vision scientists: see for example Gerbino and Dalmaso (1987), on amodal completion affecting pattern recognition; Anderson et al. (2002), Fantoni et al. (2008) and Yazdanbakhs and Watanabe (2004), on amodal surfaces; Rauschenberg et al. (2004), on mosaic and completion stages; Lee and Vecera (2005), on the influence of higher level processes in visual completion; Albert (2007) and Kellman et al. (2005, 2007) on interpolation processes; Anderson (2007), Pinna (2008), on amodal completion of colour; Chen et al. (2009) on amodal completion in face perception; Takashima et al. (2009).

Visual completion occurs not only in occlusion phenomena but also in those of contour interposition, apparent transparency (Glynn, 1954; Metelli, 1974; Rosenbach, 1902; Ware, 1980) or spontaneous splitting figure (Kanizsa, 1979; Koffka, 1935; Parks, 1986). The feature shared by these phenomena is the perception of depth or stratification. In this regard, Guibal and Dresp (2004) have found that colour can influence the perception of depth, although this in turn is strongly influenced by, for example, stimulus geometry, partial occlusion, contour interposition and positional cue, and luminance contrast.

Analyses of amodal phenomena can be grouped according to the factors responsible for their appearance, the methodologies used and their assumptions, and from a philosophical point of view. Obviously, these distinctions are not always clear-cut.

As to the first point, a number of theories have tried to explain the way in which visual system bridges the gaps generated by partially occluded objects. Tse (1999a) has categorised these theories into three groups, as follows. The first group comprises theories that use local image cues and maintain that completion occurs because of good continuation, contour orientation, and T-junction (Kellman and Shipley, 1991; Takeichi et al., 1995; Wertheimer, 1923; Wouterlood and Boselie, 1992). Some authors assume that, in early vision, the neural mechanisms responsible for amodal and modal perception are the same and that they separate in a subsequent stage (Driver et al., 2001; Kellman and Shipley, 1991; Ramachandran, 1995). The second group considers the importance of global factors: symmetry, regularity, and simplicity of form or pattern are the cues used by visual system to amodally complete occluded objects (Attneave and Arnoult, 1956; Buffart et al., 1981; Fantoni and Gerbino, 2003; Hochberg and Brooks, 1960; Moravec and Beck, 1986; Sekuler, 1994; Sekuler et al., 1994; van Lier et al., 1994, 1995). Finally, the last group consists of theories about internal representations, these being traditionally surfaces (Nakayama and Shimojo, 1992; Nakayama et al., 1989, 1995), or more recently volumes (Tse, 1998, 1999b; Tse and Albert, 1998; van Lier, 1999; van Lier and Wagemans, 1999). In this last group, a recent approach proposed by Tse emphasizes the role of volume completion, in particular regard to the concept of mergeability, i.e. by intermediate representations such as volumes, a product of global image relationships (Tse, 1999a, p. 170).

As to the second point, the methodologies adopted may be mainly descriptive in line with experimental phenomenology (Kanizsa, 1991; Metelli, 1974; Michotte et al., 1964/1991), psychophysical or neurophysiological analysis (de Wit et al., 2006; Fukushima, 2010; Hedgé et al., 2008; Murray et al., 2004; Plomp et al., 2006; Rauschenberger et al., 2006; Weigelt et al., 2007; Yazdanbash and Livingstone, 2006).

Psychophysical and neurophysiological analyses have often relied on computational models of vision (for example, Marr and Poggio, 1976; Pollard et al., 1985) (see Yin et al., 2000). In this regard, Albertazzi et al. have elsewhere defended the thesis that the complex operations in perceiving can be analysed neither solely on the basis of stimulus-defined ‘independent features’ as in Marr’s computational theory of vision, nor in terms of the behaviorist’s stimulus-response sets (see Albertazzi et al., 2011, in press). Many researchers on perception, too, including some who pioneered information-theoretic approaches in cognitive science, have recently stressed the need for new conceptualizations and computational frameworks with which to analyse perceptual and mental processes (e.g. Hoffman, 2008a, b; Richards, 1996; Richards et al., 1983). Yet there have been no systematic attempts to bring together researchers in various disciplines who share these concerns, with the consequence that the problem remains generally unaddressed.

The choice of one method rather than another also depends on the problem that one wishes to address, so that the research focuses on different aspects of the same phenomenon and which contribute to its explanation: qualitative analysis of the percept and its conditions of appearance for the phenomenological-experimental method; analysis of the correlation between stimulus and behavioural response for psychophysics; analysis of the correlates of neural activity for neuroscientific investigation.

The different research options may usefully converge (Valberg, 2001; Valberg and Lee, 1991). Kanizsa’s analysis, for example, has provided excellent bases on which to determine neurophysiological correlates of amodal contours (Baumgartner et al., 1984; De Weerd et al., 1998) while the Gestalt principle of Figure/Ground segregation has been important in the neuronal analysis of transparency phenomena (Qiu and von der Heydt, 2005, 2007). Similarly, work on the perceptual significance of medial axis representations (Leyton, 1987, 1992; van Tonder et al., 2002) suggests yet another avenue for neurophysiological investigation.

The problem arises mostly from the assumptions that guide the different options and/or from absolutist approaches to the data by the methodology adopted to explain and interpret the phenomenon. In fact, a certain barrier to communication in this regard still prevails in the community of vision scientists, although, as Spillmann has emphasised (2009), descriptive, psychophysical, and neurophysiological investigations were all present in the Gestalt proposal, which assumed the existence of isomorphism among the structures at the various levels of organization. The issue of the dependence among the various levels and types of isomorphism (Köhler, 1920; Shepard, 1992), or similarity of structure, that connects them is still far from being resolved, because it concerns the status of perception itself. Put briefly, the problem is whether physics and psychology are different because they have different contents or whether they are different because they differ in both content and formal structure. Nevertheless, correlative approaches to perception have gained increasing acceptance (Albright and Stoner, 2002; Spillmann and Ehrenstein, 1996, 2004).

Other groupings of amodal phenomena can be attempted from the philosophical point of view. Nanay (2007), for example, groups theories of amodality according to the interpretation given to it in terms of perception, belief, access (Noë, 2004; O'Regan and Noë, 2001; Pessoa et al., 1998), and visualization (Curie and Ravescroft, 2002; Kosslyn, 1980). The theory on amodality phenomena, however, has already been broadly described by the first experimenters, most notably Michotte et al. (1964/1991) and Kanizsa (1991). According to these authors, amodal phenomena are given in 'perceptive presence' (Albertazzi, 2003; Benussi, 1923-25; Metzger, 1941, 1975/2006; Musatti, 1926); that is, they exhibit the same qualitative characteristics as modal phenomena even if they are partially deprived of stimulation (on the neuronal mechanism which regulates modal perception in early vision see Kellman and Shipley, 1991; Ramachandran, 1995). This is a conception difficult to accept by those who start from a notion of information as being wholly contained in the stimuli, which accounts for its difficulty of interpretation. Conversely, it is not at all problematic for those who consider perception to be a largely subjective product, a sort of 'controlled hallucination' (Koenderink, 2011, in press).

Analysis of the perceptive component of colour, which will be considered with reference to occlusion phenomena, encounters a number of problems already mentioned in regard to the analysis of amodality – and to an even greater extent, given that colour is a characteristic of visual objects (be they surfaces or lights) of an eminently subjective nature. Classical psychophysical methodologies, in fact, do not reveal the subjective appearance of colours, although they contribute to the understanding of some relationships among them.

In the vast majority of cases, underlying neural mechanisms are understood and studied as an *explanation* of perceived colour. In regard to the neurophysiological method, however, it should be pointed out that the use of neural correlates as explanatory criteria is still problematic (Malkoc et al., 2005). Moreover, perception by itself has a very loose relationship with the underlying physics of colour due to metamerism and other relational factors (Adelson, 1995).

This conception is opposed to an explanation of colour based on cognitive activities such as memory, association, generalisation etc., deriving from past experience, culture, explicit knowledge, and linguistic conceptualizations of various kinds. In particular, the aspects of colour analysis related to linguistic and conceptual categorization necessarily concern some top-down components. Several current analyses on colour investigate the extent to which linguistic categories affect perceptual operations in the colour domain: not only, it is alleged, is colour naming determined by culture but lower-level perceptual tasks are dominated by linguistic competence. For instance, sorting colours into groups follows familiar linguistic categories more than low-level perceptual characteristics, understood as the early processing of information (Roberson et al., 1999). There is a large body of theoretical and experimental literature on colour perception and categorization produced both by the supporters of the universalistic point of view (Berlin and Kay, 1969; Cook et al., 2005; Delgado, 2004; Drivonikou et al., 2007; Gilbert et al., 2006; Hardin, 2005; Kay, 2005; Kay and McDaniel, 1978; updated in Kay et al., 1991; Kay and Regier, 2003, 2006, 2007; Kay et al., 1997; Regier and Kay, 2004; Regier et al., 2007) and by the supporters of the relativist one (Agrillo and Roberson, 2007; Boroditsky, 2001; Davidoff, 1991, 2006; Davidoff and Roberson, 2004; Davidoff et al., 1999; Gumperz and Levinson, 1996; Jameson, 2005a, b; Jameson et al., 2007; Levinson, 2000; Lucy, 1992, 1997; Lucy and Shweder, 1979; MacKeigan and Muth, 2006; O'Hanlon and Roberson, 2006, 2007; Pitchford and Mullen, 2006; Roberson, 2005; Roberson and Davidoff, 2000; Roberson et al., 2000, 2002, 2004; Saunders, 2000; Saunders and van Brakel, 1997; Soja, 1994, for a thorough discussion, see Da Pos, 2002; Da Pos and Albertazzi, 2010).

Both conceptions adopt slightly different points of view on specific aspects of the issue, and they privilege different methodologies, basing their arguments on neurolinguistic, ethnolinguistic, crosslinguistic, developmental and similar kinds of data.

The perceptive analysis of colour may concern itself with different situations, such as motion determining colour perception (Hoffman, 2003; Nijhawan, 1997) or transparency altering colour, contour and depth (Nakayama et al., 1990), etc. The aim of this study is to test whether certain characteristics of colour can influence the balance or equilibrium in the division of a bi-coloured rectangle into its respective parts when the border between them is occluded by another rectangle and therefore seen amodally.

Some perceptive attributes of colour, for instance their effect on the expansion/shrinkage and on the advancement/receding of surfaces, are phenomena of which painters and designers have always been aware of but that have received relatively little attention from scientists (Bailey et al., 2006; Chen and Lin, 2005; Da Pos, 1988; De Valois and De Valois, 1975; Egusa, 1983; Goethe, 1810/1982; Hering, 1878/1964; Jameson and Hurvich, 1955; Katz, 1935; Luckiesh, 1918; Philipona and O'Regan, 2006; Sivik, 1974; Tornquist, 1999). The hypothesis here is that top-down components like culture or language do not have an influence on the phenomenon of expansion and shrinking when the image is amodal, and hence one should not observe any effects attributable to cultural influence. However, because of the presence of a large body of relativist literature on colour, in order to verify this hypothesis of culture independence when conducting this research it was decided to involve subjects of two different nationalities, Italian and Brazilian, in the same task of assigning boundaries to occluded surfaces.

As is well known, surfaces are decisive elements in determining the figural unity of visual objects (Yin, 1998; Yin et al., 2000); nevertheless, they are the least studied in the literature on amodality, which usually focuses on the role played by edge features in visual integration (Grossberg and Mingolla, 1985; Kellman and Shipley, 1991; Livingstone and Hubel, 1987; Ramachandran, 1987; Yarbus, 1967). Correlative analyses on the neurocorrelates of amodal completion processes were not the focus of this research, although conducting them would be highly desirable.

One particular aspect of colour that is well known but caused a great deal of difficulty in the first theoretical studies is that of chromatic variations due to colour interaction (Albers, 1963). Today, this phenomenon has been the subject of scientific studies: see, for example short and long ranging interactions (Spillmann and Werner, 1996). The chromatic change is particularly obvious in the case of interactions between colours that are close to each other, and the first studies focussed on this – for instance, see Chevreul (1854) on simultaneous contrasts. Chevreul's work is of a descriptive nature, i.e. he lists a great number of cases in which colours change by proximity. The changes are usually considered greater when the colours change in opposite directions, increasing their difference, and in this case the phenomenon is described as contrast. Depending on the attributes of the colours that are interacting, several kinds of contrast may be described; for instance, yellow tends to give adjacent colours a violet blue hue, red to give a bluish green one, and blue to give an orange yellow one. An equally interesting interaction, studied subsequently, takes place when the proximity of two colours leads to a greater similitude (Helson, 1943): this phenomenon has been called ‘assimilative’ or ‘inverse contrast’. The first studies were phenomenological; the neurophysiological bases suggested for them need to be continuously updated.

This research considered chromatic phenomena as they are described at the phenomenal level to relate them to other visual phenomena such as amodal completion of partially occluded features. This problem may be described as a case of Percept-Percept coupling (Epstein, 1997), or in terms of how one perceptual size influences another - e.g. how perceived distance may influence perceived size (Gruber, 1954), or how perceived illumination may determine the perceived surface colour (Bergström, 2004). In this research it was checked whether particular phenomenal aspects of colour interaction that may be described in terms of contrast do in fact influence the figural organisation determined by amodal completion. In this case, the phenomenal contrast between colours did not occur by modal adjacency but from a distance, underneath the occluding rectangle and thus amodally. Even though the two coloured areas were perceptually seen as adjacent, they were separate at the physiological level and hence the amodality ought to have facilitated attribution of chromatic interaction to the phenomenal level.

3.1 Dimensional effects

Dimensional effects such as shrinkage or expansion of the whole configuration are commonly observed in the presence of amodal completion (Kanizsa, 1972, 1975, 1980; Kanizsa and Luccio, 1978; Luccio and Edile, 1981; Tampieri, 1979; Vicario and Tomat, 1991a, b), although it is not certain that these effects result from amodal completion (Vezzani, 1994a, b; Zanforlin, 1981a, b). While classical theories described dimensional phenomena as consequences of amodal completion, a number of authors disagree with this view. According to Vezzani (1999), partially occluded images do not shrink because they are occluded, but because they undergo two optic-geometrical illusions: the contraction of spaces divided into a few parts, especially when the occluder is higher than the occluded, and the contraction of empty or homogeneous spaces. According to Zanforlin (1981a), shrinkage in amodal completion is a limit case of Oppel-Kundt's illusion (Kundt, 1863), in which spaces divided into many parts expand, but spaces divided into just two or three parts shrink. In terms of expansion, according to Vezzani (1999), this phenomena seems to be a variation of Baldwin's illusion (see Coren and Girgus, 1978), in which a line passing behind a square appears longer than it does when uncovered, and is thus describable in terms of a size contrast effect. Nor does Vezzani consider amodal continuation to be a necessary condition for expansion: some studies have demonstrated that an image can expand even if it is not occluded by another figure (Vezzani, 1993; Parlangeli and Roncato, 1994). However, these phenomena are present or can be observed in conjunction with amodal completion (Vezzani, 1999), even if amodality is not responsible for them.

The hypothesis that we wanted to test was that the two areas of the rectangle bearing a different colour may appear of a different size depending on the colour combinations. Since one's expansion appears to occur at the same time as the other's shrinking, we wanted to see what kind of chromatic contrast may produce the two combined effects, i.e. what contrast produces the enlargement of an area and the contraction of another, and what position of the boundary is seen as the one that gives rise to a balanced division of the vertical rectangle (where by balanced is meant leading to two visually equal parts). It was tested whether the position of the margin chosen by the subjects as optimal division of the occluded rectangle was in agreement with the expectations based on the characteristics of the colours employed, i.e. whether a geometrically smaller area is chosen if its colour leads to its phenomenal expansion, and vice versa. It was also aimed to test whether the position of the occluder interferes with this determination.

The main chromatic contrast that was considered was that of lightness, so that the lighter area was expected to expand proportionally to its chromatic difference with the dark one. It was expected the difference to be greater with a black/white pair than with a pair of light/dark shades of grey.

Secondly, another kind of contrast taken into consideration was that between warm and cool colours. It was expected to find that if one colour was warmer than the other, it would correspond to a larger perceived area than its neighbour; for instance, it was expected red to determine a greater expansion than blue, at even lightness. It was also surmised that if the two colours contrast in apparent lightness, temperature and weight (light/heavy), the expansionary effect ought to be particularly marked. This is the case of the yellow/purple pair.

It was therefore expected that the border would be moved to geometrically shrink the area that was seen as larger; if the two colours had equal effects of enlargement and shrinkage, it was assumed the margin would be seen as lying precisely in the centre. Another assumption was that the optimal perceptual equilibrium that can be realised in a rectangle divided into two parts is given by two parts of equal size.

To sum up, firstly this research was interested in whether the colour of two differently coloured parts of a vertical rectangle acted on the perceived dimensions and thus, when subjects were asked to determine a balanced spatial relationship, in how they would bisect the rectangle based on various factors. It was hypothesized that this expectation also depended on the upper/lower position of each colour, since it seemed likely that by inverting the position of a pair of colours the results would not be symmetric. Indeed, if the dimensional relationship between the two areas depends essentially on the colours, then it should not depend on the position of the occluder. On the other hand, the occluder's position changes the relative dimensions of the exposed parts of the rectangle, modally seen, and therefore one expects to see a tendency towards increasing the occluded area because the hidden part is perceived as of smaller size.

The position of the occluder may interfere with the task of bisecting the vertical rectangle, since the occluder itself is subject to this bisection and interacts with the position of the bisecting margin as it is divided into two parts by the margin itself. Either one tends to maintain the bar bisected as it is moved vertically, in which case the two areas of the vertical rectangle are subject to changes in their relative dimensions, or one tends to maintain an equal division of the vertical triangle so that the occluder appears divided into parts of unequal size, whose relationship varies as a function of its position. Clearly, the viewer's attention and subjective disposition can play a significant role in this, depending on their focus while they carry out the task.

The choice of two culturally different groups might bring to light differences that are not perceptual in nature but due to top down phenomena that can be divided into different attentive strategies or inferences – procedures used to evaluate the phenomenon in a way that is as independent of contextual effects as possible.

For the study, it was decided to use a simple stimulus with relatable contours and surfaces very similar to Figure 1a in Tse (1999a, p. 166).

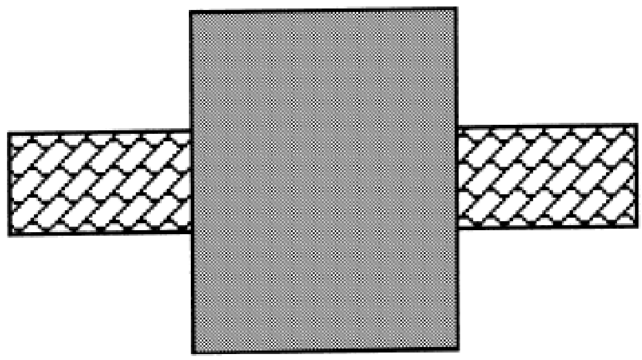


Figure 3.1 – Image with relatable contours and surface (Tse, 1999, p. 166).

3.2 Methods

3.2.1 Participants

The experiment was conducted in two countries (Brazil and Italy) with a total of 60 subjects (30 in each country): 33 females (18 Brazilians, 15 Italians) and 27 males (12 Brazilians, 15 Italians). The overall mean age was 28.1 (the Brazilian mean age was 28.8, while the Italian mean age was 27.3). In Brazil, subjects were recruited at the University of the *Vale do Itajaí* (Santa Catarina) and most of them were entirely naïve about the subject of the experiment and about experimental methods of research. In Italy, the experiment was conducted mainly with students from the Faculty of Cognitive Sciences at the University of Trento, most of whom had experimental experience and knowledge about vision perception. Both groups consisted of students attending postgraduate specialization, master, or doctorate courses. There were no major demographic or social differences between the two groups which might have given rise to differences in the results. The participants belonged more or less to the same age group, and they had similar education levels and social backgrounds. The only more substantial difference between the two groups was that the majority of the Italian subjects were full-time students, while a large proportion of the Brazilians not only studied but worked as well, both in part-time jobs at the university and steady jobs. Because of the different locations of the subjects, in Italy and Brazil, it was decided to use one and the same laptop computer, taking the steps outlined below to homogenise the conditions of observation and to keep them under careful control, as far as possible.

3.2.2 Stimuli and Apparatus

The experiment was carried out in a room with constant and controlled lighting conditions (the luminance on the table, lit at 400 lux, was about 45 cd/m^2). Luminance and colorimetric measurements of the colours are given in Table 3.1. The same conditions were recreated in the two laboratories used for the experiment in Italy and Brazil. The subjects were seated at a desk in front of a DELL Latitude D630. The observer was positioned so that they would be looking at the centre of the screen perpendicularly from a distance of 60 cm. A chin rest was not used to keep the subject at the correct distance, but it was ensured that the subjects adopted the correct posture on the chair, guaranteeing the perpendicularity of the angle of vision with respect to the screen, as well as the pre-established distance. The brightness and contrast of the screen were unchanged for all experiments, and the computer was mains powered to avoid any shifts in brightness due to power shortages.

An opaque screen was used and the ambient light source was not shining on the screen. The stimuli were presented on the aforementioned screen: they consisted of a vertical 10x3.5 cm (9.5x3.34 deg) rectangle, divided into two parts of different colours - one upper, the other lower - and of a pale orange-coloured horizontal 2x6 cm (1.9x5.7 deg) rectangle that occluded the boundary region between the two colours of the vertical rectangle.

The horizontal occluding rectangle was displayed in 13 different positions, always occluding the boundary region between the two colours. The screen centre and the vertical rectangle centre coincided at the location termed '0', which set the reference point for every other vertical position mentioned in what follows, with positive numbers above and negative numbers below. In the central position, the centre of the occluder coincided with the centre of the vertical rectangle and the centre of the screen. The occluding rectangle was drawn in six positions above and six below the centre, for a total of 13 positions at regular intervals of 0.16deg.

The visual angles of the 13 different positions of the horizontal rectangle in relation to the centre of the screen were (upper boundary/lower boundary): 1.91/-0.02 deg, 1.75/-0.18 deg, 1.59/-0.34 deg, 1.43/-0.50 deg, 1.27/-0.66 deg, 1.11/-0.82 deg, 0.95/-0.98 deg, 0.79/-1.13 deg, 0.64/-1.29 deg, 0.48/-1.45 deg, 0.32/-1.61 deg, 0.16/-1.77 deg, 0.00/-1.93 deg. The background was beige coloured.

Eight colour combinations were used, always combined in upper/lower pairs: the achromatic pair white and black, and the reverse, as the pair that manifests the highest lightness contrast; light grey and dark grey, and the reverse, where the lightness contrast is still achromatic but lower; the chromatic pair red and blue, and the reverse, manifesting the contrast of perceived temperature; yellow and purple, and the reverse, manifesting a contrast of lightness, temperature, apparent weight and apparent spatial dimension (see Table 3.1 for colour values). Hues were chosen in their nuance more significant, i.e. the high chromaticness, and the other chromatic attributes (lightness, whiteness, blackness and colourfulness) are consequential to this choice.

Table 3.1. Colours and relative measurement

Colour	L*	A*	b*
White *(155 cd/m^2)*	100.00	-9.21	17.07
Black	9.52	-0.01	1.61
Light grey	77.47	-8.65	1.04
Dark grey	43.58	-4.54	-3.23
Yellow	92.83	-9.47	76.78
Purple	30.68	19.69	-21.05
Red	55.11	58.06	57.51
Blue	47.89	-1.26	-56.10
Beige (background)	88.40	-4.98	25.78
Pale orange (occluder)	76.07	15.16	37.86

The organization of the colours also followed the concept of harmonic and disharmonic configurations of colour (Bullough 1907; Da Pos 1999), in which a harmonic configuration is composed of light colours (white, light grey, red and yellow) on the upper part of the configuration, and the dark colours (black, dark grey, blue and purple) on the bottom part. According to Bullough, dark colours appear heavier and should stay on the bottom part in order to maintain the balance of the configuration.

The combination of eight pairs of colours and 13 occluding positions of the horizontal rectangle yielded a total of 104 stimuli, which were shown randomly to each subject, who gave just one answer for each stimulus. Each confirmed answer corresponded to an exact position on the stimulus. Furthermore, a black line was displayed sometimes above, sometimes below the vertical rectangle. Figure 3.2 shows the stimulus with the horizontal rectangle in central position (0.95/-0.98 deg).

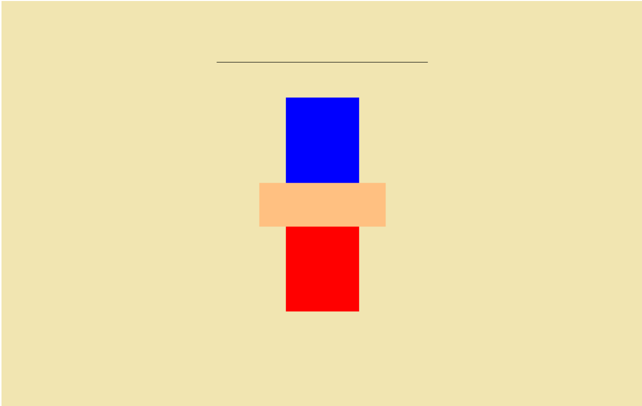


Figure 3.2 – Stimulus with occluder in the central position.

Figure 3.3 shows a situation that was never used during the experiment. Its purpose is only to demonstrate that participants were not shown a configuration where one colour, in this case blue, was present in the upper part of the vertical rectangle, and partially in the lower part of the vertical rectangle, with another colour, in this example red.

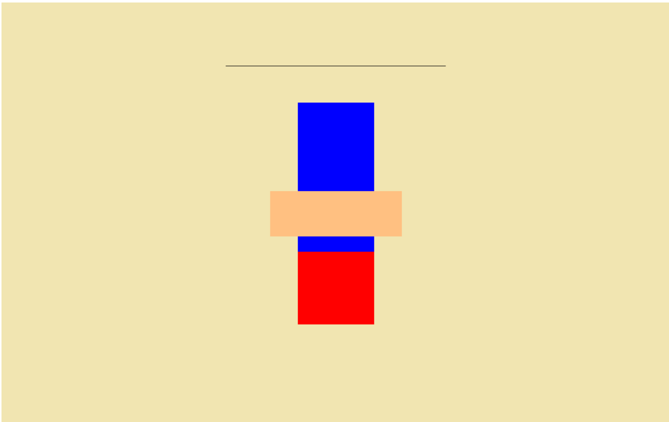


Figure 3.3 – Participants never saw a stimulus like this one.

3.2.3 Procedure

The vertical rectangle might in principle be seen as unitary due to the simplicity of the figure induced by the collinearity of the margins perpendicular to the occluder, but also, in some cases mainly due to the analytic set of the subjects or the colours used, as two adjacent, differently coloured vertical rectangles occluded by a horizontal rectangle.

It was assumed that the unitary nature of the rectangle that follows from the force of collinearity of the vertical margins remains even when the two uncovered areas are of a different colour. Consequently, there will be only one margin, amodally seen behind the horizontal rectangle, separating the two colours. An analogous phenomenon is the paradox of Kanizsa's figures, in which the unitary nature of the animal given by the continuation of the occluded margins makes the viewer see a very different animal from the one that may be described from our experience (Kanizsa 1991, Chapter 2).

What mattered for the purposes of this research is that a single, whole rectangle is seen to pass underneath the occluding rectangle, of which the two uncovered parts remain visible. To this end, before starting the test a pre-session was run in which six images of occlusion were shown (Figure 3.4).

Following this first contact with amodal completion, participants had some time to familiarize themselves with the experiment by using the computer to train with the coloured stimulus. Once any doubts had been cleared up and the subjects were feeling comfortable and able to proceed, the experiment began.

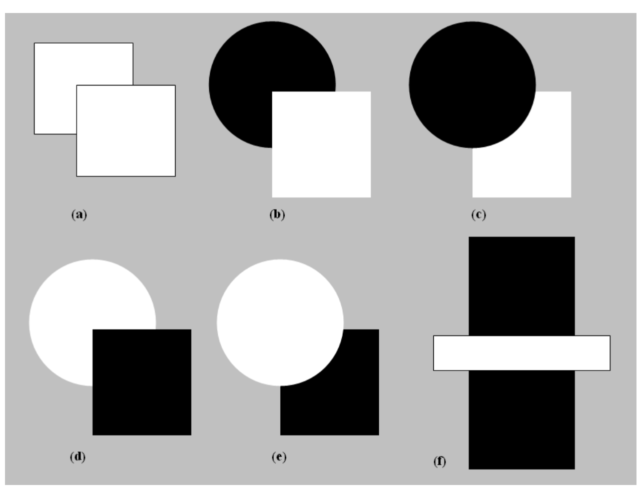


Figure 3.4 – White and black stimuli used in the pre-session test.

The subjects' task was to identify the perceptual boundary between the two coloured parts of the vertical rectangle. They were told that two coloured parts of the vertical rectangle were contiguous behind the horizontal rectangle, and that there would be a unique boundary somewhere. Subjects were also told that the colour of the parts, the position of the occluding rectangle, and the dimensions of both parts of the vertical rectangle could change in the different presentations. Finally, they were asked to mark the boundary's location by shifting the black line provided, which could be moved up and down using the mouse or keyboard. Subjects could change the position until they were satisfied; they then pressed "enter/return" to record their answer. After each answer, a new stimulus was presented until the end of the experiment. There was no time limit. No information was given about the presumed expanding/shrinking effects on the surfaces due to the colours. Each subject saw different random presentations of the 104 stimuli

INSTRUCTIONS given to the Italian and Brazilian subjects

Each test begins with the presentation of a rectangle with two different colours, partially covered by a second smaller rectangle.
Above or below the largest rectangle you will also see a black line.
The boundary between the two colours lies in the occluded zone.
Your task is to decide where the boundary lies perceptively *between the two colours.*
Use the mouse or the UP and DOWN arrow keys to move the black line and position it where you think that the boundary lies between the two colours.
When you are sure of your answer press the ENTER key to confirm it.
You will then be immediately presented with a new stimulus to evaluate.
Take all the time necessary for your choice.
The position of the line can be changed as long as the ENTER key is not pressed.
Try to be as accurate as possible.

The task given to the subjects was therefore purely perceptive, and not imaginative, in nature. The instructions were given by the same researcher for all the subjects in both countries.

3.2.4 Experimental Design

The research adopted a factorial design; two factors were investigated (position with 13 levels, and pair of colours with 8 levels). Each combination of position and pair of colours was randomly proposed to each subject. There were consequently 104 repeated measures within each subject. The results were analysed by means of a two-way analysis of variance with repeated measures on both factors (position and pair of colours, both evaluated as fixed effects) and considering subjects as a random effect. Two separate analyses were performed for Brazilians and Italians. A significance level of 0.05 was always adopted. Post hoc comparisons among means were performed employing the Bonferroni correction.

3.3 Results

3.3.1 Results of the pre-session test

In the pre-session test, six images were shown to participants in order for them to visualize some examples of amodal completion of surfaces. Table 3.2 shows the results of the pre-session test. These data exhibit some differences between the two groups, probably in function of previous knowledge about the subject of the experiment or about experimental methods. In Italy, most of the participants were students on a course in Semiotics, and thus were familiar with amodal completion.

The results show that only one Italian participant answered that Figure 3.4b consisted of a black pac-man and a white circle. In all other cases, participants said that all images were completed, except for Figure 3.4f, which was not a facsimile of the stimulus used in the experiment (Figure 3.2). In the case of Figure 3.4f, three participants said that they had seen two black squares and a horizontal white rectangle, while two other participants said that they had seen both the two black squares and a horizontal white rectangle, and a vertical black rectangle partially occluded by a horizontal white rectangle. All five participants were asked to consider the stimulus in experiment (Figure 3.2) as this last configuration.

Table 3.2. Number of answers for amodally completed figure and for other solutions in the pre-session test, according to the figures and the country.

	Brazilians		Italians	
Figure	Completed	other	completed	Other
3.4a	28	2	30	0
3.4b	24	6	29	1
3.4c	23	7	30	0
3.4d	25	5	30	0
3.4e	24	6	30	0
3.4f	20	10	25	5

In the Brazilian group, probably because almost none of its members had previous experience with experimental methods or knowledge about amodal completion, there was a larger number of answers for configurations different from amodal completion than in the Italian group. In the case of Figure 3.4a, 28 Brazilians saw it as two squares, one completed behind the other, while two participants said that they saw two boxes, i.e., they saw it three-dimensionally.

For Figures 3.4b, 3.4c, 3.4d and 3.4e, most of the participants saw figures amodally completed, but nine of them saw one or more uncompleted adjacent figures: four participants saw all the four figures uncompleted, three participants saw only one figure uncompleted, and two other participants saw respectively two and three figures uncompleted. In regard to Figure 3.4f, nine participants saw it as two black squares separated by a white horizontal rectangle. Five of them had previously seen all the figures amodally completed. One participant said that she saw a reversible figure. Sometimes the figure was seen as a black vertical rectangle partially occluded by a white horizontal rectangle, and sometimes as two black squares and a white horizontal rectangle.

The higher number of answers for this last configuration in both groups may also be partially explained by the fact that the horizontal rectangle was placed in the central area between two black areas with the same dimension, most similar to squares. Since squares are more equilibrated figures than rectangles, participants may have been more likely to see them as squares rather than as a vertical rectangle. However, during the experiment after the pre-session test, a higher horizontal rectangle was used as occluder.

3.3.2 Results of the main test

The aim of the experiment was to determine whether the position of the occluded margin as a divisor of the vertical rectangle into two equal parts depended on the characteristics of the colour and was conditioned by the position of the occluding rectangle.

As regards the colours, it was shown that the choice of position for the separating line depends on the chromatic conditions whenever the results obtained for a couple of colours are the opposite of those obtained by reversing their relative positions (top/bottom). The difference in the results clearly shows that the positioning was due to chromatic characteristics. The data of the colour pairs were organized according to the light/dark criteria (black/white, light grey/dark grey, yellow/purple, red/blue).

As regards the main effect of the pair of colours, a significant difference emerged in Brazilians ($F=3.89$; $df=7,203$; $p<0.001$) but not in Italians ($F=1.39$; $df=7,203$; $p=0.211$); although the range of the means displayed in Table 3.3 was higher in Italians (from -0.098 deg to +0.045 deg) than in Brazilians (from 0.016 deg to +0.086 deg), the former also showed a much greater variability, which led to a non-significant F value.

Four post-hoc comparisons were performed within the Brazilian sample between the white/black, black/white pairs, between the light grey/dark grey, dark grey/light grey pairs, between the yellow/purple, purple/yellow pairs, and between the red/blue, blue/red pairs, using the Bonferroni correction. Two significant differences were found when mean values of white/black and black/white were compared ($p=0.007$) and when mean values of light grey/dark grey and dark grey/ light grey were compared ($p=0.030$). On the other hand, none of the yellow/purple, purple/yellow and red/blue, blue/red pairs showed significant differences ($p>0.4$). The following figures show the results for each pair of colours and both nationalities.

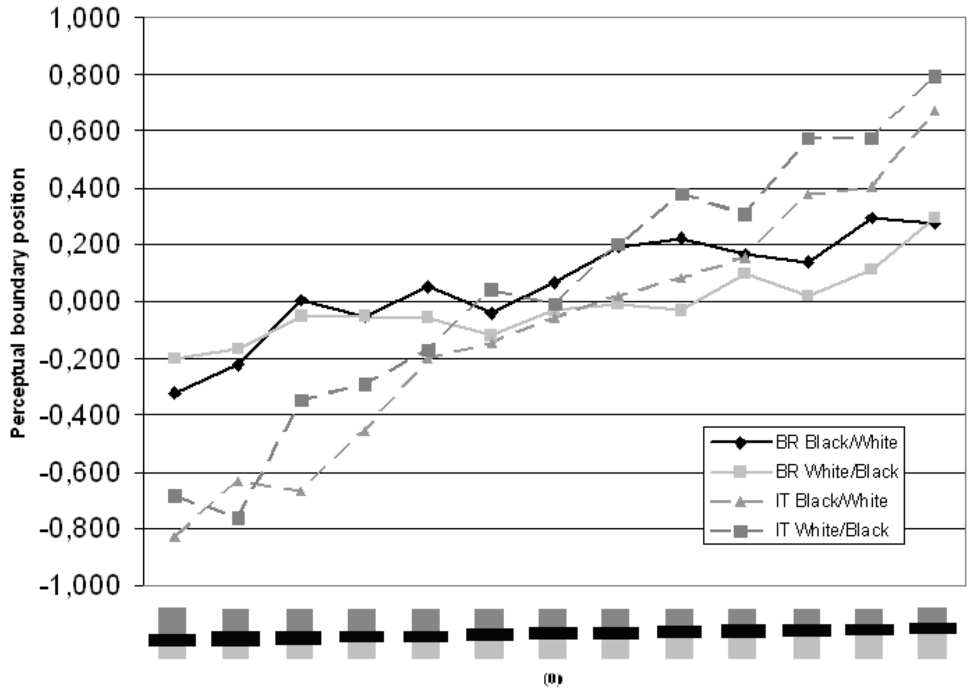


Figure 3.5 - Mean values (in visual angle deg.) of the position of the perceptual boundaries in relation to the centre of the vertical rectangle, as a function of the 13 uniformly scaled positions of the occluding rectangle, for the white and black colour pairs.

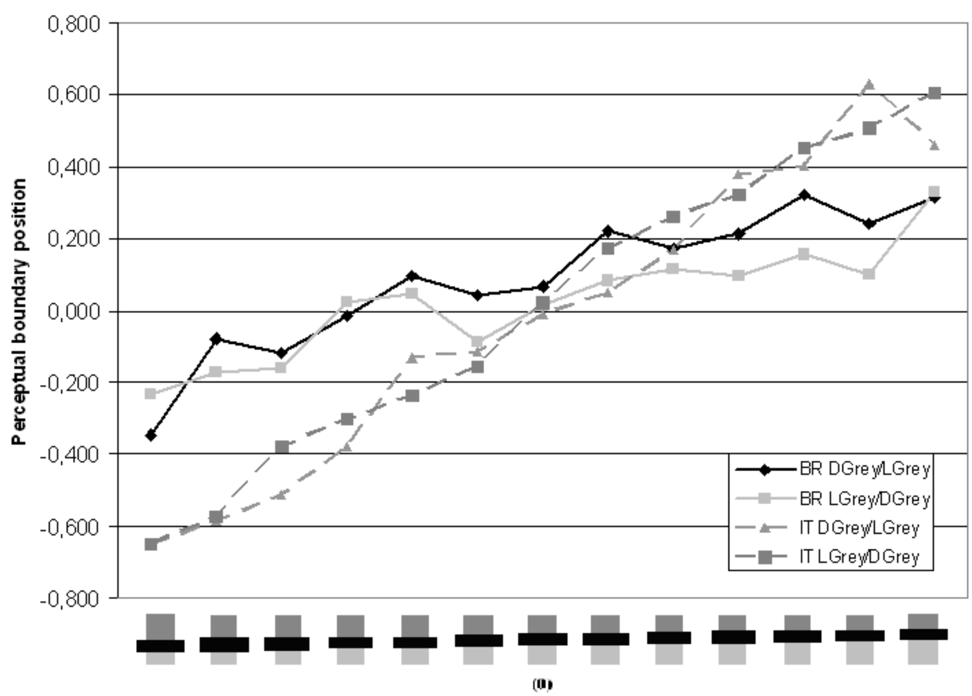


Figure 3.6 - Mean values (in visual angle deg.) of the position of the perceptual boundaries in relation to the centre of the vertical rectangle, as a function of the 13 uniformly scaled positions of the occluding rectangle, for the light grey and dark grey colour pairs.

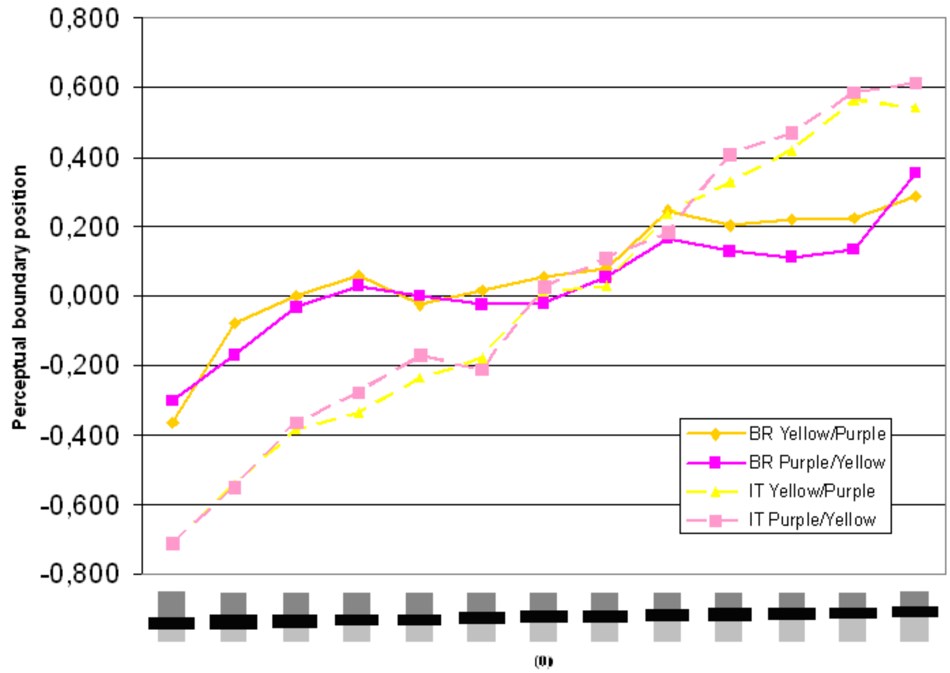


Figure 3.7 - Mean values (in visual angle deg.) of the position of the perceptual boundaries in relation to the centre of the vertical rectangle, as a function of the 13 uniformly scaled positions of the occluding rectangle, for the yellow and purple colour pairs.

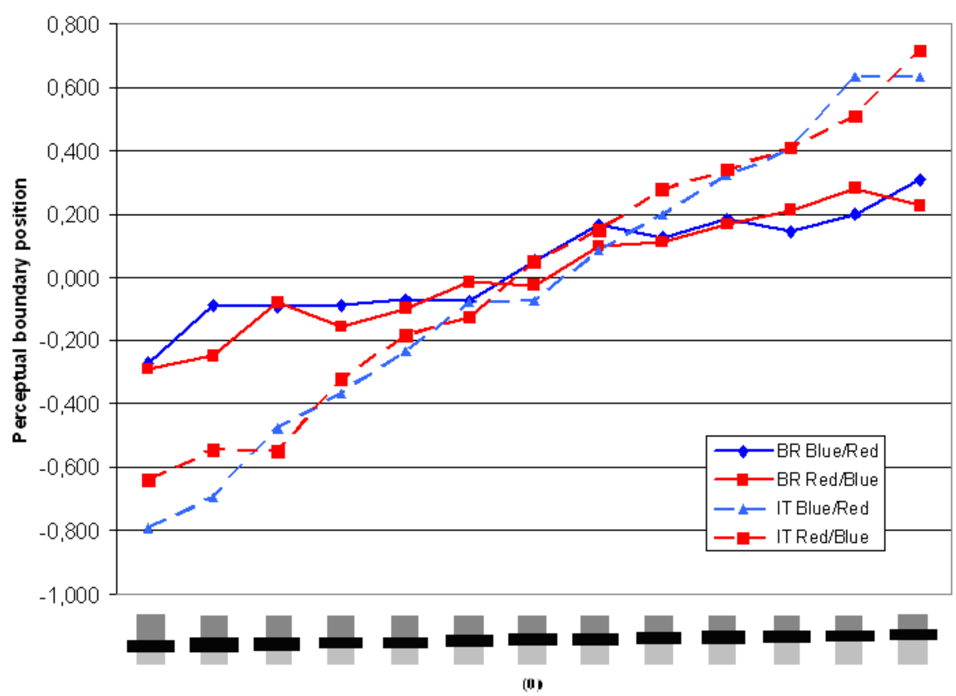


Figure 3.8 - Mean values (in visual angle deg.) of the position of the perceptual boundaries in relation to the centre of the vertical rectangle, as a function of the 13 uniformly scaled positions of the occluding rectangle, for the red and blue colour pairs.

Furthermore, two other post-hoc comparisons were performed. The first, which compared achromatic and chromatic groups of colours, was not significant ($p>0.5$); in fact, in the Brazilian sample the two means were quite similar: +0.038 deg for the achromatic groups of colours and +0.039 deg for the chromatic groups of colours. In the Italian sample, the achromatic mean was 0.018 deg, and the chromatic mean was 0.010 deg.

One last comparison was made between harmonic and disharmonic groups of colours. In this case a significant result ($p<0.001$) was found for the Brazilian sample: the mean for harmonic colours was +0.064 deg, while for disharmonic ones it was +0.014 deg. Among Italians, the mean for harmonic colours was +0.044 deg, and for disharmonic ones +0.016 deg.

This result could be considered significant ($p=0.02$) if this was the only comparison made, but since six post-hoc comparisons were performed using the Bonferroni correction, this result cannot be considered significant ($p=0.11$).

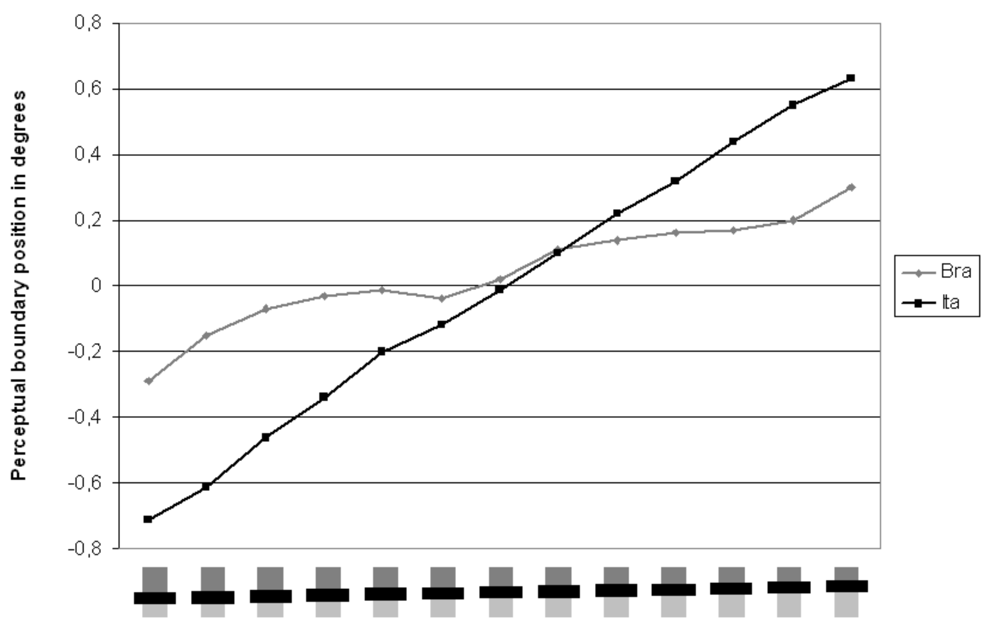


Figure 3.9 – Mean values (in visual angle deg.) of the position of the perceptual boundaries, of the position of the perceptual boundaries in relation to the centre of the vertical rectangle, as a function of the 13 uniformly scaled positions of the occluding rectangle.

The most evident effect was due to the position of the occluding rectangle. The mean values of the perceptual boundary position are shown in Figure 3.9 separately for

Brazilian and Italian subjects. These mean values were between -0.293 deg and +0.299 deg for Brazilian subjects (overall mean +0.039 deg), and between -0.708 deg and +0.628 deg for Italian ones (overall mean -0.014 deg) so that a clear difference between these two groups emerged. Furthermore, another striking difference was found in regard to the variability of the responses; the standard deviation of all the 3120 measures was 0.649 for Italians and 0.426 for Brazilians. Therefore all subsequent analyses were performed separately within these two groups.

Figure 3.9 shows the mean values of the position of the perceptual boundaries assigned by the subjects in the two groups, in relation to the centre of the vertical rectangle. Located on the horizontal axis are the 13 positions of the occluding rectangle, ranging from the lowest on the left to the highest on the right.

It will be seen that the Brazilian line does not have a linear trend. Subjects tended to place the perceptual boundary in the region close to the centre of the screen and of the vertical rectangle, with greater shifts only when the occluding rectangle was either very low (position furthest to the left in the figure) or very high (position furthest to the right in the figure).

Two phenomena are noticeable in the Brazilian subjects: the first is a tendency to halve the vertical rectangle (as expected), and the second is that when the adjustment bar gets too close to the upper or lower boundaries of the occluding rectangle, the bar tends to move in the opposite direction.

The Italian subjects instead seem to follow the shift of the occluding horizontal rectangle in a linear fashion; they make their choices only in relation to the position of the occluder, maintain the margin's position constant with respect to the occluder, and do not look at the rectangle behind it. They thereby show a selective attitude towards the occluding rectangle and the adjustments are made on that basis, while remaining true to the basic idea that a good position will divide the rectangle into two precisely equal parts.

When asked about the reasons for their choice, the Brazilian subjects replied that, given the presentation of the image, a symmetrical configuration, where the boundary remained at the centre of the vertical rectangle, seemed more *natural* to them. Thus, regardless of the position of the occluder, the two coloured parts of the vertical rectangle had to be of the same size. Many of the Brazilians said that they had looked for the centre of the vertical rectangle and were sure that they had found it in the great majority of cases.

The perturbations introduced by the position of the occluder explain the discrepancy between the perception of equilibrium in the subjects and the geometric division that might have been expected in theory.

The data shows that this (in the sense of an exact measure) happened very infrequently, despite the 'certainty' of the participants that they had identified the centre, giving the same dimension to both coloured parts. It is very likely that, despite the subjects' belief that they had found a position of perfect symmetry, they had failed to do so.

In other words, it can be explained on the basis of the difference in the modally present quantity of each area and its colour. The type of colour, in fact (for example yellow), may have exerted an effect of perceptive expansion on one of the areas, with the consequent shrinking of the other, provoking a perceptual impression of the dimensions different from the 'real' ones. Consequently, the boundary was identified according to the 'centre' of the perceptual dimensions, not the physical ones.

If the centre of the occluding rectangle is used instead of that of the vertical rectangle, Figure 3.10 is obtained. Here, the zero on the vertical axis corresponds to the centre of the occluder, while located on the horizontal axis are the 13 positions of the occluding rectangle.

If the task is understood to be the search for the boundary with respect to the occluding rectangle rather than the occluded one, the results are the following (see Figure 3.10). Note how the Italian subjects oscillate closely around the centre (+ or – 13% of the rectangle's size), while the Brazilian ones have a much larger deviation (+ or - 35%), suggesting that this is not the target of their adjustment.

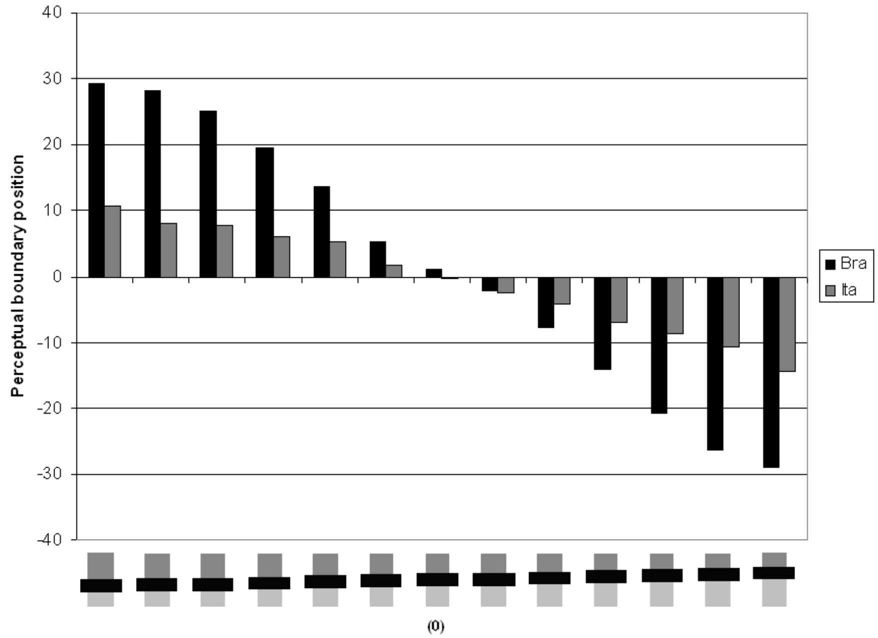


Figure 3.10 – Mean values of the perceptual boundary position taking the centre of the occluding rectangle as reference.

This figure shows that, because the Brazilian subjects preferred to select the boundary closest to the centre '0' of the vertical rectangle, they produced a greater difference if the point of reference was the centre of the occluding horizontal rectangle. When the centre of the latter approached the centre of the vertical rectangle, the differences diminished accordingly.

Since the Italian subjects instead tended to move the boundary as and how the occluder moved, the figure shows them as closer to the centre of the occluder than Brazilians. On average, the Italians do not shift markedly towards the more distant extremity of the occluder but always remain in the half of the occluder. If the occluding rectangle moves downwards (the six positions on the left), the border is assigned to the upper half of the occluder; that is, closer to the centre than to the lower border. But if the occluding rectangle moves upwards (the six positions to the right), the boundary is assigned to the lower half of the occluding rectangle, always closer to the centre than to the upper border.

One might expect to find that, the lower the position of the occluder, the lower the perceptual boundary assigned, so that the upper part, modally larger, becomes even more extensive, while the lower, modally smaller one, does not advance significantly into the amodal space.

This expectation would arise from studies based on the contour support ratio or the proportion of image-specified contours (Fantoni and Gerbino, 2003). In fact, "The ratio principle (Shipley and Kellman, 1992) states that the good continuation absolute strength depends on the ratio between lengths of the image-specified portion and the total side (including the amodal portion predicted by good continuation alone). Good continuation becomes stronger as the specified length increases relative to the total length (i.e., when the support ratio is large)" (p. 299).

According to this principle, the longer the contour, the greater becomes the extrapolation of the contour in the amodal space, so that, in our case, the boundary should move towards the shortest contour. Yet research data show exactly the opposite. The part which has the smaller modal area tends to occupy a larger area in the occluded space than does the larger part; this in turn protrudes less into the amodal area.

A higher variability in the Italian responses is confirmed by the standard deviations values shown in Table 3.3, and it is in agreement with the wider range for these subjects displayed in Figure 3.10.

Table 3.3. Mean values (in deg) and standard deviations of the perceptual boundary position according to the combination of colours and the country.

Pair of colours		Brazilians		Italians	
Upper	Lower	Mean (deg)	st. dev.	Mean (deg)	st. dev.
White	Black	0.059	0.446	-0.098	0.672
Black	White	-0.015	0.397	0.046	0.701
Light grey	Dark grey	0.087	0.437	-0.023	0.618
Dark grey	Light grey	0.024	0.423	0.004	0.624
Yellow	Purple	0.070	0.416	-0.021	0.630
Purple	Yellow	0.033	0.427	0.008	0.656
Red	Blue	0.038	0.413	-0.034	0.650
Blue	Red	0.015	0.440	0.006	0.623

Tables 3.4 and 3.5 show the mean values of the perceptual boundary as a function of the position of the occluding rectangle and the pair of colours respectively for Brazilian and Italian subjects.

Table 3.4. Mean values (in deg) of the perceptual boundary position as a function of the position of the centre occluding rectangle and the combination of colours for Brazilian subjects.

	Pair of colours (Upper/Lower) to be read vertically							
Centre of the Occluding rectangle	White Black	Black White	Light grey Dark grey	Dark grey Light grey	Yellow Purple	Purple Yellow	Red Blue	Blue Red
-42	-0.321	-0.203	-0.346	-0.234	-0.365	-0.301	-0.271	-0.290
-35	-0.223	-0.167	-0.079	-0.174	-0.080	-0.169	-0.088	-0.247
-28	0.006	-0.053	-0.120	-0.159	-0.002	-0.034	-0.092	-0.081
-21	-0.051	-0.054	-0.014	0.023	0.056	0.030	-0.089	-0.158
-14	0.053	-0.059	0.095	0.047	-0.023	-0.002	-0.071	-0.097
-7	-0.042	-0.119	0.041	-0.088	0.017	-0.024	-0.073	-0.014
0	0.069	-0.032	0.068	0.016	0.053	-0.019	0.052	-0.025
7	0.191	-0.010	0.222	0.084	0.078	0.054	0.166	0.099
14	0.224	-0.031	0.172	0.115	0.245	0.165	0.126	0.114
21	0.164	0.096	0.214	0.095	0.203	0.129	0.186	0.166
28	0.141	0.020	0.324	0.157	0.218	0.113	0.143	0.213
35	0.296	0.116	0.243	0.098	0.222	0.131	0.200	0.281
42	0.274	0.294	0.315	0.329	0.287	0.354	0.309	0.227

Table 3.5. Mean values (in deg) of the perceptual boundary position as a function of the position of the centre occluding rectangle and the combination of colours for Italian subjects.

	Pair of colours (Upper/Lower) to be read vertically							
Centre of the occluding rectangle	White Black	Black White	Light grey Dark grey	Dark grey Light grey	Yellow Purple	Purple Yellow	Red Blue	Blue Red
-42	-0.828	-0.684	-0.650	-0.649	-0.716	-0.711	-0.789	-0.641
-35	-0.634	-0.764	-0.586	-0.572	-0.542	-0.553	-0.693	-0.544
-28	-0.669	-0.345	-0.513	-0.377	-0.386	-0.365	-0.478	-0.551
-21	-0.458	-0.291	-0.377	-0.302	-0.336	-0.277	-0.366	-0.321
-14	-0.203	-0.171	-0.132	-0.238	-0.238	-0.170	-0.234	-0.186
-7	-0.147	0.039	-0.116	-0.154	-0.178	-0.210	-0.079	-0.125
0	-0.058	-0.011	-0.010	0.023	0.011	0.023	-0.073	0.048
7	0.020	0.200	0.051	0.174	0.030	0.109	0.086	0.150
14	0.082	0.377	0.170	0.260	0.238	0.182	0.197	0.277
21	0.156	0.306	0.377	0.322	0.326	0.408	0.321	0.340
28	0.379	0.575	0.402	0.453	0.418	0.470	0.405	0.407
35	0.405	0.575	0.628	0.508	0.563	0.586	0.631	0.510
42	0.673	0.794	0.459	0.606	0.542	0.612	0.633	0.712

3.4 Discussion

The research analysed the relationship between a situation of amodality of surfaces in the case of occlusion and the role of colour in comparison to spatial cues. The subjects' task was to identify the best place for the perceptual boundary between the two coloured parts of a vertical rectangle occluded by a smaller horizontal rectangle.

As said, it was expected to find some effects in the amodal perception of boundaries due to some characteristics of colour (advancing/receding, light/heavy, expanding/shrinking, harmonic/disharmonic), and some due to the relative position (lower/upper) of the coloured parts of the occluded rectangle.

The results of the Brazilian group ($F=3.89$; $df=7,203$; $p<0.001$) show that boundary perception of amodality in occluded surfaces can be influenced by colour characteristics, and that surface features integration can be influenced by the location of boundaries. Specifically, the results show that both groups of subjects tended to place the boundary in relation to the position (upwards or downwards) occupied by the occluding rectangle. However, there was a difference between the two groups: while the Italians clearly changed the boundary position according to the position of the occluder (upwards or downward), the Brazilians tended to place the boundary closer to the centre of the vertical rectangle.

When asked about their choice after the test, in most cases the Brazilians replied that they were trying to find the symmetry between the two coloured parts of the vertical rectangle. Most of them, independently of the occluder's position, perceived the two differently coloured parts of the vertical rectangle as having the same dimension. Their choice can be explained in terms of the second group of theories identified by Tse (1999a), in which completion occurs when certain conditions among global image cues are fulfilled: for example, symmetry, regularity or simplicity. If so, the choice made by the Brazilians to prefer a symmetric configuration rather than using other cues, such as the extension of both modal parts of the vertical rectangle, to decide where boundaries could be placed would also confirm Michotte's (1964/1991) hypothesis, i.e. that a global property of the whole is involved in the process and not a completion restricted to the amodal area. Naturally, it is not possible to exclude that their choice may also have involved a top-down operation: according to the stimulus that they saw, the

Brazilian subjects may first have decided that the boundaries had to be placed in the centre and subsequently calculated where the centre should be. If they proceeded in this way, the results show that although some Brazilians reportedly attempted to place the boundary in the centre of the vertical rectangle, in most cases they were unable to locate the metric centre, although some of them were convinced that they had done so. Probably, the effects of different extensions and hues of the coloured parts induced some of the subjects to perceive the central position in a place different from the metric centre of the vertical rectangle.

The Italian subjects, on the other hand, located the boundary further from the centre as the occluding rectangle came closer to the extremes of the vertical rectangle. In the case of the Italians, white, light grey, red and yellow always perceptively occupied a larger area than their opposite colours, which would confirm the perceptual effect exerted on this group of subjects by the expansion of the surfaces due to these colours. When they appeared on the upper part of the vertical rectangle, their expansion was perceived as larger than when they appeared on the lower part. The visual angle means reported in Table 3.3 show that when light colours were on the upper part, the positions attributed to the boundary had a higher visual angle than when these colours were in the lower part. For example, when white was on the upper part, the boundary was located at -0.098 deg below the centre, giving a bigger area to the white and a smaller one to the black. When white was in the lower part, boundary was located at 0.046 deg up the centre, giving always a smaller area to black and a bigger area to white, although this time the expansion of white was not so high as in the first case. In this sense, for Italians, light colours are seen as having a bigger area than dark colours.

This effect was not observed among the Brazilian subjects. In the case of this group, in fact, for 7 out of 8 situations the colour located in the lower part seemed to expand, putting the boundary in the upper part of the vertical rectangle, as if the lower part had to be bigger in order to sustain the upper part. The visual angle means for the Brazilian group in Table 3.3 show that the dark colours (in comparison with their opposites) black, dark grey, purple and blue had a higher expansion than the light colours. This may have happened because light colours, although they have the same extension of area, seemingly occupy a larger area than the dark colours (Claessen et al., 1995). Since Brazilians seem to prefer a more regular and symmetrical configuration, in order to compensate the apparent larger area of light colour, they tend to expand more dark colours areas (i.e. the heavier) in order to find a balance between both colours.

Several studies have been carried out in the field of colour aesthetics, and it is widely believed that harmony and balance are related (Da Pos, 1999). Bullough (1907) uses the concept of balance in the gravitational sense. Thus, to achieve a balance, the heavier colour should stand below the lighter one. According to Bullough, dark colours are heavier than light colours because they have an apparent "moreness". Other studies have confirmed the assumption that dark colours are seen as heavier than light colours (DeCamp, 1917; Monroe, 1925; Payne, 1958, 1961; Taylor, 1930; Warden and Flynn, 1926). In this way, a harmonic configuration would be composed of a dark and heavier colour on the lower part, and a light and lighter colour on the upper part.

Interesting results were found when groups of harmonic and disharmonic colours were compared. While the Brazilian subjects preferred to expand the lower part of the vertical rectangle, with a larger expansion of the dark coloured parts (for instance purple: when it was on the lower part, the boundary was placed at 0.070 deg above the centre, expanding the purple area and shrinking the yellow one, while in the opposite configuration, with yellow in the lower part, the boundary was placed at 0.033 deg above the centre, expanding the yellow area, but not as in purple case), the Italians expanded only the light-coloured parts of the vertical rectangle, with a larger expansion when these light-coloured parts were on the upper part of the vertical rectangle. It seems that, for the Brazilians, both the spatial configuration below/above (the lower part had to be bigger since seven of the eight lower parts expanded with the exception of white, which shrank) and the colour configuration mattered in order to find a balance (dark colours had to expand more than light colours in order to compensate for the apparently larger area of the light colours). For the Italians, on the other hand, it seems that colour configuration was the most important factor in this respect since only light-coloured parts expanded, while the spatial configuration was secondary because light-coloured parts, when they were in the upper part of the vertical rectangle, expanded more than when they were in the lower part of the vertical rectangle, showing a sort of reinforcement of the expansion value of the light colours.

Contrary to the initial hypothesis, however, results show a difference between the two groups of subjects, Italians and Brazilians, that might be interpreted as due to the presence of a top-down component influencing colour perception (for example, greater exposure and sensitivity to symmetry phenomena among the Brazilians) and consequently in the perception of amodality.

A future test using a horizontal rectangle instead of a vertical one may shed more light on the relationship between the weight of colours and spatial configuration, mainly in the Brazilian group in which there was a significant difference between the white/black and black/white configurations and between the light grey/dark grey and dark grey/light grey configurations. For the Brazilians, the black part always expanded, probably because it was seen as much smaller than the white one, with a bigger expansion when it was on the lower part of the vertical rectangle, while both greys expanded when they were on the lower part of the vertical rectangle, with a bigger expansion for the dark grey. It would be interesting to see whether these results also hold with a horizontal configuration.

It would be also important to repeat the test using different backgrounds, since there are studies which have found an interaction between the effect of colour and the effect of background brightness (Chen and Lin, 2005; Egusa, 1983; Guibal and Dresp, 2004). As already mentioned, Guibal and Dresp (2004), for instance, have observed that the background may change the perception of depth. In one of their experiments, studying colour contrast of isoluminant red, green and white, they found that red figures were perceived as ‘nearer’ when presented on a light background, while white and green figures were seen as ‘nearer’ with a dark background.

In the case of the apparent weight of some colours, there are some discrepancies among studies: for example, the results are not sufficiently consistent to assume that blue is heavier than red, since in some experiments the opposite has been found (Payne, 1958; Warden and Flynn, 1926). However, as Wright (1962) noted, in most cases studies on the apparent warmth and weight of colours do not consider all the three basic perceptual dimensions of colour – hue, brightness and saturation – so that this may be the cause of the discrepancies among researches in this field. This author points that DeCamp (1917), Payne (1958), Taylor (1930) and Warden and Flynn (1926) do not take saturation into consideration and the effects of hue and lightness were confounded in their analysis.

In conclusion, the data analysis seems to show that colour, under amodal completion, has a secondary effect compared with spatial cues, but this may depend on the context where coloured occluded areas are set. The opposition between the colours chosen and the contrast with the background may have decreased the effect, in the sense that the effect of one colour could have being annulated or became weak by the other colour. The use of different colours or spatial configurations might shed light on these issues and help understanding the dynamics behind the interactions among these cues.

The experiment could be repeated using opposing colours and/or other spatial cues, for example avoiding the overlapping of the bar on the occluder or by inserting holes in the occluding surface rather than using a bar, thereby avoiding a possible top-down component consisting in the operation of positioning the bar by the subjects. Another variation would be the presentation of the two coloured parts without an occluder. In this case, one would expect that the phenomenon will indeed manifest itself as described independently of the fact that the margin of separation between the two areas – the object of evaluation – is occluded, i.e. perceived amodally.

Finally, a possible follow-up would be to verify whether this study on surface integration can be extended to 3D objects. It would be also desirable to repeat the experiment with other nationalities, ones with more strongly different cultures, in order to verify whether in case, too, top-down components influence the privileging of some qualitative characteristics of colour over others.

Chapter 4

Crossmodal morphology

This study analyses some aspects of the functional relation between shape and hue in visual appearances. A functional link in perception is intuitively given by the phenomenal dependence between two appearances, in the sense that the appearance of the second seems to be motivated by the appearance of the first, independently of previous experience or associations. This happens for example when, given a specific shape, the observer immediately perceives its connection with other types of qualities: consider the affordance character of surfaces that 'naturally' offer support (Gibson, 1979) or of more complexes cases of phoneaesthesia, where hard sounds (like 'takete') are naturally associated with serrated shapes and, vice versa, smooth sounds (like 'maluma') are naturally associated with curved shapes, manifesting a crossmodal pattern of similarity (Köhler, 1947). Functional relations may also concern expressive qualities of perceptual objects, in the sense that shapes, for example, may appear gracious/awkward, merry/sad, feminine/masculine, etc. (Metzger, 1941, Chapter 2, § 8).

In our case, the functional relation analysed primarily concerns the relation between shape and colour, and between shape and a certain colour's characteristics like cold/warmth, softness/hardness, beauty/ugliness, strength/weakness, etc., i.e. secondary and tertiary qualities of visual appearances.

The guiding hypothesis in what follows is that perceiving comprises a kind of diffuse synaesthetic relation (Ward et al., 2006) that it is applied to the consideration of relational qualities such as, for example, a shape's patterns appearing in different perceptual configurations. The recognition of patterns, it is argued, does not depend on top-down components, like past experience or the influence of language (as in Martino and Marks, 1999, 2001), but is directly perceived. If tested to a greater extent, the hypothesis would lead to crossmodal morphology of shapes.

Morphological studies

Morphological studies have been prevalently a legacy from mathematicians, biologists and natural scientists in both the nineteenth and early twentieth centuries (the best known and most controversial example being Goethe, 1948, 1988. See Helmholtz, 1892/1971; Müller, 2006; Steigerwald, 2002). Owing to the somewhat mystic tenor of some studies, ambiguous vocabulary, the often ideological misinterpretation of the underlying philosophical ideas of the time – essentially Schelling's ideas (Shelling, 1988) – the dominance of an alternative paradigm, but mostly and more importantly the limitations of the conceptual and computational tools then available, the idea that shape patterns pervade the perceptual appearances of physical objects (like crystals) and biological ones (like microorganisms), with a common mathematical structure, remained unexplored in scientific research. In other words, the 'Goethian approach' to science, which considered "perceptions as due to mind-world processes, and not vice versa" (Koenderink, 2011, in press, p. 28) failed to establish itself. Mainstream science instead supported and developed the potential implicit in the Galilean paradigm, which produced extremely important results in terms of data manipulation, predictions and technological tools, but omitted from its framework, both theoretically and factually, analysis of the qualitative aspects of natural perceivable appearances. With these, also aspects connected with human awareness were left unexplained: for example, the question of *meaning* embedded and conveyed by appearances of visual shapes.

The morphological characteristics of visual shapes, instead, have always been of strong interest to aesthetic studies, being represented in different arts and styles (one thinks of Art Noveau, or the paintings and sculptures of Hundertwasser, Naum Gabo, and Pollock). These art works specifically represented and showed the *dynamic* aspect of visual appearances, those bearing the traces of the forces that acted upon them and contributed to shaping their final configurations (see Arnheim, 1954; Leyton, 1992; MacCurdy, 1939; Ruskin, 1857). Shape morphology, in fact, illustrates a sort of 'living design' (the expression is from Kemp, 1997) which in the nineteenth century, where the Goethian approach was able to succeed, Fichte would have expressed in terms of 'dynamic operation of the natural system' (Johnson et al., 1997). The concept of morphology, coined by Goethe, refers in fact more to a process than to a static shape (for an analogous meaning in the concept of Gestalt see Wertheimer, 2002; Albertazzi, 2006a, b, c). According to this approach, the 'goodness', and hence the aesthetic value of certain natural forms (Breidbach, 2004; Thompson, 1961), is such because it fulfils a *perceptual principle of naturalness and belonging of the various parts and components of the visual object*.

The mereological structure of perceptual configurations concerning also tertiary and expressive qualities was analysed by Koffka (1935), for example in regard to 'good /bad points' in vision; or by Benary with his principle of belongingness (Benary, 1930) of parts to the whole. These analyses showed that the inner relations of perceptual configurations do not follow the principles of extensional mereology, i.e. principles of the summativity of unrelated parts.

Also Haeckel's organic stereometry was based on the idea that the organization of living forms can be discerned *by looking* at them: the visual operation itself provides their schematic order of pattern evolution in the actual configuration of shapes, because the patterns themselves offer *clues* to their interpretation. Strong emphasis was thus put on the act of seeing itself (Berkeley, 1732; Brentano, 1995. From a scientific point of view, see the developments in Koenderink, 2011, in press; Koenderink and van Doorn, 2003) as part of the classification and recognition of natural shapes.

In fact, if one does not consider perception as merely the processing of cues or metric/computational features and espouses instead the viewpoint that the construction of empirical reality results from a series of clues which the environment gives the perceiver and his sensory systems, and which conscience organises into a system of perceptual signs or configurations, then also the study of artworks becomes a means to analyse the laws of seeing and visual appearances (Metzger, 1975/2006; Spillmann, 2007). Indeed, the artist does nothing other than test, exemplify and reshape the construction of appearances on the basis of laws that are also active in the natural perception of objects. This point of view has also been expressed to some extent by, among others, Leonardo (see Kandinsky, 1926/1979; Klee 1924, 1961; MacCurdy, 1939; Koenderink and van Doorn, 2003; Albertazzi 2006a, b, 2011, in press).

It was no accident, therefore, that in drawing the shapes of living organisms, Haeckel was explicitly referring to the entelechies of shapes claimed by Goethe and apparent in pattern uniformities in both crystallography and biology (see also Haeckel, 1866).

Understandably, producing *an experimental science of the qualitative aspects of inorganic and organic reality, based on morphological patterns and their functional connections* is an enormous challenge, because, as D'Arcy Thompson (1961) pointed out, the living organism and its forms as they appear in the environment occupy a force field of great complexity.

However, determining the relational properties of shapes, the geometry of their appearances, and the functional relations governing their morphological patterns may contribute to laying the foundations of a qualitative science of reality, which is intrinsically aesthetic and clearly goes beyond the Galilean paradigm (Albertazzi, 2010). The experimental study now described had that theoretical framework as its background.

The study

This study is part of a series of exploratory works undertaken to analyse qualitative aspects in perception, and specifically colour perception and its relationship with spatial form (see, for example, Albertazzi, 2002, 2006a, b, c; Da Pos and Albertazzi, 2010; Koenderink, 2011, in press; Koenderink et al., 2010). The study's theoretical framework considers perception from the viewpoint of its *meaningful content*, instead of that of an 'information carrier' (Humphrey, 2006; see also Albertazzi et al., 2011, in press), and thus starts directly from the description of appearances.

Previous studies (Albertazzi et al., submitted; Dadam et al., submitted) have found strong correlations between certain geometrical shapes and colours (hues). Albertazzi et al., submitted) considered twelve geometric shapes, both two-and three-dimensional. For each shape, the subjects were asked to choose from the Hue Circle the colour that they saw as most 'naturally related' to the shape. It is noteworthy that none of the subjects showed perplexity or difficulty in understanding the task: the concept of a 'natural relation' between shape and colour seems to have been intuitively clear to all of them. The results illustrated the relations which appear to be subjectively natural between hues in their maximum expression (i.e., maximum chroma) and geometric shapes. Analysis of the results showed that non-random relations exist between perceived shapes and colour, and that these relations are remarkably universal. The relationships found were not specific to synaesthetic subjects but experienced by the general population. Other interesting general results emerged in regard to the shape/colour connection. The relationship did not concern highly specific colours, but rather chromatic groups – for instance, the ranges of reds, or yellows, and so on. On the other hand some shades were selected more frequently than others in each group. Something similar has been found in the study of emotion/colour relations (Da Pos and Green-Armytage, 2007), in which specific relations between basic emotions/feelings (Ekman, 2003) and colour distributions involve most of the colour space.

Albertazzi et al.'s (submitted) results also allowed some predictions to be made: for instance, that the relation may occur in case of shapes much more complex than geometrical ones, like biological shapes. The present study concerns this last aspect of previous research, and it intends to verify the natural relations that might be expected to exist between morphological aspects of biological shapes and colours.

In order to analyse this relation, it was chosen some natural shapes taken from Haeckel's *Art Forms in Nature* (Haeckel, 2004), and specifically the configurations relative to *Diatomea*, *Cyrtoidea* and *Spumellaria*, these being drawings and consequently analysable in terms of configurational properties, texture, margins, etc.. It was not considered the natural shell shapes present in Haeckel's book because they are better known, analysed and commented upon, and in order to avoid interference by top-down components in judgment of the materials; and finally, because, as D'Arcy Thompson (1961) pointed out, shells are the 'products' of living organisms rather than being the organism themselves.

The natural shapes that it was decided to analyse, following the D'Arcy Thompson hypothesis, exhibited analogous patterns in both the qualities of the formation materials of the organisms and in the shapes, and thus seemed to fulfil the Goethian and Kantian principle of unity in variety (Kant, 1781/1881); Leuweenberg and van der Helm, 1991): the borders of the horns of certain antelopes, for example, resemble those of snails and ammonites (Thompson, 1961, ch. 7).

Much more restrictively, however, the intention was to verify whether certain natural shapes, like those of microorganisms, presenting common qualitative patterns might naturally be related to some colours or groups of colours, as has been found to happen in cases of much simpler geometrical shapes (Albertazzi et al., submitted).

The shapes chosen among the several drawings in Haeckel's book were complex also as regards the morphological patterns apparent in their configurations. To identify characteristics in the patterns it was taken into account of the suggestions provided by D'Arcy Thompson himself (Thompson, 1961).

However, given the novelty and complexity of the task, and the exploratory nature of the study, it was decided to restrict the analysis only to certain features of the patterns characterizing the shapes. Future studies might develop the direction of inquiry suggested in more detail.

In particular, because the intention was to verify the existence of functional relations between natural shapes (or better, between 'shape types' compared on base of symmetry) and colours, when deciding which images to present it was chosen those that were not drawn in colours by Haeckel himself and as they originally appeared in the text (i.e. in black-grey-white). The analysis was limited to the perceptual aspect of the shape's morphology; it did not consider either the underlying mathematical structures, specifically the aspect of symmetry, or the modelling of these shapes (Biedermann, 1987; Navon, 1977). Finally, in order to test for the influence of language and culture on recognition of the relation between the shapes' patterns and colours (Dadam et al., submitted), it was decided to involve subjects of different nationalities.

4.1 Methods

4.1.1 Participants

The experiment was conducted in two countries (Germany and Italy) with a total of 60 subjects (20 in Germany, 40 in Italy): 36 females and 24 males from 12 different countries. The main group was Italian (29 participants), followed by German (12 participants) and Brazilian (9 participants). There were also two participants from Turkey, and one from Argentina, South Korea, Kenya, India, Romania, Russia, Thailand and Vietnam. The overall mean age was 25.80. In Germany subjects were mainly recruited within the Department of Psychology of the Christian Albrechts University in Kiel. In Italy the experiment was conducted mainly with students from the Faculty of Cognitive Sciences at the University of Trento. Instructions for participants were given in four languages: English (9), German (13), Italian (29) and Portuguese (9), according to the preference of the subject.

4.1.2 Stimuli and Apparatus

The experiment was carried out in laboratories with constant and controlled lighting conditions (less than 10 lux. on the table). Subjects were seated at a desk in front of a screen where stimuli were presented, at a distance of about 60 centimetres. Subjects were seated in front of a calibrated Monitor CRT 19" View Sonic G90fB Graphics Series, controlled by a DELL Latitude D630 (Intel Corand 2 Duo T7500, 2.2 GHz, RAM 2GB, Windows XP Professional Service Pack 3).

In order to analyse this relation, 32 black-white-grey natural shapes taken from Haeckel's *Art Forms in Nature* (Haeckel, 2004) were chosen, and specifically the configurations relative to *Diatomea*, *Cyrtoidea* and *Spumellaria*, these being drawings and consequently analysable in terms of configurational properties, texture, margins, etc.. In regard to the choice of the categories with which to analyse the figures of the microorganisms drawn by Haeckel, it was first referred, as said, to the specific categorization made of the same figures by D'Arcy Thompson: for example, the distinction between *spicules* for sharp shapes, and non-spicules for round shapes like cords, horns, etc.; and, as regards texture, the distinction among *membrane*, *froth-like vesicles*, and *honeycomb patterns* (Thompson, 1961). The task of determining the categories for the figures' margins and textures was more difficult.

Secondly, owing to the complexity of the figures and the difficulty of their classification, for statistical reasons the categories were grouped together. The following classification criteria was chosen:

Orientation: figures were classified among vertical (figures 01, 03, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26 and 32), central (figures 02, 04, 05, 10, 11, 12, 15, 25, 27, 28, 29 and 31) and other orientations (including here horizontal, figure 30; and oblique in two different directions: figures 06 and 09 in the direction from up left to down right, and figures 07 and 08 in the direction from down left to up right).

Geometrical type of shape: figures were reduced to their geometrical appearance: the classification of figures included spherical (spherical, figures 02, 04, 05, 09, 11, 12, 13, 14, 15, 16, 20, 25, 27, 28, 29 and 31; cylindrical spherical, figures 07 and 08; and conic spherical, figures 01, 03, 17, 19, 21 and 24) and not spherical (cylindrical, figures 06, 10, 26, 30 and 32; and pyramidal, figures 18, 22 and 23).

Margin: figures were divided among *spicules* (figures 04, 05, 06, 07, 08, 09, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25 and 29) and non-*spicules* (cords, figure 16; horn, figure 10; membrane, figures 02 and 03; and neutral, figures 01, 26, 27, 28, 30, 31 and 32).

Texture: figures were classified among holed (simply holed, figures 02, 05, 07, 09, 11, 15, 16, 20 and 24; honeycomb holed, figures 18, 22 and 23; transparent gelatinous holed, figure 27; irregular holed, figures 01, 03, 06, 08, 13, 14, 17, 19 and 21; and froth-like vesicles, figures 04 and 12) and non-holed (simply not-holed, figures 26, 29, 31 and 32; low relief, figure 25; armour, figure 28; honeycomb not holed, figure 30; and spongy, figure 10).

Dimensionality: three-dimensional (figures 01, 02, 03, 04, 05, 06, 07, 08, 09, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 27, 28 and 29) and two-dimensional (figures 10, 26, 30, 31 and 32) figures.

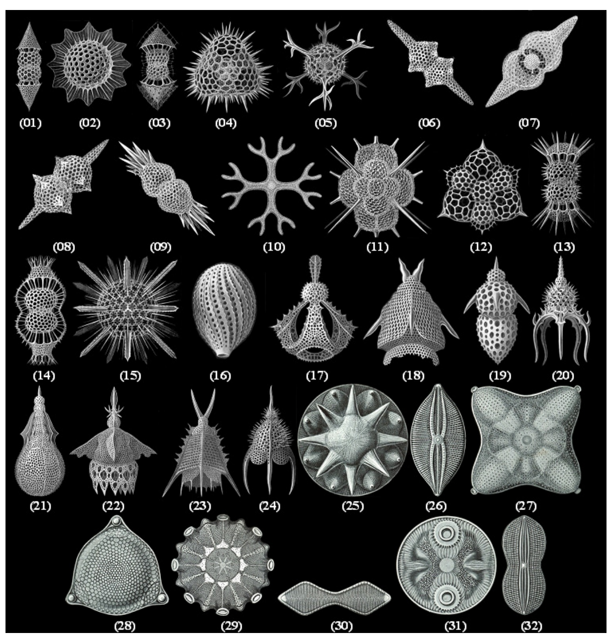


Figure 4.1 – Stimuli used in the experiment. Numbers 01-15 belong to the group of *Spumellaria*, numbers 16-24 to the *Cyrtoidea* group, and numbers 25-32 to the group of *Diatomea*[4] (Haeckel, 2004).

[4] The stimuli were (following the order of presentation in figure 4.1): Parnatus diploconus, Trochodiscus stellaris, Peripanartus amphiconus, Pylodiscus triangularis, Hexancistra quadricuspis, Cannartidium

4.1.3 Procedure

The test consisted in two tasks. Half of the participants started with task 1, and half of them with task 2, in order to off-set possible effects of past experience on some subjects, who might be influenced by previous choices made in matching figures and colours, and vice versa figures with characteristics.

In task 1 figures were presented in the centre of the screen, surrounded by a hue circle of 40 different hues. The Hue Circle had a different orientation for each figure. The order of figures presentation was fixed. In task 2 figures were also presented in the centre of the screen, in a fixed but different order from task 1. Presented in the bottom part of the screen, just under the figures, were two rectangles with the words: beautiful/ugly, hard/soft, strong/weak, warm/cold. The order of presentation for each pairs of words was always the same, but sometimes one option was presented on the left, sometimes on the right side of screen to achieve a better balance and to avoid clicking more on one side more than the other.

Task 1

In task 1, the participants were told that they were going to be shown a set of images, one at a time, surrounded by a hue circle with 40 different hues. The subjects' task was to choose a colour from the circle that most naturally matched the image. Half of the participants were told to not to make associations between the figure shown and past experiences, in order to avoid situations like that of the Jacobsen experiment (2002), in which subjects assigned yellow to the circle because of association with the sun, and red to the triangle because of association with road traffic signs. The other half did not receive this instruction in order to verify the possible influence of past experiences with such unusual shapes.

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mammiferim, Cannartiscus amphiconiscus, Cannartidium mastophorum, Cyphinus amphilophus, Dicranastrum bifurcatum, Tholoma mettallasson, Archidiscus pyloniscus, Peripanicium amphicorona, Panicium coronatum, Astrosphaera stellata, Cyrtophormis spiralis, Clathrocanium reginae, Pterocorys rhinoceros, Lithornithium falco, Alacorys Bismarckii, Stichophaena Ritteriana, Dictyocodon Annasethe, Artopilium elegans, Pterocanium trilobum, Pyrogodiscus armatus, Navicula bullata, Amphithetras elegans, Triceratium robertsianum, Grovea pedalis, Gephyria constricta, Auliscus elegans and Navicula didima.

INSTRUCTIONS given to subjects

You are going to see a set of images, one at a time.
Each image is presented with a coloured circle around it.
Your task is choose, among the colours in the circle, the one which best matches that image.
To choose a colour, left click on it with the mouse.
The image will change to colour that you have chosen.
If you click, again with the left mouse button, on another colour, the image's colour will change.
You can change colours as many times as you want.
When you have decided which colour is the best match with the image, click on the image with the right mouse button.
Your answer will be recorded, and a new image will be presented.
There is no time limit. Take all the time you need for you choice.
There are no wrong answers. Just express your perception, combining colour with image.

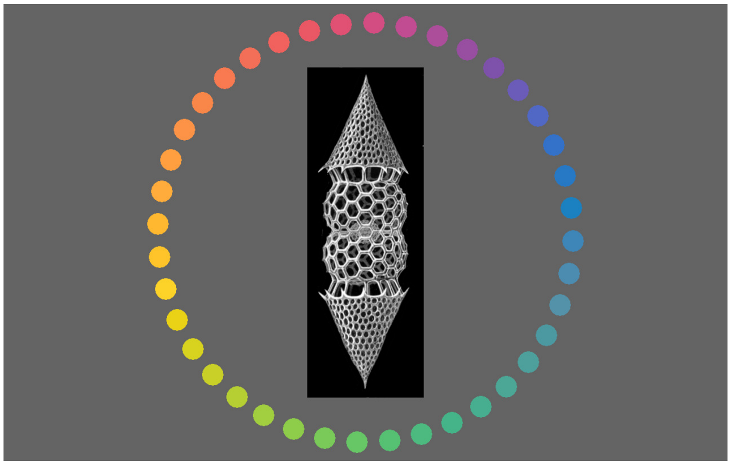

Figure 4.2 – Stimulus in task 1 before colour choice.

When a subject chose a colour, the image, originally black, grey and white, changed colour and became coloured with the colour chosen. Participants were allowed to change colours until they were satisfied with their choice. They could then confirm their choice and proceed to the next figure.

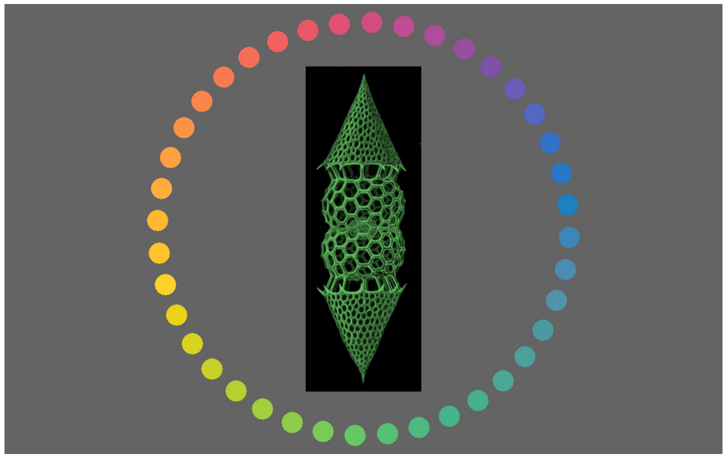

Figure 4.3 – Stimulus in task 1 after colour choice.

Task 2

In task 2 subjects were shown the same figures in their original colour (black-grey-white) but in an order different from that of task 1. Below the figures, in the lower part of the screen, there were shown two words, each in its own rectangle. Participants were asked to look at the image and to chose one of the two words by clicking on it with the mouse.

The first pair of words was ‘beautiful’ and ‘ugly’. If the subject thought that the figure was beautiful, for example, the word ‘beautiful’ was to be clicked. After the answer, another pair of words was shown to the same image. The second pair was ‘hard’ and ‘soft’, the third was ‘strong’ and ‘weak’, and the last one was ‘warm’ and ‘cold’. After participants had chosen the four words of the pairs, a new image was presented and the four pairs of options were again presented, in the same order.

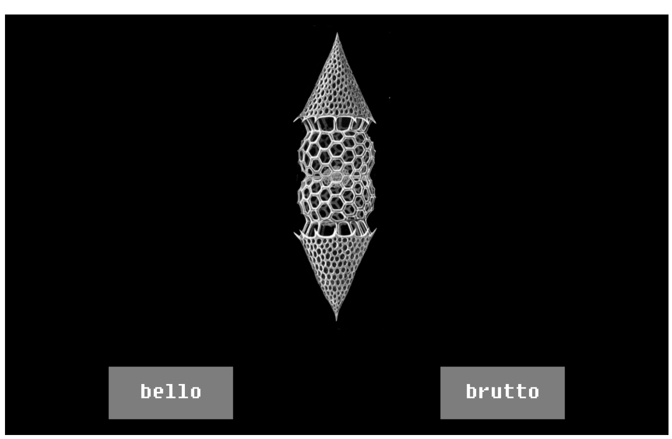

Figure 4.4 – Stimulus in task 2 with the words ‘bello’ (beautiful) and ‘brutto’ (ugly).

4.2 Results

4.2.1 Results from Task 1

As said, the task consisted in assigning a colour to each figure presented on the screen. The data analysis found a significant association between figures and colours ($p<0.0001$).

To facilitate the interpretation, colours were grouped in 8 groups of 5 colours. Four groups were composed of the unique colours (groups yellow ‘YY’, red ‘RR’, blue ‘BB’ and green ‘GG’), and their two adjacent colours. The other four groups were composed of the five colours in between the groups with the unique colours (a transition group between yellow and red ‘YR’, between red and blue ‘RB’, between blue and green ‘BG’, and a last one between green and yellow ‘GY’). After this grouping, the significant relation between shape and colour was confirmed. Specifically as regards the relationship between the 8 groups of 5 colours and the shapes, in relation to the predictions based on the chi-square test the results were the following.

In some cases results more positive than predicted were found in the association between a particular figure and a particular colour. Vice versa, in some cases, the associations were less than predicted and specifically. Table 4.1 reasumes the positive and negative associations between figures and colours.

In a few other cases the figure presented both a positive value regarding one colour and negative values regarding other colours. This concerned 26 images (1-4, 6, 8, 10-26, 28, 29, 32). Two images were only positive (30, 31); two images were only negative (9, 27). In other cases, no positive or negative result was found in relation to colour for some figures, which were ‘neutral’, so to speak: these were figures 5 and figure 7.

On the basis of these first results, both *positive and negative results* were grouped in relation to the 8 groups of colours.

Table 4.1. Positive, relatively positive, negative and relatively negative associations between figures and the eight groups of colour.

	Colour group							
Figure	YY	YR	RR	RB	BB	BG	GG	GY
01	-	-	negative	-	-	positive	-	-
02	positive	-	-	-	-	-	negative	-
03	positive	-	-	-	rel. pos	rel. neg	negative	-
04	-	rel. neg	rel. pos	negative	-	rel. pos	-	-
05	-	-	-	-	-	-	-	-
06	positive	-	-	-	rel. pos	-	-	negative
07	-	-	-	-	-	-	-	-
08	positive	-	-	rel. neg	-	positive	-	-
09	-	-	-	-	-	rel. neg	-	-
10	-	-	rel. pos	negative	-	-	positive	-
11	-	negative	-	-	-	-	negative	positive
12	-	-	positive	rel. pos	-	rel. neg	negative	-
13	-	-	-	rel. neg	-	rel. pos	-	-
14	-	-	-	positive	-	-	negative	rel. neg
15	positive	-	-	rel. neg	-	-	negative	rel. neg
16	positive	negative	negative	-	-	-	rel. pos	rel. pos
17	positive	rel. neg	positive	rel. neg	negative	-	-	rel. neg
18	-	negative	-	-	-	positive	-	-
19	-	-	negative	-	-	positive	-	rel. pos
20	-	-	-	-	-	positive	-	rel. neg
21	positive	-	-	negative	-	rel. neg	rel. neg	positive
22	rel. pos	-	-	-	-	positive	negative	-
23	-	rel. neg	-	negative	rel. pos	-	-	-
24	-	-	-	negative	positive	positive	rel. neg	rel. neg
25	-	positive	-	-	negative	-	negative	-
26	-	-	positive	-	-	-	negative	-
27	-	-	-	rel. neg	-	-	-	-
28	positive	-	-	negative	-	positive	-	negative
29	-	-	rel. pos	-	-	-	-	negative
30	-	-	-	-	positive	-	-	-
31	-	-	positive	-	-	-	-	-
32	-	-	rel. pos	rel. neg	-	-	positive	rel. neg

The YY group received 10 positive associations and no negative association. The YR group received one positive association and 6 negative associations. The RR group received 8 positive associations and 3 negative associations. The RB group received two positive associations and 12 negative associations. The BB group received 5 positive associations and two negative associations. The BG group received 10 positive associations and 4 negative associations. The GG group received 3 positive associations and 11 negative associations. The GY group received 4 positive associations and 9 negative associations. These results show that:

- BG, YY and RR groups of colours received the most positive associations;

- RB, GG and GY colours received the most negative associations.

The figures with more positive associations with YY were, in decreasing order, figures 17, 15, 2, 28, 21, 8, 16, 3, 6 and 22. Only figure 25 received a YR positive association. The figures that received the most positive associations for RR were 17, 12, 26, 31, 4, 10, 29 and 32. The figures that received the most positive associations for RB were 14, and 12.

The figures that received the most positive associations for BB were 30, 24, 6, 3 and 23. The figures that received the most positive associations for BG were 18, 24, 1, 19, 20, 22, 8, 28, 4 and 13. The figures that received the most positive associations for GG were 32, 10 and 16. The figures that received the most positive associations for YG were 11, 21, 16 and 19.

The figures that received the most negative associations for YR were 16, 18, 11, 4, 17 and 23. The figures that received the most negative associations for RR were 16, 1 and 19. The figures that received the most negative associations for RB were 4, 24, 10, 21, 23, 28, 8, 13, 15, 17, 27 and 32.

The figures that received the most negative associations for BB were 17 and 25. The figures that received the most negative associations for BG were 3, 9, 12 and 21. The figures that received the most negative associations for GG were 15, 11, 25, 2, 3, 12, 14, 22, 26, 21 and 24. The figures that received the most negative associations for GY were 28, 6, 29, 14, 15, 17, 20, 24 and 32.

These data show that some figures were *positively* associated with more than one colour, specifically:

- For the YY and RR groups, only figure 17.
- For the YY and BG groups, figures 8, 22 and 28.
- For the YY and GY groups, only figure 21.
- For the YY and BB groups, figures 3 and 6.
- For the RR and RB groups, only figure 12.
- For the RR and GG groups, figures 10 and 32.
- For the RR and BG groups, only figure 4.
- For the BB and BG groups, only figure 24.
- For the BG and GY groups, only figure 19.
- For the YY, GG and GY groups, only figure 16.

These data show that some figures were *negatively* associated with more than one colour, and precisely:

- For the YR and RR groups, only figure 16.
- For the YR and RB groups, figures 4 and 23.
- For the YR and GG groups, only figure 11.

- For the RB and GY groups, figures 28 and 32.
- For the BB and GG groups, only figure 25.
- For the BG and GG groups, figures 3 and 12.
- For the GG and GY groups, only figure 14.
- For the RB, BG and GG groups, only figure 21.
- For the RB, GG and GY groups, figures 15 and 24.
- For the YR, RB, BB and GY groups, only figure 17.

On grouping the data concerning the figures that were *positively and negatively* associated with more than one colour (in all possible combinations), it was obtained the following table showing the different combinations between positive and negative associations of the 32 figures.

Table 4.2. Positive and negative associations between the eight groups of colours and figures.

Positive	Negative	Figure
YY	GG	2
YY	RG/GG/GY	15
YY/RR	YR/RB/BB/GY	17
YY/BG	GG	22
YY/BG	RB	8
YY/BG	RB/GY	28
YY/GY	RB/BG/GG	21
YY/BB	GY	6
YY/BB	BG/GG	3
YY/GG/GY	YR/RR	16
YR	BB/GG	25
RR	-	31
RR	GG	26
RR	GY	29
RR/RB	BG/GG	12
RR/GG	RB	10
RR/GG	RB/GY	32
RR/RB	YR/RB	4
RB	GG/GY	14
BB	-	30
BB	YR/RB	23
BB/BG	RB/GG/GY	24
BG	YR	18
BG	RR	1
BG	GY	20
BG	RB	13
BG/GY	RR	19
GY	YR/GG	11
-	BG	9
-	RB	27
-	-	5, 7

For interpretation of the figures, they were grouped them according to their association with warm and cold colours. According to the CIELAB hue angle (see Table 4.3), colours 01 to 15 and 37 to 40 were warm and colours 16 to 36 were cold.

Table 4.3. Coordinates XYZ and CIELAB hue angle of the 40 colours used in the experiment.

Colour	X	Y	Z	CIELAB hue angle
01	35.068	34.757	5.4786	84
02	34.105	32.032	5.0257	79
03	33.083	29.72	5.0816	74
04	32.244	27.626	5.6666	67
05	31.297	25.499	5.6893	62
06	30.124	23.498	5.9849	56
07	28.786	21.536	6.1335	50
08	27.987	19.893	6.7092	43
09	26.523	18.183	7.2648	37
10	25.517	16.682	8.0511	29
11	23.934	15.171	8.9639	22
12	22.302	13.827	11.497	10
13	20.376	12.45	14.271	358
14	18.276	11.216	17.742	345
15	15.724	9.8664	20.013	334
16	13.601	8.7117	21.888	324
17	11.356	7.5255	24.482	313
18	11.272	7.9743	29.782	305
19	10.789	8.4051	33.803	296
20	10.211	8.8125	35.028	288
21	10.029	9.3164	34.018	282
22	9.9063	10.002	32.341	275
23	10.45	10.846	29.346	272
24	10.979	11.783	27.187	267
25	11.292	12.64	24.829	257
26	11.095	13.343	23.188	237
27	11.208	14.262	21.372	216
28	11.476	15.293	20.197	199
29	11.485	16.231	18.821	185
30	11.597	17.274	17.295	174
31	12.056	18.421	15.212	163
32	12.669	19.689	12.96	153
33	13.704	21.067	10.661	143
34	15.273	22.585	9.0211	133
35	17.058	24.078	7.2918	124
36	19.504	25.756	6.4244	115
37	22.128	27.371	5.5626	107
38	25.037	29.134	5.0128	100
39	27.723	30.937	4.6803	96
40	31.069	32.764	4.5707	90

On further grouping positive and negative associations in 4 colour groups according to the unique hues (yellow, red, blue and green), it was obtained:

- as regards positive associations, 11 associations with yellow, 8 with red, 13 with blue, and 15 with greens occurred;

- as regards negative associations, 3 associations with yellow, 13 with red, 6 with blue, and 7 with yellow occurred.

However, because in some cases a figure was associated with more than one colour, it was made a further comparison grouping in order to highlight these colours.

As to positive associations, two associations with yellow and red, two associations with yellow and green, one association with yellow and blue, two associations with blue and green, 3 associations with red and blue and 5 associations with blue and green occurred.

As to negative associations, one association with blue and green, one association with red and blue, and 3 associations with yellow and red occurred.

The results are set out in the following Table.

Table 4.4. List of positive and negative associations between the four groups of colours and figures.

Positive	Negative	Figure
Yellow	Blue	2
Yellow	Green	15
Yellow	Red / Blue	21
Yellow	Blue / Green	17
Yellow / Red	-	25
Yellow / Red	Green	3
Yellow / Blue	Red	28
Yellow / Green	Red	11, 16
Yellow / Blue / Green	Red	19, 22
Red	-	9, 31
Red	Green	29
Red / Blue	-	26
Red / Blue	Green	12, 14
Blue	-	30
Blue	Green	6
Blue / Green	-	20
Blue / Green	Red	13
Blue / Green	Yellow / Red	1, 18, 24
Green	-	7, 27
Green	Red	4, 8, 23
Green	Blue	10
-	Blue	5, 32

Considering only the *positive* associations, on comparing the data relative to the 5 classification criteria chosen and the association with the colours received by the figures, it was obtained:

Table 4.5. Classification of the figures according to the five criteria and colour.

Orientation	Shape	Margins	Texture	Dimension	Figure	Colour
Other	Non-spherical	Non-spiculed	Non-holed	2D	30	Blue
Other	Non-spherical	Spiculed	Holed	3D	6	Blue
Other	Spherical	Spiculed	Holed	3D	7, 8	Green
Other	Spherical	Spiculed	Holed	3D	9	Red
Central	Non-spherical	Non-spiculed	Non-holed	2D	10	Green
Central	Spherical	Non-spiculed	Non-holed	2D	31	Red
Central	Spherical	Non-spiculed	Non-holed	3D	28	Yellow / Red
Central	Spherical	Non-spiculed	Holed	3D	2	Yellow
Central	Spherical	Non-spiculed	Holed	3D	27	Green
Central	Spherical	Spiculed	Non-holed	3D	25	Yellow / Red
Central	Spherical	Spiculed	Non-holed	3D	29	Red
Central	Spherical	Spiculed	Holed	3D	4	Green
Central	Spherical	Spiculed	Holed	3D	5	-
Central	Spherical	Spiculed	Holed	3D	11	Yellow / Green
Central	Spherical	Spiculed	Holed	3D	12	Red / Blue
Central	Spherical	Spiculed	Holed	3D	15	Yellow
Vertical	Non-spherical	Non-spiculed	Non-holed	2D	26	Red / Blue
Vertical	Non-spherical	Non-spiculed	Non-holed	2D	32	-
Vertical	Non-spherical	Spiculed	Holed	3D	18	Blue / Green
Vertical	Non-spherical	Spiculed	Holed	3D	22	Yellow / Blue / Green
Vertical	Non-spherical	Spiculed	Holed	3D	23	Green
Vertical	Spherical	Non-spiculed	Holed	3D	1	Blue / Green
Vertical	Spherical	Non-spiculed	Holed	3D	3	Yellow / Red
Vertical	Spherical	Non-spiculed	Holed	3D	16	Yellow / Green
Vertical	Spherical	Spiculed	Holed	3D	13, 20, 24	Blue / Green
Vertical	Spherical	Spiculed	Holed	3D	14	Red / Blue
Vertical	Spherical	Spiculed	Holed	3D	17, 21	Yellow
Vertical	Spherical	Spiculed	Holed	3D	19	Yellow / Blue / Green

Statistical analysis showed that 3 of the 5 criteria adopted to classify the figures were not significant; however two were. Specifically: orientation, basic shape (spherical/non spherical), margins (spiculed/non spiculed) were not significant; texture (holed/non-holed), and dimensionality (2D and 3D) were.

In short, the analysis of the relation between the five criteria and the assignment of the colours showed a significant result only on the texture ($p=0.002373$) and dimensional appearance ($p=0.02391$) criteria.

The most significant comparison should therefore have been made between texture and dimensionality. However, because of the numerical disproportion between the two aspects (texture and dimensionality) among the figures initially considered, comparison was made between texture and dimensionality only for *non-holed* figures.

Comparison among the *non-holed* figures and *3D* figures showed that:

Figure 25 had positive associations with yellow and red; figure 29 had a positive association with red; and figure 28 had positive associations with yellow and blue.

Comparison among the *non-holed* figures and *2D* showed that:

Figure 10 had a positive association with green; figure 26 with red and blue; figure 30 with blue; figure 31 with red; and figure 32 had a relative positive association with green.

Cold and warm figures

Comparison among the figures and their positive associations with warm and cold colours showed that figures were associated with warm colour, as follows: with yellow, figures 2, 15, 17 and 21; with red, figures 9, 29 and 31; and with yellow and red, figures 3 and 25.

Figures associated with *cold* colours as follows: with blue, figures 6 and 30; with green, figures 4, 7, 8, 10, 23 and 27; and with blue and green, figures 1, 13, 18, 20 and 24.

Some figures had particular associations: figure 28 was associated with yellow and blue, and can be classified both warm and cold. Figures 19 and 22 were associated with yellow, blue and green and were considered colder than warm. Figure 19 exhibited the salience of 3 large visible spicules (one above and two lateral) and one amodal spicule because of their salience and size influence on some minor rounded parts of the figure, which, however, had a local part with a triangular tendency. Figure 22 exhibited one spicule of large size, and had a local or upper triangular shape rendered more salient by pleats in relief, and by triangular shapes in the lower part which increased the global effect.

Figures 12, 14 and 26 were associated with red and blue. In the case of figure 12 (classified as cold), the pronounced salience of the spicules (thorns) despite their limited number, probably restricted the effect of the local spherical shape, instead increasing the global triangular shape. In the case of figure 14 (classified as warm), its classification as warm was very probably due to the predominance and salience of the two central spheres compared with the spicules (stings) at its upper extreme. Figure 26 (classified as 'neutral'), probably admits to a double classification because it presented neither spicules nor marked spherical (local or global) shapes. Comparison with figure 30, classified as cold, reveals similarities of texture, but also differences of orientation and shape (more curvilinear in figure 26).

Figures 11 and 16 were associated with yellow and green and both were classified as cold. Figure 11 exhibited a global and local spherical salience of the parts and a salience of spicules (stings). Very probably, in this case such pointed and long spicules played a significant role in modifying the spherical form. In the case of figure 16, it is probable that the spicules (taking the form of thorns, not of stings - see D'Arcy Thompson, 1961, ch. 5) played a major role regarding the spherical and extended shape.

These associations evince that the warm figures primarily exhibited *global or local spherical shape and curvilinear edges*. Of these warm figures, figures 3 and 17 were least prototypical: in the case of figure 3, the lesser prototypicity was due to the triangular tendency of the two extreme vertical parts of the figure, moreover made less acute by the membranous texture. In the case of figure 17, the lesser prototypicity was due to the 3D tendency, which is spherical, attenuated by the thorny edges of the parts and by the presence of the extended upper part.

The cold figures mostly presented *global or local triangular shapes* and spiculed edges. These figures were characterized by the perceptual salience (either by number or feature) of unrounded spicules or stings. This highlights that the sharpness of the spicules plays a role in the coldness of forms. Of these cold figures, figures 27 and 10 were the least prototypical. In the case of figure 27, the lesser prototypicity was due to the salience of the diagonal parts of the texture which differentiated them from the background and tended to lengthen the figure towards the four corners. In the case of figure 10, the lesser prototypicity was due to the importance of the symmetry among the parts, which tended give the figure a spherical completion.

Figure 28, associated with yellow and blue, very probably owed its *ambiguous* classification to the balance between a global central configuration and the presence of three angular parts which deformed it triangularly. In this case, the two forms, spherical and triangular, balanced each other.

Finally a comparison was made among the figures and the *negative* associations occurring with warm and cold colours. Figures 2, 5, 6 and 32 were never associated with blue; figures 3, 6, 12, 14, 15 and 29 were never associated with green; and figures 4, 8, 11, 13, 16, 19, 22, 23 and 28 were never associated with red.

Some figures, instead, showed *mixed* associations: figure 17 (classified as warm) was negatively associated with blue and green; figure 21 (classified as balanced between warm and cold), was negatively associated with red and blue; figures 1, 18 and 24 (classified as cold), were negatively associated with yellow and red. Eight figures had no negative associations with any colour: 7, 9, 20, 25, 26, 27, 30 and 31.

Comparison among the figures *positively associated* with yellow showed that figures 2, 15, 17 and 21 were also negatively associated with blue and green (17), red and blue (21), green (15) and blue (2), confirming the results of the positive association with yellow and consequently with warm colours.

Comparison among the figures *positively associated* with red (9, 29, and 31) showed that only one figure (29) had a negative association with green, confirming the association with warm colours.

Comparison among the figures *positively associated* with yellow and red (3 and 25) showed that only one figure (3) had a negative association with green, confirming the association with warm colours.

The following figures had a very negative association with red (red was rejected): figure 28 (positively associated with yellow and blue); figures 19 and 22 (positively associated with yellow, blue and green); and figures 11 and 16 (positively associated with yellow and green).

The following figures had a very negative association with green (green was rejected): figures 12, 14 and 26 (positively associated with red and blue).

Comparison among the figures positively associated with blue (6 and 30) showed that only one a figure (6) had a negative association with green.

Comparison among the figures positively associated with green (4, 8, 7, 10, 23 and 27) showed that figures 4, 8 and 23 had a negative association with red, confirming the association with cold colours. Figure 10, instead, had a negative association with blue.

Comparison among the figures positively associated with blue and green, showed that only one figure (13) had a negative association with red, and that figures 1, 18 and 24 had a negative associations with yellow and red, confirming them as cold figures.

Comparison among the figures positively associated with red and blue showed that figure 12 (reds being more towards blue connoted it as a cold figure), and figure 14 (reds being more towards yellow connoted it as a warm figure) had a negative association with green, confirming the ambiguous nature of red and blue.

Finally, figures 5 and 32 had no positive associations with any colour (figure 32 had only a relative association with green), but they had negative associations with blue, and hence can be connoted as 'slightly cold' (both figures) or warm (figure 5). In particular figure 5 exhibited a central spherical shape that was not annulled by the simultaneous presence of very conspicuous spicules (thorns) of large size, however symmetrically organized. Figure 32, instead, showed a similarity with figure 26 (red and blue, in equilibrium between warm and cold) as to texture, inner cords and margins; and with figure 30 (blue and cold), with which it had similarity of texture, orientation, margins and a tendentially elongated shape.

4.2.2 Results from Task 2

As regards Task 2, where Osgood's semantic differential was used, participants were asked to classify the images according to four criteria (beautiful/ugly, hard/soft, strong/weak, and warm/cold).

Some images differed statistically in relation to the various pairs of adjectives, others did not. When the difference was significant, these images were more likely to be considered, for example, beautiful rather than ugly. When the difference was not significant, these images had the same probability of being considered, for example, both beautiful and ugly. Specifically:

As regards the beautiful/ugly pair, 9 images had higher probability of being considered beautiful (figures 02, 05, 10, 15, 17, 20, 22, 29 and 31), while 11 images had a higher probability of being considered ugly (figures 03, 04, 06, 07, 11, 18, 19, 23, 24, 30 and 32).

As regards the hard/soft pair, 7 images had a higher probability of being considered soft (figures 02, 07, 10, 12, 21, 27 and 29), and 13 images had a higher probability of being seen as hard (figures 01, 03, 04, 08, 09, 11, 13, 15, 17, 18, 20, 23 and 24).

As regards the strong/weak pair, 12 figures had a higher probability of being considered strong (figures 01, 04, 09, 11, 13, 15, 20, 23, 24, 25, 28 and 31), while only two figures (10 and 27) had a higher probability of being be considered weak.

As regards the warm/cold pair, 6 figures obtained a higher probability of being seen as warm (figures 02, 16, 21, 22, 27 and 29), and 11 images had a higher probability of being considered cold (figures 01, 03, 06, 08, 09, 13, 18, 20, 23, 24 and 32).

Two figures (14 and 26) showed no preferences in any of the four pairs. Seven figures had a significant statistical difference only in one pair: figure 16 was considered to be warm, figure 12 soft, figure 05 beautiful, figures 19 and 30 ugly, and figures 25 and 28 strong. Eight figures had two significant statistical difference: figure 08 was considered hard and cold, figure 21 was seen as soft and warm, figure 22 as beautiful and warm, figure 31 as beautiful and strong, figure 17 as beautiful and hard, figure 07 as ugly and soft, and figures 06 and 32 as ugly and cold.

Twelve figures had three significant differences: figure 01, 09 and 13 were considered to be hard, strong and cold; figure 27 soft, weak and warm; figure 15 beautiful, hard and strong; figures 02 and 29 beautiful, soft and warm; figure 10 beautiful, soft and weak; figures 03 and 18 ugly, hard and cold; and figures 04 and 11 ugly, hard and strong. Figures 20, 23 and 24 had significant differences in all the four pairs: figure 20 was seen as beautiful, hard, strong and cold; while figures 23 and 24 were seen as ugly, hard, strong and cold.

On the basis of the statistical significances obtained with Osgood’s differential semantic test, the frequencies of connections between the pairs were analysed in order to verify the relations among the choices made by the subjects (see Figure 4.5). The features of the figures are more or less pronounced in relation to the weights evinced by the test among the various types of connection among pairs. For example, because figures considered hard were normally seen as also strong and cold, and in most cases as ugly as well, the lines representing the connections among these pairs (hard, strong and cold), are drawn more thickly than the others.

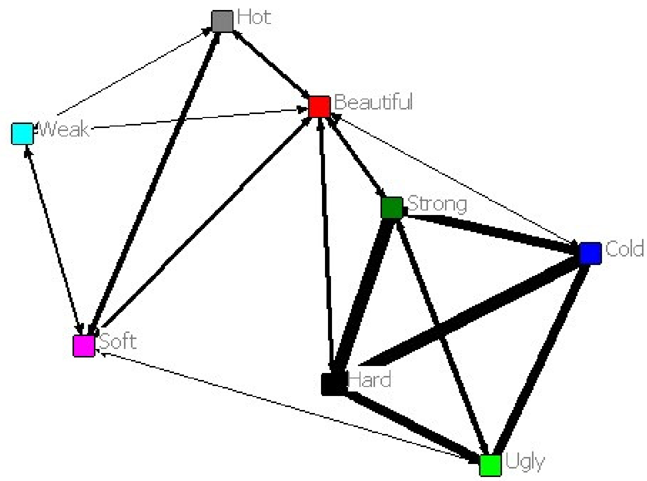

Figure 4.5 – Frequencies of connections among the eight elements used in the Osgood Differential Semantic task.

When this type of analysis was applied to the data, the words hard and strong showed nine connections, the same number for the words hard and cold, while between strong and cold there were six connections. These three words were more connected with ugly than with beautiful. Hard, for example, had six connections with ugly and three with beautiful, cold was connected six times with ugly and only once with beautiful, and strong had four connections with ugly and three with beautiful. Hard, strong, cold and ugly could be considered a group because, although hard, strong and cold also had connections with beautiful, these three words did not connect with soft, warm or weak. The word beautiful acted as a linkage between this group and the second group, composed of weak, soft and warm, although soft had a singular connection with ugly. In this second group, where the figures shared the characteristics of weak, soft and warm, soft had four connections with warm, two with weak, three with beautiful and only one with ugly; weak had one connection with beautiful, two with soft and only one with warm. Warm had connections with beautiful (3), soft (4) and weak (1).

The results show the existence of a first relevant connection: if a participant classified a figure as strong, it was very likely that this figure would be seen as cold and hard as well. Moreover, this connection correlated more with the category ‘ugly’ than with its opposite ‘beautiful’. Likewise, a weak figure, in most cases, was seen as soft and warm as well, and correlated more with the category beautiful than with its opposite ugly.

Other connections emerged from comparison between the results of the two tasks (see below).

For the pairs beautiful/ugly, warm/cold, and hard/soft a significant result was found when related to the colours chosen by the subjects in the first task. As regards the pair strong/weak, instead, the result was not meaningful.

4.2.3 Comparison among the results of the first and second tasks

Applying the same criteria to the five categories as used to classify the figures (orientation, basic geometric shape, margins, texture and dimensionality) showed that figures with vertical orientation and of other type (excluding central orientation) had a higher probability of being considered ugly, hard and cold. Vertical orientation was also considered as strong, while central orientation had a higher probability of being seen as beautiful, soft, strong and warm.

If the shape of a figure was spherical, it more likely that would be seen as beautiful and strong, while if it was a non-spherical figure, it had a higher probability of being considered ugly, hard, strong and cold. For the type of margins criterion, non-spiculed figures were seen as soft, while the spiculed figures had a higher probability of being seen as hard, strong and cold. The same occurred with holed figures and 3D figures (hard, strong and cold), while non-holed figures were seen as beautiful, soft and weak.

However, sometimes a figure had a characteristic judged, for instance, soft, and another characteristic judged as hard. In such cases, the choice of the subjects to classify a figure as hard or soft depended on which part they considered more important, the hard part (for example orientation-related) or the soft one (for instance texture-related). Because all the figures had five elements, it was possible to make several combinations, but only 13 of them had at least one figure. Table 4.6 presents a resumed version of Table 4.5 with the 13 combinations of the five criteria and the corresponding figures. Images with vertical orientation, non-spherical, with spicules and holes, and three-dimensional, had a higher probability of being considered hard, strong and cold, and ugly. The same applied if the orientation is classified as ‘other’. For the other combinations, the situation is more complicated. The central orientation was associated with beautiful, soft, strong and warm. It correlated with spherical (beautiful and strong), with non-spiculed (soft) and partially with non-holed (beautiful, soft and weak) because of the difference between strong and weak. In this case, the subjects' decision depended once again on which part of the figure they considered to be the most important.

Table 4.6. Classification of the figures according to the five criteria.

Orientation	Shape	Margins	Texture	Dimension	Figures
Other	Non-spherical	Non-spiculed	Non-holed	2D	30
Other	Non-spherical	Spiculed	Holed	3D	6
Other	Spherical	Spiculed	Holed	3D	7, 8, 9
Central	Non-spherical	Non-spiculed	Non-holed	2D	10
Central	Spherical	Non-spiculed	Non-holed	2D	31
Central	Spherical	Non-spiculed	Non-holed	3D	28
Central	Spherical	Non-spiculed	Holed	3D	2, 27
Central	Spherical	Spiculed	Non-holed	3D	25, 29
Central	Spherical	Spiculed	Holed	3D	4, 5, 11, 12, 15
Vertical	Non-spherical	Non-spiculed	Non-holed	2D	26, 32
Vertical	Non-spherical	Spiculed	Holed	3D	18, 22, 23
Vertical	Spherical	Non-spiculed	Holed	3D	1, 3, 16
Vertical	Spherical	Spiculed	Holed	3D	13, 14, 17, 19, 20, 21, 24

Judgments of the figures by the subjects agreed with the categories, except for figure 22, which was judged warm by the participants, while its characteristics suggested a cold judgment. However, the fact that a particular figure had a higher probability of being considered cold does not mean that it had to be cold, only that it would probably be classified as more cold than warm.

4.3 Discussion

Following previous analyses (Albertazzi et al., submitted), the present study has sought to verify whether natural relations can be expected to exist between the morphological aspects of biological shapes and colours.

In order to analyse this relation, it was chosen drawings of natural shapes taken from Haeckel (2004) and analysed them according to criteria of orientation, geometrical type of shape, margin, texture, and dimensionality.

The test consisted in two tasks. In task 1 figures were presented in the centre of the screen, surrounded by a hue circle of 40 different hues among which the subject had to choose the colour most naturally associated with each figure. In task 2 figures were also

presented in the centre of the screen, in a fixed but different order from task 1, and the subject has to associate with each figure one of bipolar terms presented at the bottom of the screen (beautiful/ugly, hard/soft, strong/weak, warm/cold).
Some results are interesting. For example, a significant association between colours and shapes was found. The significance of the association continued also after colours were grouped into eight groups of five colours. In some cases, there were more positive associations between figures and colours than expected (with the YY, RR and BG groups), and in other cases more negative associations (RB, GY and GG groups). Some of the figures had more than one positive or more than one negative association.

Of the five criteria used to classify figures (orientation, type of shape, margin, texture and dimensionality), only two were statistically significant: texture and dimensionality. The reduction of the categories used for the statistic analysis may have eliminated some information which could have demonstrated particular relevance for the other three criteria.

An analysis between the warm/cold aspect of the colour chosen by subjects and figures characteristics has shown that figures associated with warm colours have particular characteristics different from figures associated with cold colours. Rounded shapes and margins are more associated with warm colours, while triangular shapes and the presence of spicules of particular type are more associated with cold colours.

Figures positively associated with warm colours normally have negative associations with cold colours and vice versa, confirming that this criterion is very useful for analysis of the relations between colours and shapes. Others results are less clear and of more difficult interpretation. There may be several reasons for this, primarily the extreme complexity of organic shapes.

The results of task 2 have demonstrated the existence of different groups of figures according to the subjects' judgment. In particular, figures judged to be hard, strong and cold are strongly related with ugly. Figures judged as soft, weak and warm are more related with beautiful and consequently constitute the other group. A statistically significant result was found for three of these pairs of adjectives, except for strong/weak.

Analysis between the five criteria and the four pairs of adjectives has shown that the vertical orientation and the 'other' orientation (expect for central) are more associated with ugly, hard and cold. Vertical orientation is also considered strong. Central orientation, in its turn, is more associated with the words beautiful, soft, strong and warm. Spherical shapes are more associated with beautiful and strong, and non-spherical with ugly, hard, strong and cold. Non-spiculed figures are more associated with soft and non-holed figures with beautiful, soft and strong. Figures with the presence of spicules, holed figures and 3D figures are more associated with hard, strong and cold. In this sense, images with vertical orientation, which are non-spherical, with spicules and holes, and three-dimensional, are more associated with hard, strong, cold and ugly.

Particularly interesting is the analysis of the mixed figures, classified as yellow and green, red and blue and yellow, blue and green. These in fact have both characteristics tending more towards the prototypical forms classified as warm (sphericity, curvilinearity) and other characteristics tending towards the prototypical forms classified as cold (triangularity, presence of spicules, etc.). Analysis of the parts of the figures, considered both modally and amodally, showed that they reflected the principles of the field of forces described by Lewin (1936) and by Lipps in his aesthetics of space (Lipps, 1879), showing a *behaviour* in the perceptive field of the vision. For example, the *arcs* of a circle share with a straight line the aspect that all their parts may overlap, or more generally that each part may be shifted on to the whole. Bühler would later define a straight line as a circle with only one radius of magnitude, etc..

The already-mentioned difficulty of categorizing organic complex shapes is due to the facts that: (i) no developed classification of relational properties (that constitute patterns) is today available; and (ii) there are consequently no reliable developed tools to apply in their analysis. We hope that this study has highlighted some of the problems to be solved in developing a scientific approach to natural shape categorization based on the act of *seeing*.

In future studies we shall consider those aspects found to be relevant to the connection between shape and colour: for example, a better balance between 2D and 3D figures; and better specification of characteristics in the surface texture, because texture proves to be a significant classification criterion. In the latter case, in fact, the reduction made for statistical reasons may have cancelled relevant information (for example, as to spicules, the difference between aculei and thorns). To obviate this drawback, the number of similar forms should be increased and balanced.

In this study, moreover, it was not considered correlative analyses in animal perception, which might support the study, because the initial hypothesis was that the *visual morphology* of structures of living creatures is potentially shared by unicellular organisms, plants, animals, as well as human beings.

Further studies will analyse those aspects in detail. Others studies may also focalize on the complexity of a mathematical model for these patterns, from the viewpoint of their computational representation, in order to implement the pattern taxonomy algorithmically (for a more figural-oriented computation see Bipin Indurkya, 1994).

Conclusion

As said, this work has been conceived on the basis of a specific project: that of verifying the actuality and the inventiveness of the theses advanced by experimental phenomenology in contemporary studies of vision and specifically in psychophysical analyses.

The motivation for the study was dissatisfaction with the current research paradigms in perception studies. Whilst these approaches have indubitably advanced understanding of key aspects of cognitive science, they appear somehow unsuited to dealing with the problems and levels of complexity inherent in understanding the various aspects of perceiving (Albertazzi et al., 2011, in press; Koenderink, 2011, in press).

However, recent years have seen increasing consensus that phenomena belonging to open systems, such as biological, psychological, social and artistic ones, remain excluded and/or difficult to analyse in classical psychophysical terms, or according to the widespread notion of information in terms of Shannon theory (Albertazzi et al., 2011, in press). Such phenomena are not easily computed, and they exhibit a hyper-complexity characterized by predictive structures, internal semantics and adaptability to surroundings. This has become particularly evident in attempts to model human perceptual and cognitive structure and capacities. Despite awareness of the problem, both historically and since the AI revolution, no general theory or approach has been put forward to complement the essentially Galilean paradigm dominant in all kinds of scientific inquiry.

The analysis reported by this thesis started from how people 'experience' perception, particularly visual perception, seeking to show that visual appearances constitute the primary level of meaning in the phenomenal field.

The phenomena studied were primarily amodal completion, some aspects of colour appearances, and their interrelations in amodal surfaces, giving that these are the least studied phenomena in this field of research.

Following a series of other exploratory studies in this area of research and currently in development (Albertazzi et al., submitted) and considering their first positive results a second inquiry – the experiment reported in chapter 4 – was conducted on the morphological aspects of natural shapes, and their interrelations with colour appearances, such as their warm/cold characteristics. The second experiment was more ambitious and challenging than the first one, because it was conducted with the intention of testing a diverse and complementary guiding idea in science recently labeled the 'Goethean approach' by some eminent vision scientists (see again Koenderink, 2011, in press).

As mentioned, the inquiry started from the following questions (see introduction). In the first experimental study, on the interrelation between amodal surfaces and colour appearances, the research focused on whether a particular colour could influence the dimensional effects of a partially occluded surface, and how this happened. Also investigated was how the experimental subjects assigned the boundaries between the parts of the a partially occluded surface, the purpose being to understand the mechanisms of colour influence in this process.

The results showed a significant difference between the two groups, a strong effect due to the occluder position, and a colour effect on the expansion and shrinkage of shapes. An interesting finding concerns the way in which each group selected the position for a boundary between the two coloured parts of the rectangle: one group paid more attention to the lightness condition of colour; the other to the spatial configuration. The results also showed that the subjects' answers disagreed with the support ratio principle, according to which subjects expand the longer part, putting the boundary near the smaller one – at least regarding the completion of contours. It was seen that this principle does not apply with surface completion, although some more studies should be conducted to confirm this finding.

In the second experimental study, on the supposed 'natural' relation between shapes and colours, the research interest was the characteristics that could explain the belongingness of a shape to a specific colour, particularly the influence of orientation, type of shape, margin, texture and dimensionality. Also investigated was whether if the subject's judgment about figure characteristics, in terms of hard/soft, strong/weak, beautiful/ugly and warm/cold, could explain the relation between colour and shape.

The results showed the existence of a significant association between colours and shapes due to certain figural characteristics (aspects like the presence of sharp points or rounded margins) and colour aspects (particularly warmness and coldness). Some figures exhibited positive associations with particular groups of colours, and negative associations with other groups, reinforcing their belongingness to a particular dimension of colour. Accordingly, the figures could be divided into cold and warm groups. A secondary but also important finding was that the subjects' judgments grouped the figures into two main groups: the hard, strong and cold group, and the soft, weak and warm group. The figures shared the beautiful/ugly dimension, the latter being more associated with hard, strong and cold figures.

It is too early to conclude that this approach will be successful in research, specifically in vision science, but the exploratory work conducted holds out good prospects for more detailed and designed experiments and analyses in the future. Other experiments in this line of inquiry, in fact, are already in progress.

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