LIGHTNESS EFFECTS OBSERVED IN DELBOEUF-LIKE DISPLAYS

Settore scientifico-disciplinare M-PSI/01 Psicologia Generale

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ANNO ACCADEMICO 2009/2010
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Preface

..the moment at which man lives most fully is when he is seeking something...

F.M. Dostoevsky

With this work I am nearing the end of my doctoral research study. My research interests primary focus on visual perception. In particular I am interested in phenomena and processes related to lightness-brightness, contrast-assimilation, and figure-ground segmentation. My research interests also include the development of a psychophysical model that can account for the perception of illumination and luminosity. Some of the works I carried out during my dissertation, in collaboration with Prof. Tiziano Agostini and Dr. Daniele Zavagno, are dedicated to methodological and practical issues arising from the problem of the matching method with achromatic Munsell scales. Finally, I developed also a strong interest also towards experimental studies on visual illusions. As a result of my three years of research, I served both as primary author and as co-author in a number of publications, some of which are quoted in the present work. With all my scientific interests, it was not so easy to single out an argument for my doctoral thesis. My choice fell on an argument that bridges most of my scientific interests, while being also the one that, in my opinion, is the most developed.

The present work is about lightness effects observed in the modified Delboeuf size-contrast displays. In one of its classic forms, the Delboeuf illusion consists of two equal inner disks (targets) surrounded each by a concentric circle (inducer) that differs in size (1865). The size-contrast illusion consists in the phenomenal size difference between the two targets physically equal: the target surrounded by a small inducer appears somewhat bigger than the identical target surrounded by a big inducer. It appears that the Delboeuf display has also an affect on other features; for instance, on lightness. It was observed that the two identical targets within the Delboeuf configuration appear not only different in size but also different in lightness (Brigner, 1980; Zanuttini and Daneyko, 2010). Yet, the lightness effects reported by Brigner and by Zanuttini and Daneyko go in opposite directions: Brigner reported darkening effects, while Zanuttini and Daneyko reported a lightening effect.
In the following study I addressed the issue of the direction of the lightness effects in Delboeuf size-contrast displays, and I investigated the possible variables that determine such effects. In particular, I focused on the interaction between aspects such as lightness and depth perception, lightness and belongingness, and lightness and size. I also considered several current theories on lightness perception, from recent edge integration models to the Anchoring theory.

I wish here to thank my supervisor Prof. Tiziano Agostini and my co-supervisor Dr. Daniele Zavagno for all their assistance and guidance during the past three years. Special thanks to Daniele Zavagno who first interested me in the problem of visual perception, and who made me reformulate a number passages of this dissertation so that the argument will be meaningful not only to me, but also to those who might take the trouble to read my work.

I am grateful to Prof. Lucia Zanuttini for involving me in her research project, from which my own project originated. Without her this work would simply not exist.

Many thanks also go to Prof. Kenzo Sakurai for his warm welcome in his laboratory during my stay in Japan. It is thanks to his equipment that I was able to carry out some important parts of my research. My thoughts also fly to Sendai and to Japan in general, hit by a series of unfortunate disasters. Having lived there, sharing their culture and ways of life, I cannot but participate to their sorrow and lost.

Finally, I am indebted towards Prof. Natale Stucchi, who was always patient with me while teaching me how to program my experiments with Matlab.


Introduction

*Illusions have the same effect on psychologists as the smell of burning rubber on an engineer: an irresistible urge to find the cause*

Peter Medawar

**Visual illusions as research tools in perception**

Visual illusions are loved by everyone. To the layman, illusions are just ‘tricks’ that show how our perception can be easy manipulated by a cool work of design. The word ‘illusion’, in fact, derives from the Latin word *illusio*, which means mockery or lie (Ushakov, 1935). Taken literally, the term ‘illusion’ therefore refers to an error or something regarded as false. Let’s see how the word “illusion” is defined in the scientific field by some psychologists:

- “Illusions are systematically *non veridical perceptions* of environmental objects and events” (Palmer, 1999, p. 714);
- “When a perception departs from the *external world*, to disagree with *physical reality*, we say we experience an illusion” (Gregory, 1998, p. 194);
- “An Illusion is a confused perception resulting from the introduction of elements able to break up the usual pattern of the experience.” (Garrett, 1955, p. 177).

As one can readily see, the definitions suggest that illusions are *failures* of the visual system. Indeed, illusions are commonly interpreted as misleading images presented by visual stimuli, or erroneous perceptions of reality. Both interpretations imply that under certain conditions we do not see what we should see: the reality of the physical world.

Here I will introduce two distinct domains: *physical or external world* and *phenomenal world*, since it is customary and also important in the field of visual perception to distinguish one from the other. *Physical or external world* refers to “the system of objects external to the human consciousness that is thought to be responsible for (among other things) the sensory experiences human beings commonly have” (Aune, 1991, p.1). It is not so easy to describe in simple words what the physical reality is actually like, because it is something external to us, something that we seem to experience only through our senses. In addition to this fact, there are also *things* that exist of which we have no experience, despite they coexist with us in the physical world, and within the physical
world they are “real”.

The term *phenomenal* refers to any observable occurrence (New Oxford American dictionary, 2005). The phenomenal world is contrasted to the physical world, physical reality, physical domain, etc.: it includes the set of sensorial experiences, a reality that is distinct and different from the physical reality, which energy is capable of stimulating our sense organs. (Metzger, 1971; Ronchi, 1970). Thus, it appears that the phenomenal world is the only true nature of the world we find ourselves living in.

It is commonly thought that the phenomenal experience is the counterpart of the physical world. However things are not as clear as they seem. To put it simple, physical objects belong to the physical world, percepts corresponding to them are instead properties of the phenomenal world. The link between the physical and the phenomenal worlds has been studied for many decades by a great number of scientists, but it turns out that for how much we already know, we still know little. Since percepts, likewise physical objects, have (approximately) constant features such as shape, size and so on, some scientists, for instance Max Scheler, assumed a direct, extrasensory connection between objects and percepts (cited by Metzger, 1974), others instead consider that the phenomenal world is very likely never directly related to the physical reality or, at least, their relation does not correspond to a one-to-one ratio. For instance, already in the 19th century Kant stated that objective truth does not exist because the human mind is not capable of understanding the physical world. He denied any relationship between how we perceive the physical world and what it really is, formulating the absolute subjectivity hypothesis (Watson, 1908). Similarly Addington (1928, p. 27) wrote: “…the physical world as an intrinsically constructed out of the distances, forces, and masses which are seen now to have reference only to our own specific reference frame, we are far from a proper understanding of the nature of things…” If the phenomenal world is not exactly the reflection of the physical world, then how can we know whether our percepts are “right” or “wrong”? If we cannot actually see the physical world as such, is it correct to consider illusions as “erroneous interpretations” of reality (Helmholtz, 1910)? Yet, although the relationship between what we see and what we should see is not identified properly, nowadays we can confidently state one thing: a man is a phenomenal creature and his phenomenal world is nothing more but the *reconstruction* or *representation* of the physical world “created” by the human mind. It is this act of creation, however, that guarantees our survival in the physical world. Hence, whether our perceptions correspond to the actual physical world, or are mere illusions, is a rather trivial matter. If we cannot know a priori what the physical world is, it
appears that we actually have no way to know whether we see things “right” or “wrong” (Daneyko & Zavagno, 2008) and in some sense, philosophically speaking, it would be not so wrong to assume that all our visual experience of the physical world is just an illusory image in our mind. Sometimes we recognize that something is perceived “wrong”, like illusions, because we measure and compare stimuli, but sometimes we cannot even realize whether our perception corresponds or not to an illusion, because a certain dimension just cannot be matched or has no counterpart in the physical world, as, for instance, the colours of objects. What is the point then to consider illusions as errors?

Despite most vision scientists consider illusions as errors, erroneous judgments, or even failures of the visual system, I consider as both an epistemological and ontological mistake to think that peculiar visual outcomes of some physical stimuli are just errors. It is instead more reasonable and epistemologically profitable to consider that every part of the phenomenal world (including illusions) is the product of our perceptual systems, created in such a way so that we can behave effectively and conveniently inside of the physical world and, thus, survive, avoid, or at least minimize the dangers we may face. To Gregory (1968, p. 286) “The illusions… are not due to contingent limitations of the brain, but the result from the necessarily imperfect solution adopted to the problem of reading from images information not directly present in the image”. Gregory believed that perception of illusions are related to higher processing mechanism and can be achieved through learning. Gregory’s hypothesis is supported by an anthropological study (Segall et al. 1966) where an almost total absence of illusions was found in a case of adult recovery from infant blindness (Gregory and Wallace, 1963).

Whether visual illusions are products of evolution (nature) or the result of learning processes (nurture) is still a matter of debate. However, in one way or another the brain seems to create the phenomenal world that appears to function according to its own specific rules. What are the working rules behind illusions? What do illusions tell us about perception? Researching the factors that determine the presence of illusions can aid our understanding and appreciation of the nature of the phenomenal world. Indeed, illusions may contain crucial clues about human perception.

In fact, especially starting form the 19th century, visual illusions have been systematically used as a scientific test instrument in the study of visual perception in order to understand how the visual system operates.
The Delboeuf size-contrast illusion

The best known and the most studied are those illusions known as geometric-optical. The term, translated from the German *geometrische-optische Täuschungen*, is commonly used to refer to illusions created with lines and geometric figures. Among these illusions there is also a size-contrast illusion first published by Franz Joseph Delboeuf (1831-1896), a Belgian mathematician, philosopher, psychologist and expert in hypnosis (Fig. 1). His first publication on geometric-optical illusions appeared in the Bulletin of the Royal Academy of Belgium (Delboeuf, 1865a) and it was dedicated to the discussion of some general principals to account for Zollner’s illusion (in its classic form of parallel lines that do not appear parallel, 1860). In doing so he proposed a psychophysical theory concerning the way the eye evaluates distances and angles. In his second publication on visual illusions, Delboeuf discussed his hypothesis with reference to geometric-optical illusions (Delboeuf, 1865b) that now bear his name. In one of his original configurations, the apparent sizes of physically identical disks are modulated by the sizes of outer concentric circles: big concentric circles make inner disks (white or black in his original figures) appear smaller (Fig. 2, left part), while small concentric circle make inner disks appear bigger (Fig. 2, right part).

Figure 1. Franz Joseph Delboeuf (1831-1896), Belgian philosopher, psychologist and expert in hypnosis.

Figure 2. Example of some of Delboeuf’s original drawings (1865b). A comparison between the left and right configurations determines a contrast effect: the left disks concentric to a large circle look smaller than the same size right disks concentric to a small circle.
**Historical sketch**

After Delboeuf’s last publication on his novel size effect, many studies have been carried out to understand the role played by the spatial, photometric, and also temporal factors that influence the direction and the magnitude of this size-contrast illusion. In the classic Delboeuf displays (1865b), two identical disks are perceived to be different in size when they are surrounded by concentric circles which actually differ in size: the disk surrounded by a small concentric circle appears somewhat bigger than the disk surrounded by a large concentric circle (Fig. 2). A possible account for the size-contrast illusion claims that the apparent size of each disk depends on its relative area and on that of its surrounding circle. Delboeuf was actually the first who hypothesized that “there is a ring diameter that produces a maximal effect that can be determined by experimentation” (Cited in Nicolas, 1995). Morinaga (1935) was the first to actually demonstrate the size-ratio factor between inner and outer circles when maximum underestimation and overestimation occurs. He obtained the following results: the maximum overestimation of the smaller (inner) circle (size-assimilation) when the size-ratio between outer circle and inner circle was 3:2; the maximum underestimation (size-contrast) when instead the size-ratio between outer and inner circles were approximately 5:1 or 6:1. His results were confirmed by Ikeda and Obanai (1955), Ogasawara (1952), Piaget, Lambercier, Boesch, & Lambertini (1942), Weintraub, Wilson, Greene, & Palmquist (1969). It should be noticed that in the experiments conducted by Morinaga, by Ogasawara, and by Ikeda and Obanai, the inner circle was compared to the circle with no surround, while Piaget et al. appear to be actually the first to employ configurations consisting of identical inner circles viewed simultaneously, each surrounded by a concentric circle that differs in size.

According to some studies (Jaeger & Long, 2007; Jaeger & Lorden, 1980) both the magnitude and the direction of the illusion can be altered by luminance contrast ratios between the concentric circles (inducers) and the disks (targets). Others found instead that the luminance of the inducers is not an effective variable for the size-contrast illusion (Cooper & Weintraub, 1970). Also Oyama (1962), in his systematic work on the effect of luminance and hue on the magnitude of Delboeuf’s size illusion, found that there are no significant interactions between the luminance of the inducers and that of the targets; he also reports that the magnitude of the illusion does not depend on variations in hue. He instead reported that the magnitude of the size illusion is a function of the luminance contrast between inducers and background: the illusion is greater with higher contrast.
Similar findings were also reported by Wada (1956) and by Weintraub and Cooper (1972).

**A new effect observed within modified Delboeuf size-contrast displays.**

Delboeuf’s size-contrast illusion was found to have an effect also on other visual features. Vicario (1972), for instance, showed that the illusion has an effect on the perceived density of textures: when two identical textured targets become part of a Delboeuf-like display, the target that looks bigger appears also to be more rarefied in its texture (Fig. 3). Similarly Jaeger and Long (2007) reported that the Delboeuf illusion can be created with circumscribed letters. For instance, when letters are surrounded by a small concentric circle, their size was overestimated, but a large surrounding circle reduces the illusion.

Brigner (1980) investigated the effects of perceived size on brightness (Brigner used the term *brightness* to indicate achromatic surface colour) in both the Delboeuf and the Ebbinghaus displays. In his experiment with modified Delboeuf displays, he employed two physically equal grey disks each surrounded by a concentric circle that differed in size. These configurations were seen against either dark or bright backgrounds. He found an increment in brightness with the disk that appeared smaller. In other words, independently on the contrast polarity between disks and background, the disk that appears bigger (surrounded by a small concentric circle) appears also always darker than the disk that appears smaller (surrounded by a large concentric circle).

Zanuttini & Daneyko (2010), however, observed recently in Delboeuf’s size-contrast illusion that when the disks are lighter than the background, the perceptually

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1 I call the configurations employed by Brigner ‘Delboeuf–like displays’ or ‘modified Delboeuf displays’ for one simple reason: in the original Delboeuf drawings (1865b), the inner disks are either white or black with either white or black surrounding circles. Brigner, instead, used grey disks with light and dark concentric circles in his configurations.
larger disk (surrounded by a smaller concentric circle) appears somewhat lighter than the other disk (surrounded by a bigger concentric circle) (Fig. 4).

Figure 4. Modified from Brigner (1980). The two grey disks are equal in size and in luminance. However, the grey disk surrounded by a small concentric circle appears bigger and also darker than the disk surrounded by a big concentric circle.

Since the results reported by Brigner (1980) and by Zanuttini & Daneyko (2010) are in contradiction, I will start my investigation with an experiment that clarifies the direction of the achromatic colour phenomenon observed in the Delboeuf-like displays; then I will proceed investigating the factors that might account for the differences in lightness observed in Delboeuf’s size-contrast illusion.

Figure 5. Modified from Zanuttini and Daneyko. (2010). The two light disks are physically equal. The disk surrounded by a small concentric circle appears bigger and also lighter than the disk surrounded by a big concentric circle.

**Lightness: terminology and research issues.**

Since the present study is an investigation of a new phenomenon observed within Delboeuf-like displays concerning a differentiation in the shade appearance of two identical grey targets affected by the size-contrast illusion, the primary focus of the present study lies within achromatic surface colour perception. The technical word for the perception of a surface seen as black, white, or any shade of grey is *lightness*. The physical
counterpart of lightness is reflectance, a fairly stable property of a physical surface that indicates the percentage of luminous energy reflected by a surface independently from the absolute amount of luminous energy hitting the surface. For instance, the reflectance of a good black surface is about 3% while the reflectance of a decent white surface is about 90%. A fact that the visual system must face is that a white surface in shadow and a black surface in sunlight can reflect to the eyes of an observer the same amount of luminous energy, or it could even occur that the black surface reflects actually more energy. This because the amount of luminous energy reflected by a surface that reaches the retina (luminance) is the product of both the reflectance of that surface (which is a constant unite) and the absolute amount of energy it receives (which is a variable unite). The formula describing this fact is $L=R \times E$, where $L$ is luminance, $R$ is reflectance, and $E$ is the intensity of physical illumination insisting on the surface. Despite that the information (luminance) delivered by white and by black surfaces could be the same, still a white surface is usually perceived as white and a black surface as black, independently of the amount of luminous energy reflected to the eye. This fact is known as lightness constancy, a very problematic dimension that is still not completely understood. For instance, we may see surfaces of a certain lightness even when these do not have an immediate counterpart in the world surrounding us: it’s the case of surfaces represented in television. Or a same surface may appear brighter or darker depending on its immediate surround, as demonstrated by the illusion known as simultaneous lightness contrast (Fig. 6). Thus, our perception of a surface colour is related not only to the amount of energy reflected or emitted by a particular surface, but it must also depend on many other factors.

![Figure 6. Simultaneous lightness contrast: the two grey targets are physically equal. However, the grey target (left) on the black background appears lighter that the target on the white background.](image)

The question therefore is the following: how does the visual system compute the lightness of a given surface and what mechanisms are responsible for it? To our knowledge, human lightness computation is not perfect: this means that lightness changes
can be caused by different factors, such as changes in the level of illumination (illumination-independent constancy) or changes in the background of a surface (background-independent constancy, Fig. 6) or, indeed, by the combination of the both factors (Gilchrist, 2006). Nevertheless, lightness constancy operates well enough in most of the natural situations.

There are several situations that testify the relative “fragility” of lightness constancy. For instance, the well-known simultaneous contrast display is a vivid example of a lightness constancy failure (Fig. 6), in which two squares have the same luminance/reflectance but they appear slightly different in lightness: the square on the black background appears lighter than the square on the white background. Textbooks commonly explain the illusion in terms of a physiological mechanism known as a lateral inhibition. Lateral inhibition refers “to an architecture for neural networks in which neurons inhibit spatially neighbouring neurons” (Palmer, 1999, p. 717). In short, the receptor cells stimulated by the grey target on the white background are strongly inhibited, because the receptor cells stimulated by the white background are much more active than those activated by the black background, which therefore exert less inhibition on the cells that respond to the target on the black background. Hence, the target on the white background should appear darker than the target on the black background. There are, however, other explanations for the illusion, for instance the one based on the Anchoring theory (Gilchrist, 1999), according to which the lightness of each target is computed relative to the highest luminance of its local framework and relative to the highest luminance of the entire scene (the global framework). Such computations determine that the target on the white background is always middle grey because the anchor is the white background. On the other hand, the target on the black background is the highest luminance in the local framework, thus it is locally computed as white, but it is not the highest luminance in the global framework, hence due to weighted averaging between its local and global lightness assignments, the lightness of the target on the black background should appear lighter.

The object and the hypotheses of the study

The lightness effects observed in Delboeuf-like displays are other demonstrations of lightness constancy failures: the amount of luminous energy reflected (or emitted, when
viewed on computer screens) by the two physically equal disks is the same, yet the disk that appears bigger seems to appear also somewhat different from the other in lightness. Understanding how the visual system computes the lightness of the two disks, researching the factors that drive the lightness effects in the Delboeuf-like displays, is yet another small step toward our knowledge about the mechanisms behind achromatic surface colour perception. Since the reports concerning the lightness effects observed in Delboeuf-like displays are contrasting, the first step to be taken is to verify the consistency of the effects reported in relation to different factors, such as the contrast ratios between size-targets and backgrounds, size-targets and size-inducers, and size-inducers and backgrounds.

Once the facts about the direction of the illusion have been established, it will be possible to consider also the influence of higher-order variables on the illusion, such as perceived size and perceived target distance. In fact, the effects reported cannot be caused by physical changes in the level of illumination or by the changes in luminance of the backgrounds, factors which were held constant within configurations and between targets.

The final goal of my work is to verify whether there is a correlation or any other kind of relationship between the size illusion in Delboeuf-like displays and the lightness effects reported, the direction and consistency of which are the arguments of the next chapter.
Chapter I

Experiment 1: Brigner vs Zanuttini and Daneyko

Brigner (1980) was the first to observe a lightness effect in Delboeuf’s size-contrast illusion. He employed configurations in which two disk-targets were presented simultaneously, and he found that the disk that appears bigger appears always darker, independently from the direction of the contrast ratio between targets and background. However, a study reported by Zanuttini & Daneyko (2010) shows that when two targets are luminance increments to their background, the target that appears larger (surrounded by a small concentric inducer) appears also lighter than the target that appears smaller (surrounded by a big concentric inducer). These results are in contradiction with those reported by Brigner.

The goal of experiment 1 was to verify the direction of the lightness effects observed in Delboeuf-like displays.

1.1 Experiment 1

The previous study (Zanuttini & Daneyko, 2010) only employed white disks on darker backgrounds. In the following study I employed stimuli similar to those used by Brigner (1980): grey disks (targets) on either dark or light backgrounds. Hence the two targets viewed simultaneously in Delboeuf-like displays were either luminance increments or decrements with respect to the background. The purpose of the experiment was both to confirm the existence of lightness effects within Delboeuf size-contrast displays, and to verify the direction of the effect. There are four possible outcomes:
- no lightness effects, meaning that the findings reported in previous studies are just occasional and dependent on specific configurations or experimental set-ups rather than actual phenomena;
- the increase in perceived target size is accompanied by an increment in its lightness, in other words, the target that appears bigger appears also lighter;
- the increase in perceived target size is accompanied by a decrement in its lightness, meaning that the target that appears bigger appears also darker;
- the lightness of increment and decrement targets is affected in an opposite way in Delboeuf-like displays: for instance, the decrement target that looks bigger will also look darker with respect to the decrement target that looks smaller, while instead the increment target that looks bigger will also look lighter then the increment target that looks smaller, or vicevers.

1.1.1 Participants

Twenty-nine graduate and undergraduate students (20 female and 9 male, age 18-33) from the University of Milano-Bicocca volunteered to take part to the experiment. All participants had normal or corrected-to-normal vision and all of them were naïve with respect to the purpose of the study.

1.1.2 Materials

Stimuli consisted in two targets, one surrounded by a large concentric circle, the other surrounded by a small concentric circle, presented either on a dark or a bright background. Configurations measured 21×7.5 cm (l×h, 10.43×3.76 deg) and were printed on heavy weight matte paper with an Epson Stylus Photo R2400. Disk targets (T) measured 2 cm in diameter (1 deg); the small and the large outlined concentric circles (inducers, line width=0.2 cm) measured respectively 3.2 cm (1.6 deg) and 5.2 cm (2.6 deg) in diameter. The width of the gap between T and inducer measured 1.34 cm (0.67 deg) with large inducers and 0.35 cm (0.17 deg) with small inducers. Disks were viewed in pairs; each disk in a configuration could have one of the following luminance values: 136, 145, 158, 167, 171, 178, 200 cd/m²; background luminance was either 45.7 or 444 cd/m². On the dark background inducers’ luminance was 444 cd/m², on the bright background it was 45.7 cd/m² (Fig. 1.1). The combination of disk luminance and background luminance determined 49 pairs of targets for each background.
1.1.3 Procedure

Stimuli were presented at the distance 114 cm in random order in a dim room, and were illuminated by a spotlight directed on the stimuli (Fig. 1.2). Stimuli were viewed only once and they were randomly presented right side up or upside down, meaning that the disk that appeared bigger could be either on the left or the right side of a configuration. A forced-choice task with a within-group design was employed. Participants were instructed to indicate in each configuration which disk was darker, (left or right?).

1.1.4 Results

Figure 1.3 displays the results for increment and decrement targets grouped by luminance comparisons. Table 1.1 displays the results of chi-square tests performed on the data from those configurations in which targets had equal luminance.

Figure 1.1. Example of the modified Delboeuf configurations used in experiment 1: increment targets (top) and decrement targets (bottom).
Figure 1.3. Results for experiment 1 grouped by the luminance of T surrounded by small inducers. Black squares indicate decrement targets, grey squares increment targets; large squares indicate configurations in which two targets had the same luminance.

Increment and decrement targets determine opposite results when targets are equal in luminance: the target that appears bigger appears lighter when it is an increment to a dark background, and darker when it is a decrement to a bright background. This finding can also be summarized as follows: in all configurations with Ts of equal luminance, the
target surrounded by a small inducer was always seen as more contrasted to the background.

Table 1.1. Chi-square tests (df=1; p-values with Bonferroni correction for target pairs of equal luminance)

<table>
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<th>145</th>
<th>158</th>
<th>167</th>
<th>171</th>
<th>178</th>
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<tr>
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<td>χ²=18.24</td>
<td>p&lt;.0007</td>
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<td>χ²=18.24</td>
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<td>χ²=21.55</td>
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<td>p&lt;.0007</td>
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1.2 Discussion

Results for increment targets (Fig. 1.1 top) are consistent with those obtained by Zanuttini & Daneyko (2010), who only employed pairs of incremental targets, but not with those reported by Brigner (1980), who employed both pairs of incremental and decremental targets. In a nutshell, when a pair of targets in a stimulus have the same luminance, the target that appears bigger appears also lighter. Brigner instead reported the opposite, that is when a pair of targets in a stimulus have the same luminance, the target that appears bigger appears instead darker, independently from the contrast sign between targets and background. Brigner’s results were confirmed instead with decrement targets (Fig. 1.1 bottom): when targets are equal in luminance, the target that appears bigger appears also darker. Thus, it appears to me that Brigner failed to notice the role played by the contrast sign between targets and background in the lightness outcomes: the target that looks bigger appears also darker only when it is a luminance decrement to the background; vice versa, when the targets are increments, the target that looks bigger appears also lighter.
Chapter II

Testing the role played by the luminance values of the size inducers

In experiment 1, when a pair of targets was equal in luminance, the target that appeared bigger appeared also darker when it was a luminance decrement to the background, and lighter when it was a luminance increment. It is useful to underline that increment targets were surrounded by inducers that were luminance increments to both the background and the targets, while decrement targets were surrounded by inducers that were luminance decrements to both the background and the targets. What is the role played by the luminance of the size contrast inducers on the lightness effects reported in exp. 1?

There are several studies on the effect of luminance on the direction and magnitude of Delboeuf’s size-contrast illusion. Some studies concluded that the luminance of the inducers is an ineffective variable (Cooper & Weintraub, 1970). Jaeger and Lorden (1980) reported effects arising from the manipulation of contour luminance. Jaeger and Long (2007) reported similar effects in configurations in which the target consisted in a letter (either A or S). They reported that the size illusion is stronger when the luminance contrast between inner circle and outer circle is higher and the contrast between background and inner circle is lower. However, there appears to be little rationale concerning the influence of inducer-target luminance contrast in their pattern of results.

Oyama (1962), in his systematic work on the
effect of luminance and hue on the magnitude of this size illusion claimed that there are no significant interactions between the luminance of the inducer and that of the target circle. He instead reported that the magnitude of the size illusion is a function of inducer-background luminance contrast: the illusion is greater with higher contrast. Similar findings were reported by Wada (1956), Weintraub and Cooper (1972).

A part from somewhat contradictory findings in the literature, I must point out that the stimuli employed bare little structural resemblance to my configurations. In the studies by Oyama and by Jaeger and Lorden, for instance, a circle (target) surrounded by an outer concentric circle (inducer) is compared to a circle of equal size with no surrounding inducer. This appears to be the modern version of Delboeuf’s size-contrast illusion used commonly to study the effect (Nicolas, 1995).

Summarizing, according to some literature a modification in luminance contrast between inducers and background (Oyama, 1962), or inducers and target (Jaeger & Long, 2007; Jaeger & Lorden, 1980), should affect the magnitude of the size illusion: higher contrast should increase the magnitude of the illusion, lower contrast should reduce it. Therefore, if the lightness effects observed in the previous studies depend on the illusory size effect, then a reduction in luminance contrast between inducer and background (Oyama, 1962) should reduce or nullify such lightness effects since the size-contrast effect should also be weaker. No clear predictions are instead derivable concerning the effect of inducer and target luminance contrast.

Leaving aside the controversial behind the effects of the luminance components on Delboeuf’s size-contrast illusion, one can probably try to explain the lightness effects of exp. 1 with reference to lightness contrast and assimilation literature. In particular, the results of exp. 1 could be described in terms of assimilation effects: the contrast sign between inducer and target affects the lightness of the target surrounded by a small inducer. In other words, a dark inducer makes the small target look darker, and a light inducer makes the small target look lighter. According to this account, the key features we ought to consider are the contrast sign between inducers and targets and the relative proximity of an inducer to its target.

What does assimilation literature have to say about the role of proximity between lightness inducers and the lightness appearance of targets? I searched the literature for an answer but I was unable to find any direct reference to the role played by proximity in lightness assimilation effects. Nevertheless, classic assimilation studies (Bezold, 1876; Helson, 1963; Helson & Joy, 1962; Newhall, 1942) employed stimuli with high frequency
luminance profiles, which in some sense can be described also in terms of target-inducer proximity. However, in all classic assimilation displays ‘inducers’ and ‘targets’ are actually adjacent (Fig. 2.2). If the effects reported in exp. 1 are of a lightness assimilation nature, then the direction of the effects should be reverted if one changes the contrast sign between inducers and targets, independently of the luminance of the background. In other words, if the luminance of the inducers is an increment to the targets, then the target surrounded by a small inducer (higher degree of proximity) should appear lighter on both a dark and a light background. Vice versa, if the inducers are luminance decrements to the targets, then the target surrounded by the small inducer should appear darker on both light and dark backgrounds.

Finally, the observed lightness effects could be also accounted for in terms of an edge integration model (EIM). If so, those effects would be a case of ‘induction-induction effect’ caused by multiple inducers. According to an EIM, the Delboeuf-like displays used in the previous study would comprise two sets of inducers: two remote inducers (in my case the size-contrast inducers, alias circles) and two local inducers (the portion of background shaped like a ring surrounding the target). The story could go roughly as follows (Fig. 2.3): the remote inducers cause the darkening (dark backgrounds) or the brightening (bright backgrounds) of the local inducers, which would then affect the appearance of the targets. In my stimuli, the lightness difference between the two targets of equal luminance would be caused by the width of the local inducer: a small width should facilitate brightness filling-in (Rudd & Arrington, 2001). The small local inducer would be therefore either darker or lighter than the large local inducer, depending on the contrast polarity between remote and local inducers. This difference would then translate to the target surrounded by the small local inducer (Rudd & Zemach, 2007). Hence, by
manipulating the luminance of the remote inducers one should be able to reverse the lightness effects found in exp. 1. In particular, if one were to change the luminance of the remote inducers in Fig. 2.2 from decrements to increments to the local inducers, the model should predict that the target surrounded by a small inducer appears lighter. In this sense, predictions based on EIM are equal to those based on a more simple assimilation account. According to other studies, instead, contrast is expected when the contrast polarities between sets of edges are similar; when instead contrast polarities are opposite, “partial assimilation” is predicted (Vladusich, Lucassen & Cornelissen, 2006). This means that assuming the background is an increment to the target, one would expect the target surrounded by a small inducer to appear darker when the inducer is a luminance increment to the background, while the effect should reverse or disappear (partial assimilation?) when the inducer is a luminance decrement. Hence, the two different takes on edge integration would roughly predict the same outcomes.

2.1 Experiment 2

In one way or another, for all the aforementioned accounts the luminance of the size-contrast inducers is a critical feature. Hence, in experiment 2 I manipulated the luminance of the size-contrast inducers in Delboeuf-like displays otherwise similar to those employed in exp. 1: for both incremental or decremental targets, inducer pairs were either both black, white or middle grey (Fig. 2.4). According to aforementioned possible explanations, these manipulations should produce different results.

2.1.1 Participants
Twenty-one participants from Tohoku Gakuin University in Sendai (age 17-55, 10 female, 11 male) volunteered to take part to the experiment. All participants had normal or corrected-to-normal vision.

2.1.2 Materials
Stimuli (Fig. 2.4) were similar to those employed in experiment 1 except for the following features: i) targets had all the same luminance (60.5 cd/m²); the luminance of pairs of inducers (concentric circles) was 186 (white), 60.5 (middle grey), or 10.6 cd/m² (black)
on both dark (15.8 cd/m²) and bright backgrounds (157 cd/m²). The combination of inducer luminance and background luminance determined 6 configurations labelled as follows: iW, iG, iB, dW, dG, and dB (Fig. 2.4).

2.1.3 Procedure
Stimuli were presented in a dim room, viewed at a distance of 114 cm. Illumination was provided by a theatrical spotlight pointed on the stimuli (Fig. 1.2). Each stimulus was placed on a self-adhesive cork poster board mounted on a perpendicular wooden panel. Outlined corners were drawn on the board to secure correct placement of the stimuli throughout the experiment. Stimuli were viewed only once and they were randomly presented right side up or upside down, meaning that the disk that appeared bigger could be either on the left or on the right side of a configuration. A forced-choice task with a within-group design was employed. Participants were instructed to indicate in each configuration which disk was darker, (left or right?).

2.1.4 Results
Figure 2.5 displays the results for experiment 2. As one can readily see, the luminance of the inducers does not affect the direction of the illusion. Chi-Square tests (df 1, N=21) were carried out confirming a significant difference between the lightness appearance of each pair of targets: df=1, χ²W=8.05, p<0.005; χ²B=5.8, p<0.05; χ²G=5.8, p<0.05; χ²iW=13.8, p<0.0001; χ²iG=13.8, p<0.0001. Two Cochran’s Q tests were carried out to verify whether the proportions were the same across configurations with a same background luminance (df 2, N=21) and different inducer luminance; no significant differences were found: dark backgrounds, Q=0.3, p=0.8; light backgrounds, Q=2.6, p=0.2.
Fig. 2.5. Results for experiment 2: on the left increment targets, on the right decrement targets. Independently of the contrast polarity between size inducers and background, the target surrounded by a small inducer appeared lighter if it was an increment to the background; vice versa it appeared darker if it was a decrement.

2.2 Discussion

The luminance of the size-contrast inducers is not an effective variable for the lightness effects observed: effects are comparable to those obtained in the previous study, regardless of the luminance contrast ratio between “remote” (size-contrast inducers) and “local” inducers (background rings), and regardless of the contrast polarities inside each stimulus. Edge integration models cannot handle these data, moreover, my data limit the possibility to account for the illusion by advocating contrast or assimilation type of explanations. According to a brightness assimilation hypothesis, there should be no lightness difference between targets viewed simultaneously when the inducers and targets share the same luminance, or when the inducers are either increments or decrements respectively to a decrement target or an increment target. Furthermore, these results can be considered a test even for an account based on simple contrast mechanisms, according to which the lightness induction of a target should be positively affected by the proximity of the inducer (Cole & Diamond, 1971; Dunn & Leibowitz, 1961), and which would predict opposite lightness effects when the inducer is either a luminance decrement or increment to respectively increment or decrement targets (e.g. left top and bottom configurations dB and iW in Fig. 2.4; right data points in the two graphs in Fig. 2.5).
As discussed previously, according to some studies the magnitude and the direction of the Delboeuf size-contrast illusion are affected by the luminance contrast either between inducers and the background (Oyama, 1962) or between targets and inducers (Jaeger & Long, 2007; Jaeger & Lorden, 1980). A part from the fact that both studies only employed concentric circles which were always decrements to the background (which was always white, therefore it is impossible to generalize the findings from those size-contrast experiments to account for the data I collected on lightness differences), results are not modulated by any of the contrast ratios. It cannot be said either that the contrast ratios are not different enough among configurations with a same background and different inducer luminance: especially with target decrements (bright backgrounds) contrast ratios are quite different (see Table 2.1). Could it be that the size-contrast illusion was simply not present in the configurations used in exp. 2?

<table>
<thead>
<tr>
<th>iW</th>
<th>iG</th>
<th>iB</th>
<th>dW</th>
<th>dG</th>
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<td>0.2</td>
<td>0.1</td>
<td>0.5</td>
<td>1.7</td>
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</table>

2.3 Experiment 3: is the size-contrast effect still there?

I ran a control experiment to verify whether the size-contrast effect was present in the stimuli employed in exp. 2.

2.3.1 Participants
Eleven members of the psychology department of the University of Milano-Bicocca (age 26-47, 7 female, 4 male), who did not participate to the previous two experiments and who were unaware of the purpose of the study, volunteered to take part to the experiment. All participants had normal or corrected-to-normal vision.

2.3.2 Material
The set of stimuli consisted in those used in experiment 2 (Fig. 2.4). Stimuli were displayed in a viewing chamber at a distance of 57 cm (Fig. 2.6). Luminance values were
the following: targets=13.6 cd/m²; grey inducers=13.6 cd/m²; white inducers=50.27 cd/m²; black inducers=1.7 cd/m²; dark background=3.5 cd/m²; bright background=37.2 cd/m².

2.3.4 Procedure
Targets were presented in random order, right side up or upside down inside of the viewing chamber. Participants were seated in front of the chamber with chair height adjusted to their comfort. Participants inserted their face completely into the mask cavity, which was large enough to accommodate comfortably even subjects wearing glasses. Participants were asked to report which of two targets appeared bigger in a forced choice task.

2.3.5 Results and discussion
Results are displayed in Figure 2.7. As one can see, results confirm the presence of the size-contrast illusion in all configurations used in experiment 2. One of the younger participants commented that the experiment was “too easy” because all of the effects were “too strong”, except in one case (incremental disks with black inducers, iB) for which he indicated the target surrounded by the big black inducer as biggest. While this experiment did not test the magnitude of the size-contrast illusions in my displays, it confirms that the illusion is nevertheless present, thus allowing to hypothesize a relationship between the
size-contrast effects and the lightness differences observed, despite the controversial reports about the effects of the luminance contrast of different features in the Delboeuf size-contrast illusion.

![Graph](image)

**Fig. 2.7.** Results for exp. 3 confirm the presence of Delboeuf's size-contrast illusion in the configurations used in experiment 2.

### 2.4 General discussion

Experiment 3 confirms the presence of Delboeuf’s basic size-contrast illusion in the displays used in exp. 2 to test the role played by the luminance of the inducers on the lightness effects reported in exp. 1. Given that the results of exp. 2 do not show an effect of inducer luminance on the direction of the lightness effects reported, thus ruling out accounts based on edge integration models or lightness assimilation, one might be tempted to rule out also any explanation based on a relationship between perceived size and the enhanced contrast effects between the target that appears bigger and the background. Nevertheless, results from exp. 3 add to the controversial findings about the role of luminance contrast features in Delboeuf’s size-contrast illusion. In addition to this fact, those results do not measure the magnitude of the size-contrast illusion, they only register its presence in the displays. Finally, I ought to consider also that the literature reporting the effects of luminance features on the magnitude of the illusion is not only controversial, but
also based on configurations with only white backgrounds. Hence, a relationship between perceived size and perceived lightness in the configurations employed in experiments 1 and 2 cannot be simply ruled out. But then, if the luminance of the inducers is not a crucial factor for the lightness effects found within Delboeuf-like displays, what is responsible for these lightness effects?
Chapter III

Testing the role played by perceived depth

Results from exp.2 rule out the possibility to account for the lightness effects in Delboeuf-like displays in terms of contrast or assimilation processes, while the role played by the luminance features on the magnitude of the size-contrast illusion is far from being clear. On the other hand, it has been suggested that size-contrast illusions, e.g. the ones by Delboeuf and by Ebbinghaus, are triggered by different factors, including implicit depth indexes (Coren & Girgus, 1975; Girgus, Coren, & Agdern, 1972; Gregory, 1963, 1966, 1968, 1970, 1974; Kristof, 1961; Tausch, 1954; Thiery, 1896).

Gregory explained illusions on the basis of misapplied size-constancy scaling: when mechanisms that help maintain size constancy in the three-dimensional world are applied to two dimensional pictures, an illusion of size sometimes results. Gregory (1966, 1967) pointed out that size constancy normally helps us to maintain a stable perception of objects by taking distances into account. Size constancy mechanisms may however determine visual illusions when applied to objects represented on a two-dimensional surface. He tested his theory on the Müller-Lyer illusion (Fig. 3.1), which consists of two lines of equal length that appear to be of different length because of additional ‘fins’ applied to the ends of lines, which can be directed inward or outward. According to Gregory, we are not necessarily aware that the Muller-Lyer configuration represents three-dimensional structures: the system unconsciously takes the depth information contained in the Muller-Lyer figures into account. He suggested that the combination of lines and ‘fins’ delivers information about concave and convex angles.

Fig. 3.1. The Müller-Lyer (1889) illusion in a ‘natural display’.
(respectively Fig. 3.1 left and right): if these subtend the same visual angle while the depth cues indicate different distances, then the line that in a natural scene would appear more distant should also appear longer, whether differences in distances are actually perceived or not.

Vicario (1972) reported a rarefaction effect concerning physically equal textured targets inserted in Delboeuf contrast rings. He found that the target that appears bigger (inserted inside the small circle) appears also less dense (Introduction, Fig. 3). While he experimentally demonstrated that phenomenal rarefaction and visual acuity are separate phenomena, meaning that real distance displacements of Delboeuf-like stimuli with textured targets does not lead to greater visual acuity (discriminability of the texture elements) of the textured target that appears bigger, still one cannot exclude that behind the phenomenon he reported mechanisms concerning apparent depth are at work. The phenomenon studied by Jaeger and Long (2007) is not dissimilar from that produced earlier by Vicario: they showed that the visibility of a letter is more enhanced when inscribed inside a smaller circle than when inscribed inside a larger one (see chapter 2 for a brief discussion of their findings). Even this effect could be considered as due to constancy mechanisms at work driven by specific field information. In other words, the lightness effects found in experiments 1 and 2 may depend on perceived depth differences between two targets presented simultaneously in Delboeuf-like displays. Nevertheless, Delboeuf configurations can lead to two opposite depth interpretations of the scene: the target that appears bigger appears closer to the observer (a magnification effect), or the target that appears bigger appears more distant (misapplied size-constancy scaling). While the first case seemingly fits more the account proposed by Vicario (1972) to explain the rarefaction effect, the second case cannot be easily used to explain Vicario’s findings, but it can account for the letter effect reported by Jaeger and Long (2007). In particular, one can consider that a low contrast between target and background may constitute depth information. For instance, the further away from the observer, the less contrasted a target will be with respect to the background.

3.1 Experiment 3: which target appears closer?

My first attempt to test whether depth perception mechanisms are involved in the lightness effects found in experiments 1 and 2 consisted in presenting the stimuli used in exp. 2,
asking the participants to refer which of two targets appeared closer.

3.1.1 Participants
Participants were 18 undergraduate students (13 female) from the University of Milano-Bicocca who volunteered to take part to the experiment. All participants had normal or corrected-to-normal vision and were naive to the purpose of the experiment.

3.1.2 Materials
Stimuli were the same as those employed in experiment 2 (Fig. 2.4) with the following luminance values: targets measured 238 cd/m²; light inducers measured 899 cd/m², grey inducers measured 238 cd/m², and dark inducers measured 33 cd/m²; the dark background measured 65.2 cd/m² while the bright background measured 731 cd/m².

3.1.3 Procedure
Stimuli were presented in a dim room, viewed at a distance of 114 cm. Illumination was provided by a theatrical spotlight pointed on the stimuli. Stimuli were viewed only once and they were randomly presented right side up or upside down, meaning that the disk that appeared bigger could be either on the left or on the right side of a configuration. A forced-choice task with a within-group design was employed. Participants were instructed to indicate in each configuration which disk appears closer, (left or right?).

3.1.4 Results.
Figure 3.2 displays the results for experiment 3. Chi-Square tests (df 1, N=18) were carried out, but no significant differences were found for the distance appearance of the targets all configurations: df=1, \( \chi^2_{aw}=2, p=0.157; \chi^2_{db}=2, p=0.157; \chi^2_{ag}=0.22, p=0.637; \chi^2_{iw}=0.889, p=0.345; \chi^2_{ib}=0.9, p=0.345, \chi^2_{ig}=3.556, p=0.06. Nevertheless, in configuration iG (dark background and grey inducer) the target surrounded by a small inducer showed a tendency to appear more in distance.

3.1.5 Discussion
Experiment 3 led to no clear result about the presence of depth differences in two targets viewed in Delboeuf-like displays. Only in one case there was a tendency toward a significant difference between targets on a dark background with grey inducers, with the target appearing smaller having a stronger tendency to be chosen as closer in this forced
choice experiment. The direction complies with the misapplied size-constancy scaling hypothesis, because the target that appears bigger is chosen less times as closer. Nevertheless, the fact that there was no statistical agreement among subjects concerning which of two targets in a display appeared closer allows me to conclude that none of the two targets of a display appear to be explicitly on different depth planes.

![Graph](image)

**Fig. 3.2.** Results for experiment 3: (a) results for increment targets; (b) results for decrement targets.

However, it must be pointed out that exp. 3 required from the observers an *explicit* depth estimation between two targets in modified Delboeuf displays. Gregory (1963) instead spoke about *implicit* depth cues that might never result consciously in the perceptual experience. According to Gregory, such depth cues can be unconsciously taken into account by the visual system. If this were the case, and if the lightness effects observed in experiments 1 and 2 actually depended on implicit depth information then I should be able to determine similar lightness in displays in which I manipulate another depth index: retinal disparity.

### 3.2 Experiment 4: lightness and depth in stereoscopic displays

To test the aforementioned hypothesis I ran an experiment in which instead of using Delboeuf-like displays I used displays consisting in two squares physically equal in size but perceived at two different depth planes, one closer and one more in distance. To achieve this stimuli were viewed through a stereoscope. According to Emmert’s law (1881), the target that appeared more distant also appeared bigger than the target that appeared floating in the front plane.
3.2.1. Participants

Four participants (1 female and 3 male, age 25-55), who were either members or guests of the Psychology Department at Tohoku Gakuin University in Sendai, Japan, volunteered to take part to the experiment. All participants had normal or corrected-to-normal vision. One participant is the author of this study (O), another participant was aware of the purpose of the study (D), while the other two participants were completely naïve to the purpose of the study (P and T).

Fig. 3.3. Example of the stereograms used in the experiment 4. With uncrossed fixation, the left target in the upper displays and the right target in the lower displays appear to be floating in front plane.

3.2.2 Stimuli

Stimuli were stereograms (Fig. 3.3) with target disparities set to ±0.24°. Targets consisted in two grey squares (sides 0.5 cm) seen against a square background (side 6.5 cm) that was surrounded by a random dot frame (width 2.5 cm). The far target had luminance 38.8 cd/m². The near target had one of the following luminance values: 34.3, 35.5, 36.6, 37.4,
38.8, 40.0, 41.1, 42.1, and 43.2 cd/m². The left-right positions of the two targets were balanced. Targets were seen either on a dark (8.5 cd/m²) or on a bright background (98.4 cd/m²). A small red fixation cross was present at the centre of each configuration and it appeared to be floating on a middle plane, coplanar to the random dot frame. The combination of target luminance × background luminance determined 18 configurations, each of which was presented 20 times in random order on a CRT Sony™ MultiScan G520® controlled by an Apple™ MacBook Intel Core Duo 2®. Configurations were viewed at a distance of 61 cm through a mirror stereoscope mounted on a chin-head rest.

3.2.3 Procedure
The method of constant stimuli was used with a forced-choice task: participants were asked to indicate which of two targets appeared darker, the left one or the right one, by pressing a yellow key for the left target or a red key for the right target. The yellow key and the red key were positioned at opposite ends of a keyboard. Participants were first presented with a training task to verify whether they perceived stereo depth correctly. All participants carried out the task easily and quickly without errors. After the training trials, instructions appeared for the actual task; if there were no questions, the participant was instructed to press either one of the two response keys to start the experiment. A pause was set after 5 blocks of trials. Participants were invited to press either one of the response keys when they were ready to resume the experiment. During the experiment each stimulus was presented 20 times. The entire experiment lasted for about 40 minutes, depending on participants’ response times. At the end of the experiment, subjects were asked whether the targets appeared equal in size. All subjects saw the targets in the far plane as bigger than the targets in the near plane.

3.2.4 Results
Figure 3.4 displays the results for increments and decrements for each participant. As one can readily see, all four participants responded practically in the same way when the comparison stimulus (near target) and the standard stimulus (far target) had the same luminance (38.8 cd/m²): with increments, the standard stimulus appeared lighter; with decrements it appeared darker than the comparison stimulus. Furthermore with increment configurations, for participant D the standard stimulus appeared lighter with all comparison stimuli >38.8 cd/m²; for participants O and P the point of subjective equality
corresponded to the comparison stimulus =43.2 cd/m²; for participant T, the PSE corresponded to 42.1 cd/m². With decrement configurations, for participants D and O the PSE corresponded to the comparison stimulus =34.3 cd/m²; for participant P the PSE corresponded to the comparison stimulus =36.6 cd/m²; for participant T the PSE corresponded to comparison stimulus =35.5 cd/m². PSEs are confirmed statistically by binomial tests in which the theoretical proportion of the standard stimulus appearing darker in both increment and decrement configurations was set respectively to 0.6 and 0.4, given that the standard stimulus was physically either more or less intense than the comparison stimulus.

3.2.5 Discussion
In experiment 4 two targets equal in size were seen simultaneously at different depths by means of stereoscopic presentations. When the targets were equal in luminance, the target that appeared in the front plane appeared smaller and less contrasted to the background, independently from whether the targets were luminance increments or decrements with respect to the background. This experiment supports the hypothesis that the lightness effects in the Delboeuf displays might be related to a combination of perceived size and perceived depth.

3.3 Discussing the results with reference to lightness theories
There are different theories and models that seek to model lightness perception. I will discuss the results obtained in experiment 4 with reference to the three different approaches: sensory theories, the anchoring theory, and a gestalt approach.

3.3.1 Sensory theories
Sensory theories for lightness/brightness perception all derive ultimately from the discovery of lateral inhibition processes occurring among ganglion cells (Hartline & Ratliff, 1957): the idea is that sensory cells inhibit one another. Lateral inhibition models claim that retinal proximity is the crucial factor driving lateral inhibitory interactions. According to this model, when two targets equal in luminance are retinally adjacent to the same background, even though they appear at different distances (like the two targets in exp. 4) they should still appear of the same lightness because the neurons whose receptive
fields lie within each target are fired at the same rate given that the luminance of the surround for both targets is the same.

Results of exp. 4 do not support lateral inhibition accounts: more than retinal adjacency, what seems to count in those results is the apparent proximity to the background of the two targets. In fact, the target that appears more distant and bigger, appears also attached to the background and more contrasted to it, while the other target that appears near and smaller, appears also to be floating in front of the background and less contrasted to it.

The latest versions of edge integration models propose that lightness computation is based on the integration of luminance signals across edges (Rudd & Zemach, 2004). Some
of these models postulate neural filling-in processes. Hence, it could be that a filling-in process is relatively easier when applied to a perceptually smaller target (the target that appears closer) and this could explain why it appears less contrasted to the background. In particular, in the case of decremental targets, lightness is modulated by the luminance of the bright background. The model would account for this modulation in terms of a darkness filling-in mechanism: the cells that receive signals from the bright background inhibit more the response of the cells that respond to the edges of the targets. This may be considered as a ‘darkness’ signal, which fills-in the two targets, meaning that when filling-in is accomplished, the two targets should appear darker than they would if they were increments. However, the perceptually smaller target should appear even darker than the other target because it has less area to ‘fill-in’. A similar reasoning would apply for incremental targets of equal luminance, but in this case, instead of darkness filling-in the model would speak about brightness filling-in: the cells responding to the dark background would exert less inhibition on the cells responding to the edges of the targets, hence these cells would fire at a higher rate causing a brightness filling-in of the target area, which would be more effective for the smaller target, which should appear lighter.

A part from the fact that the predictions made by a similar model are the exact opposite of my data, there is the fact that the model is 2D and at the moment is unable to account for 3D stimuli, even if only phenomenally 3D. Finally, consider that such a model would be based on the amount of cell connections, which is equal for surfaces of equal area physically placed at the same distance from the observer, even if the surfaces appear phenomenally at different depths. Hence, the model cannot account for lightness effects somehow related to illusory size differences, but only for actual retinal size differences.

3.3.2 The Anchoring theory

Anchoring theories hold as important components of their models the decomposition of the visual scene into frameworks (one global, and at least one local in the original version of the theory) mainly by means of Gestalt grouping principles (Bressan, 2006; Gilchrist et al., 1999), and the definition of anchors for each framework – surfaces which serve as an anchor (the highest luminance in a framework is temporary computed as white in that framework) to solve the lightness scaling problem (Gilchrist et al., 1999). In predicting the effects observed in exp. 4, the Anchoring theory does a little bit of a better job than edge integration models. In particular, according to the original Anchoring theory (Gilchrist et al., 1999), lightness differences between targets of equal luminance should occur only for
decremental targets: the target that appears coplanar to the background is grouped with this, hence its anchors in the local and the global frameworks coincide with the bright background, therefore such target should appear grey. On the other hand, the decremental target floating in the front plane has the bright background as the global anchor, and itself as the local anchor. Hence, by means of a weighted average between the two temporary lightness assignments for the two frameworks, the target floating in front should appear somewhat lighter that the other target. This translates into the appearance of the target coplanar to the background appearing somewhat darker.

The story told relative to increment targets, however, is different. If targets are equal in luminance they should not appear different even if one is seen as coplanar to the background, because in their local frameworks both targets are the highest luminance, and thus they are computed as white. If the visual scene was filled with the display, then both targets should appear white because they would be computed as white also in the global framework. My displays, however, viewed through the stereoscope consisted of a white background with a central random dot frame surrounding a background that ‘penetrated’ the screen, with two targets, one coplanar to deep background, the other floating in front of it. Logically speaking, the global framework should be the white screen surrounding the random dot frame for both targets. Hence temporary lightness assignments for both targets should coincide, leading to two targets that do not appear different in lightness. But this prediction is not what I found with incremental targets.

3.3.3 A Gestalt approach
While the anchoring theory in its classic formulation is considered to derive from Gestalt principles, there is a ‘basic’ Gestalt approach according to which lightness contrast between two areas retinally adjacent is directly related to a factor called belongingness. Belongingness could be easily confused with retinal proximity, however Agostini and Proffitt (1993) and Agostini and Galmonte (2002) showed two lightness contrast effects in which proximity is equal but the effects are modulated by belongingness.

3.3.3.1 Lightness and belongingness
The influence of belongingness on lightness was demonstrated by both Koffka (1915) and Benussi (1916). They showed that a grey ring lying on a split background, half white and half black, appears homogeneous until a thin vertical line, coinciding with the boundary
between the backgrounds, is placed on it. The line segregates the figure into the two perceptual groups: the part of the ring that appears to belong to the bright background appears also somewhat darker than the other that appears to belong to the black background (Fig. 3.5). Later Wertheimer and his student Benary (1924) showed another example how belongingness affects lightness: two triangles appear slightly different in lightness, even though they have identical local surrounds (Fig. 3.6). However, one triangle appears to belong to the black cross, while the other appears to belong to the white background.

![Fig. 3.5. Koffka-Benussi ring. The part of the grey ring against the black background appears somewhat lighter than the rest of the ring against the white background (on the left). The effect is enhanced when the vertical line is added across the ring, along the black-white junction (on the right).](image)

3.3.3.2 Lightness and depth

Rock's (1973, 1975) classic question: Is brightness (some authors used term brightness to indicate achromatic surface colour) determined by retinal proximity or by perceived proximity? Wolff (1933) showed that in simultaneous lightness contrast (Introduction, Fig. 6), the lightness difference between two targets of equal physical intensity is greatly reduced when the targets are coplanar to each other but separated in depth from their backgrounds. The effect of separation between the inducing field (background) and the test fields (targets) in the simultaneous contrast display has been also studied by Cole and Diamond (1971), Dunn and Leibowitz (1961), Fry and Alpern (1953), and Lebowitz, Moto and Thurlow (1953). All researchers found that the perceptually darker target (on the bright background) increased in lightness with increasing the separation between the target and the background, however the lighter target (on the dark background) does not appear to change with such manipulations. At the time this lightness effect was explained in terms
of a lateral inhibition account according to which the darker target becomes lighter with increasing separation between target and its background due to the drop off of inhibition strength with spatial separation across the retina. The much younger Anchoring theory gave another explanation for the aforementioned lightness effect, suggesting that the lighter target did not change in lightness because it has the highest luminance relative to the dark surround (local framework). By altering its degree of belongingness to that background, the target stays unchanged because it is still the highest luminance its local framework. As for the darker target (on the bright background) the less its proximity to the brighter background the less weight is given to the local framework, in which it is assigned the level of middle grey when target and background are coplanar. As the target is moved forward from the background it becomes more and more a local framework by itself, with the assignment of white in its local framework, much close to the assignment of the other target. Hence, the contrast effect is greatly reduced or even nullified.

Yet, while this effect was observed with an actual depth separation, it was not found when targets and background were seen in different depth planes by means of stereopsi (Gibbs & Lawson, 1974; Julesz, 1971, Menshikova, 2010). Other studies (Gogel & Mershon, 1969; Mershon, 1971; Mershon & Gogel, 1970) reported instead that the simultaneous “whiteness” (the term “whiteness” refers to achromatic surface colour, and was used also by Koffka (1935) contrast is affected by the depth adjacency in the stereoscopic display. Some researchers founded that belongingness relations in the White's (1981) illusion can be also inversed by employing stereopsis (Anderson, 1997; Spehar, Gilchrist, & Arend, 1995; Taya, Ehrenstein, & Cavonius, 1995).

3.4 Lightness, depth, and belongingness

The results of experiment 4 could be explained by the Gestalt factor belongingness: in incremental displays, for instance, not only does the target seen adjacent to the background appear lighter than a target of equal luminance floating in a front plane, but it appears also lighter with respect to targets physically lighter. The luminance difference between targets might be small, but the effect is nevertheless robust. These findings are also in line with those reported by Coren (1969), who studied the Wertheimer-Benary cross configuration in stereoscopic presentations (Fig. 3.6): when the targets were seen floating in front of the cross, the lightness effect virtually disappeared. My results are also consistent with
findings reported by Kardos (1934): in his experiments when a middle grey disk was adjacent to a dark background in the far plane it appeared lighter than when it was floating in a near plane detached from the same background. Kardos’ observations were confirmed later by Gilchrist and Todorovic (1999), who replicated the experiment deriving also quantitative data. Finally, Wist and Susen (1973) showed that when two halves of the Koffka-Benussi ring were separated in depth, the contrast effects decreased even though the two parts of the ring were retinally adjacent.

Given these considerations, the results obtained in experiment 4 support two hypotheses:

1) lightness is affected by perceived size (the target that appears bigger appears also more contrasted to the background);

2) lightness is affected by belongingness (the target that is seen adjacent to the background appears more contrasted.

Only the first hypothesis applies directly to the lightness effects observed in the Delboeuf illusion (reported in experiments 1 and 2). Nevertheless, the two hypotheses are not mutually exclusive; in fact, the effects of size and belongingness may be combined in this experiment.

3.4.1. The representation of perceived angular size in the human primary visual cortex

The results of exp. 4 might be also explained in terms of a neural mechanism (Murray, Boyaci & Kersten, 2006). It was demonstrated that a distant object that appears to occupy a larger portion of the visual field activates a larger area in V1 than an object of equal angular size that is perceived to be closer and smaller, suggesting that the retinal size of an object and the depth information in a scene are combined at a relatively early stage in the human visual system. The results are consistent with some earlier works suggesting that neural
responses in early coding in the visual cortex may change as a function of depth to allow for object scaling (Marg & Adams, 1970; Richards, 1967, 1968). If such findings are to be extended to explain the results of the exp. 4, it might be suggested that the spatial extent of the activation in the human primary visual cortex related to a perceptually bigger target might also produce a greater contrast effect between that target and its background.
Chapter IV

Belongingness or size?

In experiment 4 the target that appears far in depth appears also bigger. This is easily accounted for by Emmert’s law (1881): \( S = k(R \times D) \), where \( S \) is perceived size, \( R \) is retinal size, \( D \) is perceived distance, and \( k \) is a proportionality factor (constant scaling factor). Since the two targets have the same retinal (angular) size but appear at different distances from the observer due to induced retinal disparity and stereoscopic fusion, the target that appears more distant also appears bigger.

The fact that in experiment 4 the target that appears far appears also always bigger makes it difficult to understand whether there is such a thing as size effect on lightness. There are in fact at least three possibilities:

1) There is no such effect: the findings of exp. 4 are determined by solely the Gestalt factor belongingness, and we are left with a complete mystery for what concerns the lightness effects in Delboeuf-like displays. If this hypothesis were confirmed it would support also that part of literature which claims to have found Wolff’s belongingness effect in simultaneous lightness contrast with stereoscopic displays.

2) The findings of exp. 4 are explained by a supposed size factor, which would also account for the effects found in Delboeuf-like displays, leaving us with the not easy task of understanding the logic behind the role of such a factor. If this hypothesis were confirmed it would support also that part of literature which claims that Wolff’s findings concerning the factor belongingness on simultaneous lightness contrast cannot be extended to stereoscopic displays.

3) The findings of exp. 4 are a combination of both belongingness and size, which effects have the same polarity in those displays. If this hypothesis were confirmed, it would support the hypothesis that the lightness effects in Delboeuf-like displays are due to a size factor, since the belongingness factor should have the same weight for two targets seen simultaneously in normal binocular vision.
In my first attempt to tease apart the two factors, I ran another experiment where I employed targets physically different in size. Furthermore, this experimental condition is also a test for the hypothesis drawn out from Murray et al.’s experiment (2006) where it is suggested that a greater neural activity of a perceptually bigger target might produce a stronger contrast effect between that target and its background. While in Murray’s experiment the target that appeared far appeared always bigger, in this next experiment I also employed configurations in which the physically bigger target is also perceptually bigger and located on a near plane with respect to the other target located in depth by stereopsis. If the stronger contrast effect is the consequence of the extended neural activity in V1, then independently from the target’s position (near or far), the target that appears bigger should always appear more contrasted to the background with respect to the target that appears smaller. If instead the main effect is due to the factor belongingness, then independently from the size of the target, the target that appears to belong more to the background because of its immediate proximity to it should also appear more contrasted.

4.1 Experiment 5: size versus belongingness

4.1.1 Participants
Four participants (1 female and 3 male, age 25-55), who were either members or guests of the Psychology Department of Tohoku Gakuin University in Sendai, volunteered to take part to the experiment. All participants had normal or corrected-to-normal vision. One participant is the author of this study (O), another participant was aware of the purpose of the study (D), while the other two participants were completely naïve to the purpose of the study (K and T).

4.1.2 Stimuli
Stimuli were stereograms (Fig. 4.1) with target disparities set to ±0.24°. Targets consisted in two grey squares different in size (side 0.63, and 0.35 cm) seen against a square background (side 6.5 cm) that was surrounded by a random dot frame (width 2.5 cm). The luminance of the big target was 38.8 cd/m². The small target had one of the following luminance values: 36.6, 37.4, 38.8, 40.0, and 41.1 cd/m². In this experiment two experimental conditions were employed: (1) The big target appears far while the small target appears floating in front plane; (2) The small target appears far while the big target
appears floating in front plane. The left-right positions of big and small targets were balanced. Targets were seen either against a dark (8.5 cd/m$^2$) or a bright background (98.4 cd/m$^2$). A red fixation cross was present at the centre of each configuration and it appeared to be floating in a middle plane, coplanar to the random dot frame.

Fig. 4.1. Example of the stereograms used in experiment 5.

4.1.3 Procedure
The experimental procedure was similar to that used in the exp. 4 apart for the following feature: each stimulus was presented 16 times. Likewise as in experiment 4, participants were asked to indicate which of two targets (far or near) appeared darker. At the end of the experiment, subjects were asked whether the target that appeared near appeared also always smaller in size than the target in the far plane. All four subjects saw the target in the near plane either bigger or smaller, depending on its actual size.
4.1.4 Results

Figure 4.2 shows the results for experimental condition (1) when the big target is seen far, adjacent to the background; Figure 4.3 shows the results for condition 2 when the small target is seen far, adjacent to the background. As one can readily see, all four participants responded in a similar way.

In condition 1 the results are very similar to those obtained in the experiment 4: when the small target (near stimulus) and big target (far stimulus) had the same luminance (38.8 cd/m²), with increments the big target appeared lighter while with decrements it appeared darker than the small target. Furthermore with increment configurations a binomial test revealed the following results: for participants D, O, and T the big target appeared lighter with all small targets >38.8 cd/m², while participant K’s PSE corresponded to a small target =40.0 cd/m². With decrement configurations, for participants D, T and O the PSE corresponded to a small target =36.6 cd/m². Only for participant K the PSE corresponded to the small target =38.8 cd/m², suggesting that both targets have equal probability to be chosen as darker. Nevertheless the binomial test shows the tendency toward significativity (two-tailed test p = 0.07), meaning that when standard and comparison stimuli have the same luminance (38.8 cd/m²) the participant K choose the standard stimulus as darker in most cases (12 out of 16 times).

With regards to experimental condition 2 (Fig. 4.3, big target in front, small target in depth adjacent to the background), when the big and the far targets had the same luminance, with increments the big target appeared darker; with decrements it appeared lighter than the small target. Furthermore with increment configurations, for participant D the PSE corresponded to a small target =36.6 cd/m², for participants K and T PSE =37.4 cd/m², for participant O the big target appeared darker with all small targets < 38.8. With target decrements, for participants D and O the big target appeared darker with all small stimuli >38.8 cd/m²; for participant K PSE =41.1 cd/m²; for participant T PSE corresponded to a small target =38.8 cd/m², suggesting that when the big and small targets have the same luminance (38.8 cd/m²) for participant T they appear to be more or less equal. Nevertheless a binomial test shows the tendency toward significativity (p = 0.07), meaning that when standard and comparison stimuli have the same luminance (38.8 cd/m²) the participant T choose the standard stimulus as darker in most cases (12 out of 16 times).
Fig. 4.2. Results for exp. 5 condition 1 (big target far adjacent to the background): (a) increment targets, (b) decrement targets. X-axes show the percentage (%) of an big target (38.8 cd/m²) indicated as the target that appears darker; Y-axes show the corresponding luminance of the small target. The large squares indicate the condition in which targets measured both 38.8 cd/m².
Fig. 4.3. Results for exp. 5 condition 2 (big target floating on a front plane). (a) increment targets; (b) decrement targets. X-axes show the percentage (%) of the big target (38.8 cd/m²) chosen as darker; Y-axes show the corresponding luminance of the small target. The large squares indicate the condition in which targets measured both 38.8 cd/m².
4.1.5 Discussion

The results of experiment 5 show that when two targets have the same luminance and are viewed stereoscopically in such a way that one target appears attached in distance to the background while the other appears to be floating on a near front plane, the target that appears attached to the background appears also more contrasted to it, and this regardless of which target happens to appear bigger. In other words, the results of experiment 5 confirm a crucial role of the Gestalt factor belongingness on the lightness appearance of a target. These findings therefore should be considered in support of early findings reported by Wolff (1933) and also in support of those who claim to have found effects due to belongingness in stereoscopic displays.

Belongingness appears to be a crucial factor in lightness perception, however edge integration models and sophisticated new lateral inhibition models, such as ODOG (Blakeslee, Reetz, & McCourt, 2009), still fail to acknowledge it. While my findings are new, there is older evidence that never finds space in lightness studies with a sensory approach, showing nevertheless how that belongingness can be engaged in many ways. An interesting example is the demonstration by Agostini and Proffitt (1993) in which the factor belongingness is declined in terms of common fate (Fig. 4.4).

Finally, the results do not support the hypothesis according to which the lightness effects observed are directly related to the enhancement of neural activity due to the apparent or actual size of targets (Murray et al., 2006): the bigger target does appear more contrasted to the background, but only when it is seen as more attached to the background than the smaller target.

But what about perceived size per se? As I see it, the results from exp. 5 still do not rule out the possibility that size plays some role in lightness perception. As a matter of fact, so far only hypothesis 2 (stated at the beginning of this chapter) has been ruled out completely. The question whether lightness is affected also by a difference in perceived size between two coplanar targets presented simultaneously still remains. In fact, the results from exp. 5 can mean two different things: 1) again that there is no such thing as a size factor in lightness perception; or 2) that belongingness is a stronger factor that hinders
the effects of the hypothetical size factor. Maybe it is time to consider what the literature has to say about the role played by perceived size on lightness.

4.2 Experiment 6: Lightness and perceived size

I searched the literature for an answer but I was unable to find any direct reference to the role of size on lightness. There are instead studies where it was found that perceptual organization affects the perceived size of surfaces and also their luminous threshold (the luminance value at which a surface appears to glow). For instance, Bonato and Cataliotti (2000) used a stimulus created by dividing a rectangular space into two regions of equal area using the profile of a face: a face in profile against a white background and a face in profile against a black background. Although the physical area of the two regions was equal, the perceived area of the two was not. The background region was perceived to have a larger area than the face region, a finding consistent with Rubin’s (1921) observation that ground regions are perceived to extend behind figural regions. Bonato and Cataliotti also found a higher luminance threshold for the background regions than for the face region. This is consistent with Coren’s (1969) findings when he tested contrast effects using a reversible women - rabbit figure containing one lighter and one darker grey region (in Coren’s stimuli the central patch was seen as a grey rabbit on a black background; when the display was rotated 180 degrees, the same test patch appeared as grey space between two black women profiles). The grey region surrounded by black appears lighter when it appears as figure than when the same grey region appears as background. He said his findings “make it quite clear that brightness contrast is not simply determined by the brightness differences in adjacent areas. Cognitive factors, such as whether the test patch is seen as a figure or as ground, produced larger differences in the amount of perceived brightness” (1969, p. 521).

Wolff (1934) created the pattern in Figure 4.5 to show the role played by figure-ground segregation in lightness. The light and dark areas of the two figures are equal. However, when the light grey disks (the left image) are increments (lighter than the background) they appear lighter with respect to the area of equal luminance seen as a background. When instead dark disks (Fig. 4.5, right image) are decrements (darker than the background) they appear darker than the dark grey area of equal luminance seen as background.
Apart from the aforementioned studies, the majority of experiments that refer to an effect of size on lightness/brightness mainly considered the effect of the size of *inducers* on the lightness induction of a target (for example, Diamond, 1955; Newson, 1958; Wallach, 1948, etc.), and not the effect of size of the target itself affecting the way it appears.

While the studies reported so far found effects of size on the lightness/brightness dimension of targets, those effects are related to figure-ground organization. In my stimuli, instead, two targets (squares) are both seen as figures and they are different not only in their perceptual but also in their physical size. Finally, it was also shown that when two adjacent surfaces cover the entire visual field, with the darker of the two being larger, as the darker surface grows in area, its lightness value increases. However, for what we know, the “area rule” applies to a visual field composed of two adjacent surfaces (Gilchrist & Radonjic, 2009; Li & Gilchrist, 1999). My configurations instead consist of two separate surfaces different in size, one of which appears to belong to a homogeneous background.

To test the existence of a *pure* size effect, I ran another experiment quite similar to the last one except for a few conditions, one of which concerned the degree of belongingness to the background, kept equal between two targets of different size.

### 4.2.1 Participants

Four participants (4 male, age 25-40), who were either members or guests of the Psychology Department of Tohoku Gakuin University in Sendai, volunteered to take part in the experiment. All participants had normal or corrected-to-normal vision and were naïve with respect to the purpose of the experiment.

### 4.2.2 Materials

The experimental set up is similar to that in experiment 3 (Fig. 4.6), except for the following factors: (1) this time I did not use random dots stereograms to frame the stimuli (the bright and dark backgrounds filled the entire screen); (2) both targets appear either adjacent in depth to the background or floating on a front plane (degree of belongingness...
to the background was always equal between the two targets); (3) There were 40
configurations, each presented 20 times in random order. The luminance of the big target
was set to 38.8 cd/m²; the luminance values for the small target were the same as in exp. 6.

![Fig. 4.6. Two of the configurations used in exp. 6.](image)

### 4.2.3 Procedure

The experimental procedure was similar to that used in the exp. 5: participants were asked
to indicate which of two targets (small or big) appeared darker (forced choice task).

### 4.2.4 Results

Figure 4.7 (a, b) shows the results for the experimental condition (1) when both big and
small targets are seen adjacent in depth to the background. Figure 4.8 (a, b) shows the
results for the condition (2) when both targets appear to be floating on a front plane. As
one can readily see, all four participants responded in the same way and results of
condition 1 are similar to those obtained in condition 2: when the two targets had the same
luminance (38.8 cd/m²) regardless of the position the targets relative to the background, the
bigger target appears more contrasted to the background. In particular, in condition 1 with
increment configurations, for all four participants the PSE corresponded to a small target
With decrement configurations, for participants G and J the PSE corresponded to a small target \(=37.4\, \text{cd/m}^2\); for participants O and T the big target appeared darker with all small targets \(<38.8\, \text{cd/m}^2\).

With regards to condition 2, when targets were equal in luminance, with increments the big target appeared darker; with decrements it appeared lighter than the small target. Furthermore with increment configurations, for participant G and O the PSE corresponded to a small target \(=40.0\, \text{cd/m}^2\), for participant J it was equal to \(41.1\, \text{cd/m}^2\), only for participant T PSE corresponded to a small target \(=38.8\, \text{cd/m}^2\), suggesting that when the big and small targets have the same luminance \((38.8\, \text{cd/m}^2)\) they have equal probability to be chosen as darker. Nevertheless a one-tailed binomial test showed a tendency toward a significant difference \((p=0.057)\). With decremental configurations, for all four participants PSE corresponded to a small target \(=37.4\, \text{cd/m}^2\).

4.2.5 Discussion

The result of the experiment 6 show that when two targets have the same luminance and the same degree of belongingness to the background, but differ in size, regardless of their position relative to the background, the bigger target is seen as more contrasted to the background.

The results for decrement targets rule out a hypothesis based on a generic simplification of an otherwise important “area rule”, according to which bigger areas tend to appear brighter (Gilchrist & Radonjic, 2009; Li & Gilchrist, 1999). In Gilchrist’s experiments two surfaces filled the entire visual scene; in my experiment targets are tiny in comparison. Furthermore, it is not clear whether the adjacent surfaces in Gilchrist’s experiments have both the status of surfaces adjacent to each other, or if one of the two played instead the role of a background (the authors did not ask their subjects to report about figure-ground segregation). Nevertheless, the fact that an area that appears bigger appears also somewhat lighter makes sense. Recently I experienced a similar perceptual result when I bought tiles for my new house. I was actually surprised when I first saw the tiles in their box: they looked much darker than those I saw displayed at the store. However, when all the tiles were put down on the floor, the floor appeared lighter than just a single tile. But this is the point: each tile appeared to be part of the whole floor, and thus it looked more like the background while a tile viewed separately appears more like an object.
Fig. 4.7. Results for exp. 6 (condition 1, both targets adjacent to the background): (a) increments; (b) decrements. X-axes show the percentage (%) of the big target (38.8 cd/m²) chosen as darker; Y-axes indicate the corresponding luminance of the small target. Large squares indicate the condition in which targets measured both 38.8 cd/m². When two targets have the same luminance, the bigger target appears more contrasted to the background.
Fig. 4.8. Results for exp. 6 (condition 2, both targets floating on a front plane): (a) increments; (b) decrements; X-axes show the percentage (%) of the big target (38.8 cd/m²) chosen as darker; Y-axes indicate the corresponding luminance of the small target. Large squares indicate the condition in which targets measured both 38.8 cd/m². When two targets have the same luminance, the bigger target appears more contrasted to the background.
4.3. General discussion

I must point out here that the set up of experiment 6 is probably the best way to test for the existence of a pure size effect. In fact it should be noticed that when two separate objects different in size are presented simultaneously on a homogeneous background, seeing them as coplanar is not that easy (Zavagno, 2007), it requires an attitude. On the contrary, it is very easy to see 2D displays as somewhat three-dimensional, that is displays with some depth inside them. It appears that the visual system has evolved to render three-dimensional images in spite of a two-dimensional input. I tried in fact to run this experiment without stereopsis, but the physically smaller target tends to appear more far away than the target physically bigger, meaning that once again one would find a combination of two different factors: belongingness and size. This might be, in fact, one of the reasons why a pure size effect went unnoticed for so long.

The comparison between experiments 5 and 6 tells us an important thing: that the factor belongingness weighs more than size when it comes to the determination of lightness. In fact, while in exp. 5 the two targets of different size always differed in their degree of belongingness to the background, in exp. 6 this factor was held constant between targets. The results were that when targets shared the same luminance, in exp. 5 the target adjacent to the background always appeared more contrasted, regardless of its size, in exp. 6, instead, the bigger target appeared more contrasted, regardless of the degree of belongingness to the background shared by the two targets.

I must confess that the findings of exp. 6 surprised me. At the beginning of my research, when I was dealing only with the lightness effect in Delboeuf-like displays, I thought that the effects were due to some sort of ‘magnification’ process: a sort of enhancement of the features related to the target that appeared bigger. In this view, I thought also that the target that appeared bigger should also appear somewhat closer. I know that many would reason in the opposite way: the target that appears bigger should appear also somewhat far away, according to Emmert’s law. However, either way one wants to think it, the results of exp. 3 made me reject this idea: Delboeuf’s size-contrast illusion does not appear to be related to perceived depth. The results of exp. 6 were therefore a pleasant surprise, but now I must face a not trivial question. Why is it important for us to see the bigger objects as more contrasted, in other words, more visible or more pronounced. Once again the idea of a magnification or enhancement process comes to my mind.
Let me try some wild speculations. The process by which the enhancement of an object occurs may go along with other visual processes. The sum of the enhancement effects could be discussed in terms of their ecological value, and if the phenomenon could be treated in these terms then the explanation could go roughly as the following: bigger objects generally weigh more (have more value or appeal) than small objects and thus eventually attract more attention. For instance, we know that when a fruit grows it becomes bigger in size and more mature. A mature fruit is a guarantee for more nutrition. Certainly everyone would like to pick up a big fruit instead of a small one. The visual system, that serves also to facilitate an accurate detection of food (Troscianko et. al., 2003), maybe includes some hidden mechanism that render bigger objects also as more pronounced. One of the ways to make an object appear more visible is, for instance, to make it appear more contrasted against the background. But once again, this is just a wild speculation.
Chapter V

How are size and lightness bound in Delboeuf-like displays?

Findings of experiment 6 show a contrast enhancement between target and background for the target that appears bigger. The magnitude of the effect is not huge, but it is consistent and goes in the same direction as the lightness effects found with Delboeuf-like displays: the target that appears bigger, either because it is physically bigger (exp. 6) or perceptually bigger (exps. 1 and 2), appears lighter when it is an increment to its background, and darker when it is a decrement. In the next experiment I will try to understand what kind of relationship ties perceived size to the lightness effects observed in Delboeuf-like displays.

5.1 Experiment 7

Experiment 7 was conducted to verify the correlation between the size-contrast illusion and the lightness effects observed in the Delboeuf-like displays. With in mind the experiments carried out so far, there are three possible outcomes:

- The contrast enhancement and the size contrast illusions are positively correlated. In other words, as the apparent size difference increases, also the magnitudes of the lightness differences between the two targets increases, regardless of the contrast polarity between targets and background.
- There is no correlation between the size-contrast illusion and the lightness illusion. In other words, as the apparent size differences between two targets increases, the lightness effect should vanish or reverse, meaning that what I found so far just appeared due to a diabolic combination of circumstances, all still to define.
- There is no statistically significant correlation between the two phenomena because the lightness effects due to size are of the type ‘all or none’. In other words, the lightness enhancement effect – which result in the bigger target appearing more
contrasted to its background, when the factor belongingness is equal for both targets – is not scalable: if the factors are favourable, the effect will occur always with approximately the same magnitude; if the factors are not favourable, it will not occur.

Given these possibilities, I designed an experiment in which observers were asked to adjust in separate blocks of trials the size or the lightness of one of two targets in Delboeuf-like displays in order to match the other target. The important variable that I manipulated in this experiment was the size of the large size-contrast inducer.

Reviewing the history of experiments related to Delboeuf’s size-contrast illusion, I found that the magnitude of the illusion is sensitive to the diameter ratio between two concentric circles. According to studies by Morinaga (1935), Ogasawara (1952), Ikeda and Obanai (1955), Piaget et al. (1942), Weintraub et al. (1969), a maximum overestimation (size assimilation) of the inner circle occurs when the diameter ratio between the outer circle and the inner circle is 3:2. When instead the diameter ratio is approximately 5:1 or 6:1 the maximum underestimation (size contrast) occurs. If I were to apply these findings to my configurations, I should find that as I increase the size of the bigger inducer, the size difference between the two circumscribed targets should also increase. What about the lightness difference, would this also increase?

As discussed in chapter 2, there is no common agreement on whether the luminance of the inducer affects the magnitude and the direction of the size-contrast illusion. According to a study conducted by Jaeger and Long (2007), both the magnitude and the direction of the illusion can be altered by luminance contrast ratios between the concentric circle (inducer) and the target (inner circle, or letter). Oyama (1962), however, demonstrated that the contrast ratio and the difference in colour between inner and outer concentric circle is an affective variable for the direction and the magnitude of the illusion, emphasising the importance of the perceptual structure of the Delboeuf illusion, based on the Gestalt principle of the perceptual grouping. Such findings were confirmed more recently by Noguchi (2002). According to Naguchi (2002), the Delboeuf illusion tends to be organized as a whole or unified percept. Oyama however also claimed that the contrast ratio between the background and the inducer can affect the magnitude and the direction of the illusion.

It is important to point out here that the previous studies conducted to study the magnitude and the direction of the size-contrast illusion commonly employed stimuli configurations that are substantially different from those used in my study: in those studies
the test target was free from any concentric circle; in my experiments I used the simultaneous presentation of targets surrounded by inducers which differed in size.

5.1.1 Participants
Thirteen people who were graduate students, undergraduate students, or members of the Psychology Department of the University of Milano-Bicocca (5 male, age 20-47) volunteered to take part in the experiment. All participants had normal or corrected to normal vision.

5.1.2 Materials
Stimuli were computer generated using a custom software written with MatLab combined with Psychtoolbox-3. The stimuli were two grey disks arranged horizontally side by side. One disk (test target, adjustable either in size or luminance) was surrounded by an inducer fixed to a diameter of 2.5 cm; the other disk (matching target, fixed in size and luminance) was surrounded by an inducer that could have one of the following diameters: 3.5 (S), 5.0 (M), 7.5 (L). Two backgrounds were employed, a bright one (88.3 cd/m²) and a dark one (7.06 cd/m²). The luminance of both inducers could be either 121 cd/m² or 0.8 cd/m²; inducers measured 0.15 cm in thickness.

The experiment was divided into two parts. The first part consisted of trials in which the luminance value of test and matching targets were both set to 34.2 cd/m². Matching target size was fixed to 1.5 cm, while test target varied in size randomly in such a way that it always appeared noticeably bigger or smaller than the matching target.

In the second block of trials, the size of both test and matching targets was fixed to 1.5 cm; the luminance of the matching target was fixed to 34.2 cd/m2, while the test target varied randomly in luminance in such a way that it always appeared noticeably lighter or darker than the matching target.

![Fig. 5.1 Example of decrement stimuli used in experiment 7; the letters S, M, and L stand for the relative size of the inducer of the matching target (small, medium, large).]
The combination of background luminance, inducers luminance, position of the test target (left or right) and direction of the adjustment (up or down) determined 48 configurations. Configurations were presented twice in random order in both parts of the experiment. Trials were separated from each other by a mask (random dots stereogram) which lasted 0.8 secs.

5.1.3 Procedure
Stimuli were displayed on a 21-inch computer monitor Samsung SyncMaster 1100 Plus in a dimly lit laboratory. Observers viewed the stimuli binocularly and freely from a distance of 55 cm. In the first part of the experiment observers were asked to adjust the size of the test target until it appeared equal in size to the matching target. In the second part of the experiment observers were instructed to adjust the lightness of the test target to achieve the achromatic colour match of the matching target. Training trials for both parts of the experiment preceded the actual experiment. Adjustments were performed using arrow keys on a keyboard: upward arrow for increasing size or lightness, downward arrow for decreasing such features. Each time one of those keys was pressed, the test target increased or decreased either in diameter (0.03 cm variation) or in luminance (1 RGB value, which corresponded roughly to steps of 0.4 cd/m²), depending on the task. The entire experiment lasted for about 40-50 min, depending on the observer’s response times. There was a 5 minute break between the two parts of the experiment.

5.1.4 Results and discussion
Experimental results for size adjustments are shown in Figure 5.2, while those relative to lightness adjustments appear in Figure 5.3. Data for size adjustments and those for lightness adjustments were analyzed first separately.

5.1.4.1 Results and discussion for size adjustments
For what concerns size adjustments, an ANOVA for repeated measures (3×2×2) (Inducer size × Background luminance × Inducer luminance) was conducted on the data: the factor “Inducer size” produced significant effects: \( F_{2, 24} = 61.23, p<0.0001 \), while factors “Background luminance” and “Inducer Luminance” did not determine significant effects (respectively: \( F_{1, 12} = 3.5, p=0.08 \); \( F_{1, 12} = 0.01, p=0.8 \)). Factor interactions did not produce significant effects. One group t-tests were carried out to verify whether size adjustments were statistically different than the actual size of the matching target: alla mean
adjustments resulted significatively different from the actual size, except for S dark inducer on a dark background (t=-2.03, p=0.06). Paired t-tests revealed a significant difference between size adjustments on the bright background with large dark and bright inducers (t=-2.55, p<0.05) Experimental results clearly show that the size of the inducers affects the magnitude of the size-contrast effects. In particular, the bigger the difference between the inducer of the test target and that of the matching target, the greater the apparent size difference between targets.

Fig. 5.2. Size-contrast effect as a function of inducer size and background luminance. The bigger the size of the inducer the smaller the central target appears, regardless of the luminance of the background. Letters S, M, and L indicate the size of the inducer of the matching target. Dark symbols stand for dark inducer (7.06 cd/m²); light symbols stand for light inducer (121 cd/m²). The dashed line indicates the physical size of the matching target in pixels.

The results for size adjuments are in agreement with those reported by Morinaga (1935), Ogasawara (1952), Ikeda and Obanai (1955), Piaget et al. (1942) Weintraub, Wilson, Greene, & Palmquist (1969). Despite I found no significant effect of the interaction “Background luminance” × “Inducers luminance”, a careful look at the Fig. 5.4a reveals that a greater contrast between inducer luminance and background determines somewhat stronger size effects. Similar findings were reported by Oyama (1969), who
found with decrement targets that the size-contrast illusion was greater when the “brightness difference between outer circle and background was greater than a certain value” (p. 48).

In general, experimental results confirm the findings obtained in early studies: the size of the inducer affects the magnitude of the size-contrast illusion (Morinaga, 1935; Ogasawara, 1952; Ikeda & Obanai, 1955; Piaget et al., 1942; Weintraub et al., 1969). It was important, however, to verify these findings with my stimuli configuration where both test and matching targets have inducers. The previous studies were in fact conducted to study both the magnitude and the direction of the size-contrast illusion by employing stimuli in which the test target was free from inducers. In my study I was interested only in the magnitude of the illusion, since my test target was always surrounded by a small inducer, forcing the illusion to move only in one direction. This strategy was necessary to study the possible relationship between the size-contrast effect and the lightness effects observed in experiments 1 and 2.

5.1.4.2 Results and discussion for lightness adjustments

![Fig. 5.3](image)

**Fig. 5.3.** Lightness adjustments as a function of inducer size and background luminance. The magnitudes of lightness adjustments remain the same regardless of the size of the inducer of the matching target, but are modulated by background luminance. Letters S, M, and L indicate the size of the inducer of the matching target. Dark symbols stand for dark inducer (7.06 cd/m²); light symbols stand for light inducer (121 cd/m²). The dashed line indicates the actual luminance of the matching target.
For what concerns lightness adjustment, an ANOVA for repeated measures (3×2×2) (Inducer size × Background luminance × Inducer luminance) was conducted on the data: only the factor “Background luminance” produced a significant effect: $F_{1, 12}=133.31$, $p<0.0001$), while factors “Inducer Size” and “Inducer Luminance” did not determine significant effects (respectively: $F_{2, 24}=0.98$, $p=0.38$; $F_{1, 12}=2.19$, $p=0.16$). All interactions were non significant, except “Inducer luminance” × “Background luminance”, which showed a strong tendency towards significance ($F_{2, 24}=3.35$, $p=0.052$). However, paired t-tests did not reveal significant differences between mean adjustments for targets on the same background with inducers of the same size but of different luminance. One group t-tests, carried out to verify whether mean luminance adjustments for lightness were statistically different from the actual luminance value of the matching target, revealed that all adjustments were statistically different form the actual value.

There is no surprise that background luminance determined significant effects on lightness adjustments within configurations similar in inducer size, regardless of the luminance of the inducer. The same grey target set against a dark background looks lighter than an identical grey target set against a light background. It is a well-known lightness contrast effect. What is interesting, instead, is that the factor “Inducer size” appears to have no effect on the magnitude of the lightness illusion. The graph plotted in Fig. 5.3, shows the basic effect obtained in the experiments 1 and 2. However, to truly understand this finding we must consider the task of the observer, who was required to adjust the luminance of the test target surrounded by a small inducer to match that of a matching target surrounded by a bigger inducer. Hence, if the target surrounded by a small inducer tends to appear more contrasted to the background, it is expected that the adjustments will go in opposite direction with regards to what found in my previous experiments with Delboeuf-like displays. For instance, if the targets are increments, the target that appears bigger (test target) would appear lighter when it has the same luminance of the matching target, hence the observer must decrease the luminance of the test target below that of the matching target to see both targets of equal luminance. The same reasoning must be inverted for decrement targets.

5.1.4.3 Correlation?

The correlation between the two dependent variables size and lightness is not significant with respect to both increment and decrement targets (respectively: $r =0.02$, $p =0.85$; $r =-0.05$, $p =0.65$). However, this probably depends on the fact that the lightness effects
reported appear to be of the type “all-or-none”, as stated in one of the hypothesis at the beginning of this chapter.

5.2 General discussion

In conclusion, I did not find a correlation between the size-contrast illusion and the lightness effects I found in Delboeuf-like displays. This however does not exclude the existence of a relationship between the two phenomena. The findings of exp. 7 are a consequence of the way the two effects present themselves. In fact, while the size-contrast illusion appears to be modulated by the size of the inducers, the associated lightness effects are not sensitive to the size of the inducers; they appear instead to be sensitive to the existence of a size difference between targets. In other words, results suggest that the lightness effects related to size differences are of the type all-or-none: if the conditions are appropriate (same degree of belongingness to the background, difference in apparent or actual size between two targets), then the target seen as bigger will also appear more contrasted. Hence, one cannot exclude a causal connection between the apparent size differences of the two targets and their apparent contrast difference to the background. However, on the basis of the present experimental results it would be wise to refrain from any definitive conclusions about how the two illusions could be related to each other.

Fig 5.4. (a) The size effect and (b) the lightness effect as a function of the interaction between background luminance and inducer luminance. There is a similar tendency towards stronger effects when the contrast between background luminance and inducer luminance is higher. Dark symbols stand for dark inducer (7.06 cd/m²); light symbols stand for light inducer (121 cd/m²). (a) The actual physical value of the matching target is 75 (px). (b) Dashed line indicates the actual luminance value of the matching target (34.2 cd/m²).

With reference to the magnitude of the size-contrast illusion, it should be noticed that depending on the dimension of the inducer the magnitude of the size contrast effect
varies from 2,19 cm to 2,05 cm. A modulation of 14 mm is not small in geometric-optical illusions. However, such range could be too small to determine a range of differences in lightness effects directly related to apparent or actual size differences. However, these are just speculations that require further experiments to be tested.

What is interesting here instead is that the lightness effects are not affected by the luminance of the inducers, a finding that confirms the data of exp. 2, nor are they affected by the size of the inducers (Fig. 5.5b). The lightness effects however appear clearly, and they are consistent with the findings of experiments 1 and 2, hence the only plausible explanation left is that they actually are somehow associated with the size-contrast effect, even if they appear to be disassociated from the variables that affect apparent size: while apparent size is sensitive to inducer size (Fig. 5.5a), apparent lightness contrast is not; while the direction of apparent lightness contrast is affected by background luminance (Fig. 5.4b), the direction and magnitude of the size-contrast effect is relatively insensitive to such factor. Both effects, however, appear to be slightly influenced by the contrast ratio between inducer and background luminance: the effects are somewhat stronger when the contrast is greater (Fig. 5.4).

![Graphs showing size and lightness effects](image)

**Fig. 5.5.** (a) The size effect and (b) the lightness effect as a function of the interaction between background luminance and inducer size. (a) Size adjustments are significantly affected by the size of the inducer, but not by the luminance of the background. (b) While background affects the direction of luminance adjustments, the size of the inducer does not produce significant effects. Letters S-M-L indicate the size of the inducer of the matching target. Dark symbols stand for dark inducer (7.06 cd/m²); light symbols stand for light inducer (121 cd/m²). Dashed lines indicate the physical value of the matching target.
Chapter VI

Lightness effects in Ebbinghaus displays

Experimental results so far support the hypothesis that the lightness effects originally observed in Delboeuf-like displays are related to an actual size effect on lightness that occurs when two targets possess the same degree of belongingness to the background, but one appears bigger than the other, or because it is actually or just apparently bigger. It is therefore interesting to verify whether similar lightness effects can be observed in other size-contrast illusions. In this chapter I will consider the Ebbinghaus size-contrast illusion (1902).

According to some researchers (e.g. Naguchi, 2002), the Delboeuf illusion and the Ebbinghaus illusion differ in their figural characteristics. In particular, the Delboeuf’s size-contrast illusions tends to be organized as unified whole, while the components of the Ebbinghaus type of size-contrast illusions tend to be separated into different groups. Despite this hypothesis, there is also an important similarity between the two illusions: both induce misleading size estimations because of the different sizes of the inducers surrounding two targets.

The basic configuration of the Ebbinghaus illusion consists of two targets (in our case grey disks) surrounded each by a group of 6 disks (inducers, in our case outlined circles). For one target the diameter of the inducers is smaller than that of the target, while for the other target the diameter of the inducers is bigger (Fig. 6.1). Just as in the case of Delboeuf’s illusion, the target surrounded by small inducers appears bigger than the target surrounded by large inducers. Does this type of configuration affect lightness in the same way as found in Delboeuf’s illusion?

6.1 Experiment 8: lightness and the Ebbinghaus illusion
In the new stimuli I kept the distance between target and inducers equal for both targets
(Fig. 6.1), which translated into configurations in which the perpendicular distance between small inducers and their target is relatively larger than usually found in textbook versions of the illusion. It was been found that target-inducer distance affects negatively the magnitude of the Ebbinghaus illusion (Ehrenstein & Hamada 1995; Roberts, Harris, & Yates 2005). Nevertheless, I considered this aspect as a necessary control because the configuration is much more complex than in Delboeuf’s illusion, and therefore I wanted to reduce eventual effects due to the interaction between the luminance of the inducers and that of the targets. Nevertheless, it should be noticed that if the luminance of the inducers had an effect on the lightness of the targets, then the lightness effects would go in an opposite direction as what observed in Delboeuf-like displays, because the large inducers associated with the appearance of a smaller target offer more edge extension for any type of induction effect: regardless of the direction of the eventual size-contrast illusion, the target surrounded by large inducers should appear more contrasted to the background because the greater extension of the large inducers’ contours. For what concerns the reduction in the magnitude of the illusion with my displays, I am less concerned because of the results of exp. 7: as long as the two targets appear different, I should still find that the

![Fig. 6.1. Modified Ebbinghaus displays. Top: increment targets on the; bottom: decrement targets.](image-url)
target that appears bigger appears more contrasted to the background, both with increment and decrement targets.

6.1.1 Participants
Ten graduate and undergraduate students from the University of Milano-Bicocca (age 18-29, 5 female, 5 male), who did not participate to the previous experiments and who were unaware of the purpose of the study, volunteered to take part to the experiment. All participants had normal or corrected-to-normal vision.

6.1.2 Stimuli
Stimuli were 26 configurations created in the same way as described in experiment 1. Configurations measured 29×13.5 cm (14.2×6.7 deg). Disk targets (T) measured 2 cm in diameter (1 deg). Configurations showed two Ts, one surrounded by six small outlined circles (small inducers, diameter 0.8 deg) and the other surrounded by big outlined circles (big inducers, diameter 1.8 deg). The orthogonal distance between a target and its inducers was constant for big and small inducers (0.65 deg). The luminance values for the Ts were the following: 136, 145, 158, 167, 171, 178, and 200 cd/m², however in all configurations one of the two targets always measured 167 cd/m². Background luminance was either 45.7 or 444 cd/m². On the dark background, inducers’ luminance was 444 cd/m², on the bright background it was 45.7 cd/m² (Fig. 6.1).

6.1.3 Procedure
Procedure was the same as described in experiment 1 (ch. 1).

6.1.4 Results and discussion
Figure 6.2a shows the results for comparisons with decrement and increment targets 167 cd/m² surrounded by small inducers, while Fig. 6.2b displays the results for decrement and increment targets 167 cd/m² surrounded by big inducers. As one can readily see, when paired targets measured both 167 cd/m², the increment target that appears bigger appears also lighter, while vice versa the decrement target that appears bigger appears also darker. I compared the data of experiment 8 with the data of experiment 1 for similar luminance target configurations with a Kruskal-Wallis H tests (df=1, N exp. 1=29, N exp. 8=10) and found no significant difference for increment and decrement targets (0.09≤p≤1).
Fig. 6.2. Results for experiment 8. Black squares stand for decrement targets, grey squares for increment targets; large squares indicate the condition in which targets measured both 167 cd/m². The target that appears bigger (surrounded by small inducers) appears also more contrasted: it appears lighter when targets are increments; vice versa, it appears darker when targets are decrements.

Results are consistent with those of experiments 1 and 2, and they support the hypothesis of a link or a relationship between size differences (apparent or actual) and lightness differences between targets of equal luminance viewed simultaneously.

6.2 Experiment 9: is the size illusion still there?

Since by keeping the perpendicular distance between inducer and target equal for both targets, a factor which is reported has affecting the magnitude of the Ebbinghaus illusion, Experiment 9 was conducted to test the presence (not the magnitude) of the size-contrast illusion in the displays used in the experiment 8.
6.2.1 Participants

Eleven members of the psychology department (age 26-47, 7 female, 4 male), who did not participate to exp. 8 and who were unaware of the purpose of the study, volunteered to take part to the experiment. All participants had normal or corrected-to-normal vision.

6.2.2 Stimuli

Stimuli employed were 2 of the configurations used in exp. 8, one for increments and one for decrements, and precisely those in which the two targets shared the same reflectance. Stimuli were displayed one at a time in a viewing chamber at a distance of 57 cm. Luminance values were the following:

- targets=16.21 cd/m²;
- dark inducers and dark background=3.5 cd/m²;
- bright inducers and bright background=37.2 cd/m².

6.2.3 Procedure

Targets were presented in random order, right side up or upside down. Participants were asked to report which of two targets appeared bigger in a forced choice task.

6.2.4 Results and discussion

Results confirm the appearance of the size-contrast illusions in both displays: all participants without exception have chosen the target surrounded by small inducers as the one that appeared bigger. While this experiment did not test the magnitude of the Ebbinghaus size-contrast illusions in our displays, it confirms that the illusion is present, thus allowing to hypothesize a relationship between the apparent size difference and the lightness difference observed in my Ebbinghaus-like configurations.

6.3 General discussion

There is not much to say: the results are in line with my previous findings. The target that appears bigger appears also somewhat more contrasted to the background: if targets are increments, then the target that appears bigger appears also lighter than the other target; vice versa, if targets are decrements, then the target that appears bigger appears also somewhat darker.

I did not test the role played by the luminance of the inducers in my Ebbinghaus-like displays, as I did instead with my Delboeuf-like displays in exp. 2 (Ch. 2). However if
a role were played by the luminance of the inducers, one would expect that this effect
would be co-determined by the relative proximity of the inducers and, even more crucial in
these displays, by the extension of inducers around the targets. While I held proximity
constant between targets, the extension of the inducing borders was greater for a target
surrounded by big inducers than for a target surrounded by small inducers. Therefore, if
there were a major effect of inducer luminance on the lightness appearance of the targets,
then this should be more effective on the target surrounded by big inducers. Would such a
hypothetical effect be of a contrast or of an assimilation type? If one assumed an assimilation
outcome, then results would be opposite with respect to those found in exp. 8; if one
expected a contrast effect, then results would be in line with my actual results.
Nevertheless, considering the findings of experiments 2 and 7, the question appears rather
trivial.

More interesting would be instead to verify experimentally whether the magnitude
of the size illusion affects the magnitude of the lightness difference. In fact, it appears to
me that by manipulating both the size of the inducers and inducer-target orthogonal
distance one will achieve a wider range of apparent size differences than what experienced
in Delboeuf-like displays. Would there be a concomitant effect on the lightness differences
between two targets? I reserve to deal with this question in future research.
Chapter VII

Conclusions and future research

The present study was dedicated to the lightness effects observed, first by Brigner (1980) and then by Zanuttini and Daneyko (2010), within Delboeuf size-contrast configurations. The core points of the study can be summarized as follows:

1. I found that the lightness effects in Delboeuf-like displays are affected by the contrast polarity between target and background (exp. 1, Ch. I). In this sense, my findings are in partial contradiction with those by Brigner, who found that regardless of the contrast polarity between targets and background luminance, the target that appears bigger always appears somewhat darker. The main effects I found, instead, are that when targets are increments (targets lighter than the background), the target that appears bigger appears also lighter than the physically identical target that appears smaller; when instead targets are decrements (targets darker than the background), the target that appears bigger appears also darker. The effect is not strong, in the sense that one should not expect a dramatic difference; however it is consistent, and therefore robust.

2. I considered the factors that logically appeared responsible for the aforementioned lightness effects. I therefore investigated three factors:

   • First factor: the luminance of the concentric circles (exp. 2, Ch. II). The question was whether the luminance of the size-contrast inducers were factors affecting also the appearance and the direction of the lightness effects in Delboeuf-like displays. Results were discussed with reference to edge integration models and to more generic assimilation-contrast hypotheses. None of the models considered could account for the data, given that the luminance of the size contrast inducers has no influence over the direction of the lightness effects observed in Delboeuf-like displays. In other words, the luminance of the size inducers appears to be an ineffective variable for the observed lightness effects.
• **Second factor: perceived depth** (experiments 3 and 4, Ch. 3). Many vision scientists argue that size illusions are influenced by implicit depth cues (Coren & Girgus, 1975; Girgus, Coren, & Agder, 1972; Gregory, 1963, 1966, 1968, 1970; Kristof, 1961; Tausc, 1954; Thiery, 1896). I therefore hypothesized that maybe a difference in depth was responsible for the lightness effects reported in experiments 1 and 2. In experiment 3 I simply asked observers to choose which of two targets appeared closer in Delboeuf-like displays. Results, however, showed no prevailing target. Therefore in exp. 4 I tried another approach: I used simple geometric configurations consisting of two square targets physically equal in size, placed on a light or dark background. A depth difference between targets was induced by means of retinal disparity (configurations were stereograms viewed with a mirror stereoscope). Observers were asked to choose which of two targets appeared darker. At a first sight, experimental results appear to support the hypothesis of an effect of perceived depth on lightness: the target that appears far away appears also more contrasted to the background against which it is seen. Nevertheless, there are two problems haunting such a hypothesis: 1) the target that appears more in distance appears also bigger, hence it is still not clear whether the results are due to an apparent depth or to an apparent size difference between two targets viewed simultaneously; 2) the target that appears more in distance appears also coplanar to the background. With regards to this second point, Wolff (1933) observed that simultaneous lightness contrast is affected by the degree of belongingness of the targets to their backgrounds. His results are consistent with those reported by Coren (1969), Kardos (1934), Wist and Susen (1973).

• **Third factor: perceptual size difference** (experiments 5 and 6, Ch. 4). Given the aforementioned problems raised by the findings of exp. 4, I designed other two experiments with stereoscopic stimuli, very similar to the stimuli employed in exp. 4, except for the size of the targets, which were physically different, one being the double of the other. Results of exp. 5 support the hypothesis that the degree of belongingness of a target to its background influences the lightness appearance of the target: the target that appears coplanar to the background appears also more contrasted to it, regardless of its size. In exp. 6, instead, I kept the degree of belongingness to the background equal between targets, and found a pure size effect: the bigger target always appeared more contrasted to the background. In particular,
the big target appears lighter when targets are increments, and vice versa it appears
darker when targets are decrements to the background.

3. Having found a pure size effect on the lightness of two targets presented simultaneously,
I attempted to verify whether the magnitude of the effect covaried with the magnitude of
the size-contrast illusion in Delboeuf-like displays (exp. 7, Ch. 5). I therefore designed an
experiment in which the main independent variable was the size of the big inducer
surrounding one of the targets (3 levels). Observers were asked to perform two different
tasks in two separate parts of the experiment: first they were asked to adjust the size of the
target surrounded by a small inducer to match that of the target surrounded by a big
inducer; then they were asked to adjust the lightness of the target surrounded by a small
inducer to match the lightness of the target surrounded by a big inducer. Results were that
inducer size affected the magnitude of Delboeuf’s size-contrast illusion, as reported in the
literature, but not the magnitude of the lightness effects, which were however congruent
with those reported in experiments 1 and 2. The results from exp. 7 suggest that the
lightness effects related to a size difference (apparent or actual) between targets viewed
simultaneously with the same degree of belongingness to the background are of the type
all-or-none: when two targets share the same luminance, the target seen as bigger will
appear lighter if targets are increments, or darker if targets are decrements to the
background.

4. I showed that the lightness effects determined by a perceptual size difference can be
found also in the Ebbinghaus size-contrast illusion (exp. 8, Ch. 6).

7.1 The point
If we consider the chain of findings from all experiments, we are left with the hypothesis
that the lightness effects observed in Delboeuf-like displays are directly related to the size-
contrast illusion. The strongest evidence in support of this thesis is that a pure size effect
was found (exp. 6, Ch. 4): when two targets are equal in luminance and in their degree of
belongingness to the background, but are physically different in size, the bigger target
appears more contrasted to the background, regardless of the contrast polarity between
targets and background. As argued in the previous chapters, the lightness effect is not
huge, meaning that its magnitude is not something that leaves in awe. In fact, the effect is
easily wiped away by another factor: the degree of belongingness of the target to its
background: when two targets are equal and luminance but differ in size, the target that is adjacent to the background will appear more contrasted to it, regardless of size and luminance polarity between targets and background. It should be noticed that I spoke about ‘degree of belongingness’, nevertheless even this is a hypothesis that ought to be tested, in the sense that so far no one has studied the problem whether belongingness is an ‘intensive’ factor (the more a surface belongs to other surfaces, the stronger lightness induction), or of the type ‘all or none’. While quite an interesting question, it is a problem that goes beyond the purpose of this dissertation.

Despite the lightness effects reported in this work are not strong, they cannot be just labelled as exceptions. They are, in fact, very consistent, and it is this consistency that makes them worthy of investigation. A question that one might want to pose is what do they stand for. Or, in other words, what is their ecological value within the economy of the visual system? While the question is not trivial, only wild speculations are at the moment possible. On the other hand, a similar question can be posed to Delboeuf’s illusion or any other type of illusion. However, the value of an illusion lies not exclusively in the fact that we understand why it appears, but because such phenomena are ‘natural laboratories’ that can aid our understanding on how the visual system works in creating the visual world (Kanizsa, 1979). Said this, I can dare try to give an answer to the question posed above.

Let’s first consider the fact that the effect of size (apparent or actual) on lightness is observed when there are two targets noticeably different in size, yet not exaggeratedly different. Then we must keep in mind that the effect is wiped out if the two targets are seen in different depth planes. With this in mind, my hypothesis is that the effect of size on lightness is an enhancement effect aimed to render the bigger target even more salient with respect to other components of the visual scene otherwise similar to the big target. Of course, many experiments are required before such a hypothesis can be seriously held in consideration.

7.2 Future research

First of all, given the appropriate conditions, is the size effect observable also in other size illusions, besides the Delboeuf and the Ebbinghaus illusions? If the effect of size on lightness is associated with an enhancement of a surface, then we should expect the effect to be found in other size illusions, such as in the Jastrow illusion (Fig. 7.1a). Is the effect
also associated with length differences? Would it appear in a modified Müller-Lyer (Fig. 7.1b)?

![Fig. 7.1: a) The Jastrow illusion; b) the Müller-Lyer illusion. The first is a size-area illusion, the second is an extension illusion.]

While dedicated experiments can answer such a question, I believe that we might find some surprises. The Jastrow illusion, for instance, in the version shown in Fig. 7.1, conveys also an impression of depth. How this will affect the lightness of the targets is not clear to me.

Another priority is to verify whether the contrast enhancement effect is actually of the type all-or-none as hypothesized in Ch. 5. I actually already tried to carry out another experiment with stereoscopic displays in an experimental design that can be considered a combination of experiments 6 and 7. However, I was not able to run the experiment yet because I am still looking for suitable stereoscope similar to the one I used for the experiments I carried out in Sendai. Configurations should consist of two squares of different size. The size of one of the squares will be fixed, the size of the other will vary from smaller to much larger (5 levels). A stereoscopic set-up is required to control for belongingness and depth perception, to avoid that size differences induce different depth impressions in two targets viewed simultaneously.

I also think that another experiment can be carried out to answer the same question. In exp. 8 I showed that lightness differences also appear in the Ebbinghaus illusion, despite the size effect in the displays I used might be less conspicuous with respect to textbook.
versions of the same illusion. The illusion is, in fact, sensitive to two factors: the distance between a target and its surrounding inducers, and the size difference in the surrounding inducers. By manipulating these two factors one should be able to determine a larger range of size differences than observable in Delboeuf’s illusion. This wider range of perceived size differences can be used to address the issue of what type of relationship links the perceived size of a target to its lightness in scenes in which at least two targets are presented simultaneously.

The Ebbinghaus illusion might be suitable also to address the issue whether the lightness effects reported are some sort of enhancement effect. It is useful here to remember that Vicario (1980) found that physically equivalent textured targets appeared different in the texture spacing when inserted within Delboeuf-like displays. In a somewhat similar fashion, Jaeger and Long (2007) found that a letter surrounded by a small inducer appeared somewhat bigger. Maybe these effects can be considered enhancements of target features. If this were the case, one would expect to find similar effects within the Ebbinghaus illusion, just as I found lightness effects similar to those found in Delboeuf-like displays. In addition, since the Ebbinghaus illusion appears also to be sensitive to the Gestalt factor ‘similarity’, in the sense that the effect is stronger when targets and inducers are similar in shape (Coren & Enns, 1993; Deni & Brigner, 1997; for another story, see also Rose & Bressan, 2002), it should be possible to verify what happens to all the aforementioned effects when targets and inducers are dissimilar in various ways: geometrically or categorically. The role of similarity suggests, in fact, that a component of the illusion is depth perception: small inducers and big inducers might induce apparent depth differences, which are stronger when targets and inducers are categorically related. A battery of experiments are of course required to verify many aspects, not to mention the problem that belongingness might overrun other effects. Given this last aspect, one must deal first with the issue of belongingness in pictorial displays observed in free vision: is belongingness an effective variable in such displays, or does such a factor work only when illusory depth is not a matter of opinion but actually observed, as in stereoscopic stimuli?

While considering possible future lines of research related to the findings reported in this study, I realize that I somewhat gave for granted that size does have an effect on the lightness of targets, given the appropriate conditions, which I have mentioned already several times. However, considering the body of data I produced, I think it would be illogical to reject the hypothesis that the lightness effects reported are directly related to an apparent or actual size difference between targets, even in spite of the results of exp. 7 that
do not allow to speak directly about a covariation or a correlation between the two phenomena. This finding is probably the most peculiar fact in this whole study, and it requires to be addressed with new experiments, some of which I just described. Nevertheless, if size in one way or another is not responsible for the lightness effects reported, then what else is left?
References


Abstract

The present study is dedicated to a lightness effect (achromatic surface colour) observed in Delboeuf size-contrast displays. In one of its classic forms, the Delboeuf illusion (1865) consists of two inner disks (targets) equal in diameter, surrounded each by a concentric circle (inducers) that differ in diameter. The size-contrast illusion consists in the phenomenal size difference between the two targets: the target surrounded by the small inducer appears somewhat bigger than the identical target surrounded by the big inducer. Brigner (Brigner, W., L., 1980. Effect of perceived size upon perceived brightness. *Perceptual and Motor Skills*, 51, 1331-1334.) was the first to observe a lightness effect in Delboeuf’s size-contrast displays. In particular, he found that the target that appears bigger appears also darker than the target that appears smaller, independently from the contrast polarity between targets and background. However results reported recently by Zanuttini & Daneyko (Zanuttini L. & Daneyko O., 2010. Illusory lightness in the Delboeuf figure. *Perceptual and Motor Skills*, 111, 799-804) are in contradiction with those reported by Brigner. In particular, they showed that when two targets are luminance increments to the background, the target that appears bigger appears also lighter than the target that appears smaller. The goal of the present study was: 1) to verify the existence and the direction of the lightness effects observed within Delboeuf size-contrast displays, and 2) to explore and test the possible factors underlying the aforementioned lightness effects.

To achieve the first goal, in experiment 1 (Ch. 1) I have employed two backgrounds, one dark and one bright, so that targets were either luminance increments or decrements to the background. I found for increment targets results that are consistent with those obtained in the previous study by Zanuttini and Daneyko (2010): when a pair of targets in a stimulus have the same luminance, the target that appears bigger appears also lighter. Decrement targets show instead opposite results: when targets are equal in luminance, the target that appears bigger appears instead darker, and they are consistent with those reported by Brigner for decrement targets.

To achieve the second goal, I considered three factors:
1) The role played by the luminance of the inducers (outer concentric circles; exp. 2, Ch. 2; exp. 7, Ch. 5);
2) The role of perceived depth (some researchers hypothesized that Delboeuf’s size illusion depends on the presence of implicit depth indexes; experiments 3 e 4, Ch. 3);
3) The role of perceived size differences between targets. (exp. 5 e 6, Ch. 4; exp. 7, Ch. 5; exp. 8, Ch. 6).

In experiment 2 I tested the effect of inducer luminance on the lightness difference between the targets in Delboeuf-like displays. For the predictions on possible results I referred to several group of hypothesis, among which those derivable from edge integration models for achromatic colour (Rudd M. & Zemach I., 2004. Quantitative properties of Achromatic color induction: An edge integration analysis. *Vision Research*, 44, 971-981), according to which a greater induction effect should be expected with small inducer+target than with big inducer+target. In addition, the direction of the induction effects should be different depending on whether the luminance of the inducers is an increment or a decrement with respect to the luminance of the target. Results showed instead that the luminance of the inducers is an ineffective variable for the lightness illusion observed within Delboeuf-like displays.

The hypothesis about the role of perceived depth on the observed lightness effects was inspired by those studies that suggested that size-contrast illusions are triggered by different mechanisms, including implicit depth clues (Coren S. & Girgus J. S., 1975. A size illusion based upon a minimal interposition cue. *Perception, 4*, 251-254). In exp. 3 I asked observers to choose which of two targets appeared closer in configurations similar to those employed in exp. 2. No significant result was found. Therefore I proceeded designing a new experiment with configurations geometrically simpler: two square targets of equal size seen against a dark or a bright background. I created an illusory depth differences between the two targets by employing stereograms viewed through a mirror stereoscope. Results were that the target that appeared more in depth appeared also more contrasted and bigger than the other target. In order to verify whether depth perception was causing the enhanced contrast effect with the background, or if the effects were due actually to a perceived size difference induced by stereopsis (according to Emmert’s law, with targets of equal angular size, the target that appears further away appears also bigger), I conducted experiments 5 and 6, from which it appears that the factors in play are not perceived depth, but first of all the degree of belongingness of a target to its background (exp. 5), and secondly the size difference
between targets (exp. 6). The results regarding belongingness are in agreement with those reported by Wolff (Wolff W., 1933. Concerning the contrast-causing effect of Transformed colors. Psychologische Forschung, 18, 90-97) and Kardos (Kardos L., 1934. Ding und Schatten [Object and shadow]. Zeitschrift für Psychologie, Erg. Bd, 23). Those which refer instead to size are new in the literature.

Experiment 7 was conducted to verify whether there is a correlation between how the size-contrast effect in Delboeuf-like displays is modulated by the size of the inducers, and the lightness effects observed in those displays. No correlation was found, so now my working hypothesis is that the effect of lightness differences observed in those displays is of the type *all or none*: when the conditions are favourable (same degree of belongingness to the background for the two targets; difference in apparent size), the target seen as bigger will also appear more contrasted to the background, but the enhanced contrast is not modulated by the magnitude of the size difference itself.

Finally, exp. 8 was conducted to verify whether the lightness effect exists also in Ebbinghaus’ illusion, another size geometric-optical illusion. Having found the effect also in the Ebbinghaus size-contrast illusion, and even though more parametric research is required to understand the extension of the illusion and its eventual modulations, I feel I can conclude that the effect of lightness difference between two targets of equal luminance presented simultaneously on a dark or bright background depends on the size difference between the two targets, but it is not modulated by the magnitude of such difference: the target that appears bigger (because it is somewhat bigger physically or only phenomenally) will appear lighter if the targets are luminance increments to the background, and darker if they are luminance decrements.

Per raggiungere il primo obiettivo, nell'esperimento 1 (cap. 1), ho usato due sfondi diversi, uno chiaro ed uno scuro, di modo che i target erano in un caso incrementi di luminanza rispetto allo sfondo, e nell’altro caso decrementi. Ho trovato che i risultati per target incrementali sono coerenti con quelli ottenuti nello studio precedente condotto da Zanuttini & Daneyko (2010): quando i due target sono uguali in luminanza, il target che appare più grande appare anche più chiaro. I target decrementali, invece, mostrano risultati opposti: quando i due target sono uguali in luminanza, il target che appare più grande appare più scuro, come riportato da Brigner per target decrementali.

Per raggiungere il secondo obiettivo, ho considerato tre fattori:
1) Il ruolo della luminanza degli induttori (i cerchi concentrici nell’illusione di Delboeuf; esp. 2, cap. 2; esp. 7, cap. 5);
2) Il ruolo della profondità percepita (alcuni studiosi ritengono che l’illusione di Delboeuf dipenda da indici impliciti di profondità; esperimenti 3 e 4, cap. 3);
3) il ruolo della grandezza relativa dei target (esp. 5 e 6, cap. 4; esp. 7, cap. 5; esp. 8, cap. 6)


L’ipotesi sul possibile ruolo della profondità percepita sugli effetti di bianchezza osservati è ispirata dall’ipotesi che le illusioni di contrasto di dimensione sono determinate da fattori diversi, tra cui indici impliciti di profondità (Coren S. & Girgus J.S., 1975. A size illusion based upon a minimal interposition cue. Perception, 4, 251-254). In esp. 3 ho chiesto agli osservatori semplicemente di indicare quale target apparisse più vicino in configurazioni alla Delboeuf simili a quelli utilizzati nell’esp. 2. I risultati non hanno indicato alcuna differenza statisticamente significativa tra la scelta di quale target apparisse più vicino. Ho quindi proceduto con un secondo esperimento (esp. 4) usando configurazioni geometricamente più semplici: due target di uguale dimensione e di forma quadrata posti sopra uno sfondo chiaro oppure scuro. Ho creato la profondità percepita mediante presentazione stereoscopica. È risultato che il target che appare più distante appare anche più contrastato e più grande. Per verificare se la profondità percepita era la variabile che causava l’effetto di contrasto osservato in esp. 4, oppure se tale effetto era dovuto alla grandezza apparente del target (per la legge di Emmert, a parità di grandezza retinica, il target più distante appare anche più grande), ho condotto altri due esperimenti, la 5 e la 6, da cui sono emersi che i fattori in gioco non sono la profondità percepita, bensì

L’esperimento 7 è stato condotto per verificare se vi fosse una correlazione tra la modulazione dell’effetto di grandezza nell’illusione di Delboeuf e l’effetto di bianchezza ritrovata in quel tipo di display. La correlazione statistica non è emersa, e l’ipotesi è che l’effetto di incremento di contrasto rispetto allo sfondo per il target che appare più grande sia del tipo ‘o tutto o niente’: quando le condizioni sono presenti (stesso grado di appartenenza allo sfondo per i due target; diversa grandezza fenomenica), allora si verifica l’effetto e non è graduato dalla differenza apparente di grandezza dei target.

L’esperimento 8, infine, è stato condotto per verificare se il fenomeno esiste anche nell’illusione di Ebbinghaus, un’altra illusione ottico-geometrico di grandezza. Avendo ritrovato l’effetto di differenza di contrasto rispetto allo sfondo anche lì, e sebbene siano ancora necessari esperimenti parametrici per verificare l’estensione dell’illusione, penso di poter concludere dicendo che l’effetto di differenza di bianchezza tra target aventi la stessa luminanza, visti simultaneamente sopra uno sfondo chiaro oppure scuro, dipende dalla diversa grandezza relativa dei target, ma non dall’entità di tale differenza: il target più grande (fisicamente o solo fenomenicamente) apparirà più chiaro se i target sono un incremento di luminanza rispetto allo sfondo, e più scuro se sono un decremento.