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Abstract

The experience of light determined some of the most intriguing cultural universals, yet it is an underrepresented problem in vision sciences. In their attempt to represent cultural universals, artists adopted empirical solutions to the representation of light sources. We believe that such graphic solutions are showcases of visual indexes related to the phenomenology of light, and therefore they already constitute a level of explanation for luminosity perception. This claim is supported by psychophysical experiments on the 'glare effect', an illusion that generates a vivid impression of self-luminosity only by means of quasi-linear luminance ramps. Recent studies show that a similar illusion can be obtained in absence of physically continuous luminance ramps. Results from several experiments suggest that: 1) the key features for luminosity perception lie within the photo-geometric structure of the proximal stimulus; 2) the processes involved in luminosity perception are intrinsically different from those involved in surface color perception.

Key words: *Light, Pictorial representations, Luminosity, Glare effect*

1. *Lux aut lumen*?

Gibson (1979) posed a question that can sound trivial to the crowd but is intriguing to the vision scientist: *do we ever see light as such?* His answer was *no*: we do not see electromagnetic energy or photons, but a world of meaningful things. His take on the role of light in visual perception dampened the scientific interest on luminosity perception; or maybe just a common sense about why certain objects appear luminous veiled an otherwise rather challenging problem. Fact is that only few studies have been devoted to the perception of luminosity.

Part of the problem might relate to the use of the word 'light'. Gibson used it to refer to the physical energy that is capable of stimulating photoreceptors. His claim is that if light were visible we would not see the visual information it delivers. Light therefore belongs to the domain of physics; it concerns vision scientists not because it is a perceptual entity, but because it is the proper stimulus for vision.

Despite this view, the word 'light' is also used in everyday language to denote some common visual experiences, such as luminosity and illumination. Hence the word 'light' belongs to two distinct yet interrelated domains: the physical and the phenomenal.

Ronchi (1970) proposed to reconsider the fine distinction made by medieval thinkers who used the term *lumen* to speak about the entity that entered the eye making visual perception possible, and the word *lux* to speak about the visual experience of light and luminosity. He therefore suggested that a different set of words should be used to keep distinct those two domains. In fact, light as a source of stimulation and light as a visual experience are two different things. Lets consider the expression "to be without light": in physics it means that an environment is free of wandering photons (and therefore photoreceptors are not stimulated). Instead in the phenomenal domain it literally means that one is in a dark environment. Being in a dark environment does not imply the absence of photons: it means that the environment is characterized as not being sufficiently illuminated.

Conforming to Ronchi's proposal, in the following study we shall use the words 'light', 'luminosity' and 'brightness' to refer to visual experiences, and we shall use words such as 'electromagnetic energy', 'photons', 'luminous energy', to refer to the physical entity capable of stimulating photoreceptors.

2. Light in art

The significance of light as a visual experience should not be undermined: it informed myths, religious believes, and it nourished philosophical speculations. For instance, cosmogonies originating from different cultures typically indicate light as one of the first divine creations. Along with this supremacy, light has always been a metaphor for higher knowledge, theological revelation, and all what is good as opposed to what is evil (and therefore dark): *The light shines in the darkness, but the darkness has not understood it* (*New Testament,* John, 1 3-9). Light is therefore a fundamental cultural universal, and as such it has been object of many representations in visual arts. The collection of such artifacts constitutes a showcase of the pictorial indexes involved in light perception.

2.1. Irradiation and Rectilinear diffusion

The first attempts to depict light are to be found in the representations of the sun and the moon. Though the moon only reflects luminous energy, it appears self-luminous at night: *How beautiful both eyes of Amon-Ra /* [...] */ Men began to see / when first thy right eye sparkled out / and thy left drove off night's gloom* (Theban hymn, Vavilov, 1955, pp. 6-8). Early depictions of solar deities already present the graphic translation of two fundamental visual indexes for light perception: *irradiation* and *rectilinear diffusion*: in the *Stele of Ur-Nammu*, the solar disc is surrounded by triangular and rectangular spikes (Fig. 1).

Fig.1. *Stele of Ur-Nammu* (detail, Mesopotamia, end of III millenium B.C.).

While the triangular spikes represent a basic graphic solution to the representation of both rectilinear diffusion and irradiation found in other cultures (Fig. 2-3), the rectangular spikes with their internal wavy lines deliver rather accurately the idea of light irradiation, an experience that can be both visual and tactile (Fig. 4).

Fig. 2. *Atzec sun stone* (XV century, Mexico).

Fig. 3. *Helios* (detail, Troy VIII, 300 B.C.).

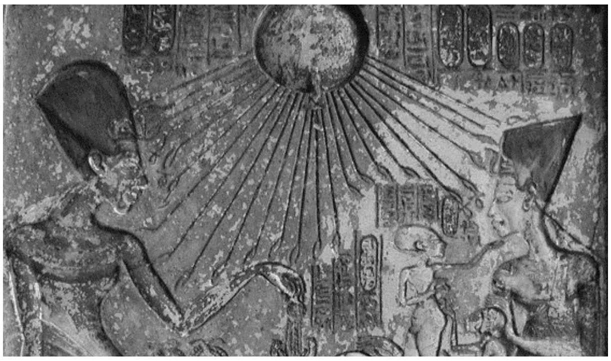

Fig. 4. *Akhenaton and his family worshipping Aton* (detail, New Kingdom, XVIII dynasty, 1375-1358 B.C.).

2.2. Reflection, diffraction, and refraction

Opaque surfaces *reflect* luminous energy, but also cause its *diffraction*, i.e. changes in the direction of its flow. When luminous energy travels from one medium to another at an angle (e.g. from sky to water, or between portions of sky of different densities) it is *refracted*. The combination of these three effects determines various visual phenomena. The experience of light irradiation and rectilinear diffusion are among these phenomena, but the most peculiar ones are glories, halos and fringes of light. These in particular have been invested of mystical and transcendental significance in many cultures. The visual experience of a glory was identified as *Buddha's light* in ancient Chinese culture, and it has been figuratively translated as a disk surrounding the head or the entire figure of Buddha (Fig. 5).

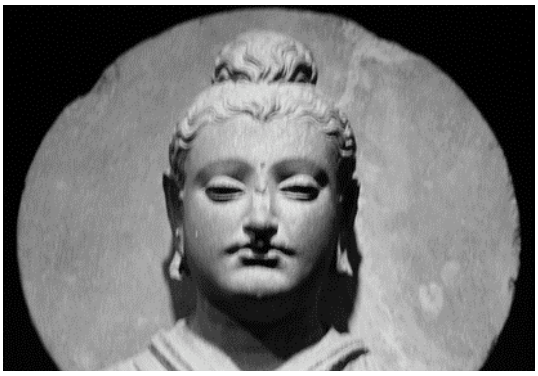

Fig. 5. *Buddha*(detail, Kushan dynasty, II-III century A.C.).

In Christian culture, the head of Jesus and of the many saints are commonly represented surrounded by haloes (Fig. 6), while the entire figure of Jesus and of Mary are sometimes represented surrounded by a glory. Both the Christian and Buddhism iconographies were most likely influenced by Hellenistic representations of Helios (Fig. 2), later identified by the Romans as *Sol Invictus*.

Fig. 6. Tintoretto, *Last supper* (detail, Venezia, San Giorgio Maggiore).

2.3. Shadows

The artist creates the illusion of a luminous object in a picture not so much by painting the object in particularly bright colours as by distributing the light and shadow appropriately with reference to the object within the pictorially represented space. When Katz (1935, p. 28) wrote these words, he was thinking about 'nocturne nativity' paintings, like those by Geertgen tot Sint Jans (1460-1490), Correggio (1489-1534), and Gerard van Honthorst (1590-1656). In agreement with Katz, Metzger (1975) describes the baby as appearing luminous in the *Adoration of the shepards* by Gerard van Hornthorst.

The issue whether a pictorial representation can provide an actual experience of luminosity is rather complex (Zavagno & Massironi, 1997). Katz in this regards is ambiguous: in the passage reported above he seems positive about such a possibility, but on the same page he also reports Hering's hypothesis on luminosity perception, according to whom *a colour must be brighter than white under the same conditions of illumination if it is to be characterized as luminous* (Katz, 1935, p. 28).

3. Luminosity thresholds and the glare effect

Because there is no pigment brighter than white that can be used, according to Hering an artist can only suggest the impression of a light source in a painting, not actually show luminosity. This view is supported by the empirical studies conducted by Bonato and Gilchrist (1994, 1999), according to whom a surface starts to appear self-luminous when its luminance is about 1.7 times the luminance of a surface that would appear white in the same illumination conditions. The threshold defined by Bonato and Gilchrist inevitably anchors luminosity perception to the upper limit of the lightness scale (i.e. achromatic surface color).

We however suggest that the supposed luminosity threshold actually stands for something else: it is the intensity at which the proximal stimulus of a surface that appears luminous is accompanied by fringes of light, haloes, and a general intraocular light scatter of a certain entity that determines the presence of a luminance ramp around the surface. We derive our hypothesis from several studies conducted on the glare effect (Fig. 7), a pictorial luminosity illusion (Zavagno, 1999). Two of the studies in particular demonstrate that luminosity is independent from lightness, and if anything it is the presence of a light source that influences the perception of lightness, not vice versa (Zavagno & Caputo, 2005; Daneyko & Zavagno, 2008).

Bonato and Gilchrist (1994), and Ullman (1976) before, prepared their stimuli in order to avoid as much as possible the presence of what they considered to be "visual noise": light fringes and haloes. In our experiments observers artificially determined similar features in the distal stimulus, achieving luminosity perception at much lower luminance values than those required to see a surface as white in the same illumination conditions.

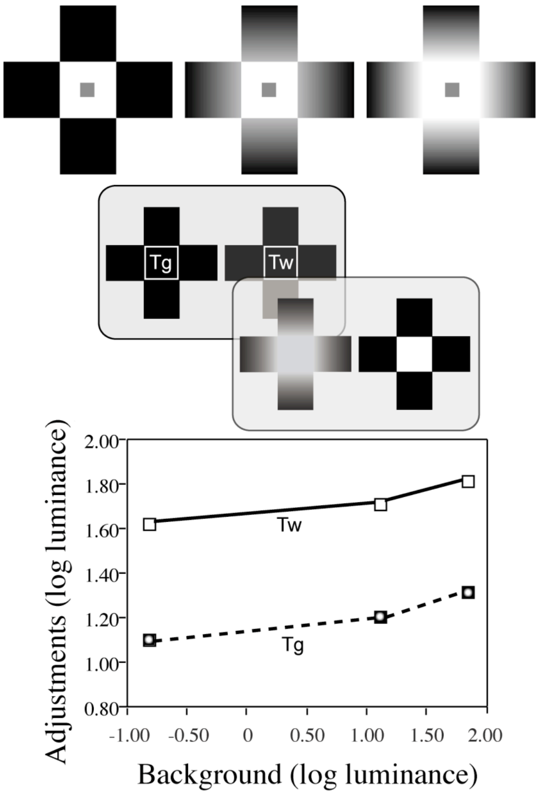

Fig. 7. Above: differences in the range of surrounding luminance ramps determine brightness differences among the white central squares, affecting also the lightness of targets equal in reflectance. Below: mean luminance adjustments by 6 observers for two target areas presented simultaneously. Observer's task was to increase the luminance of Tw until it appeared white, and the luminance of Tg until it appeared luminous. Modifications in the luminance of Tg were accompanied by equal luminance changes in the luminance ramps. Adjustments were performed in a bright room.

There are still several issues that need to be addressed. One of them concerns the integration of photo-geometric features across space. For instance, an impression of luminosity can be induced with what we call luminance 'pseudo-ramps' (Fig. 8). Such configurations show effects on lightness of the same magnitude as those produced with regular luminance ramps (Zavagno & Daneyko, 2008).

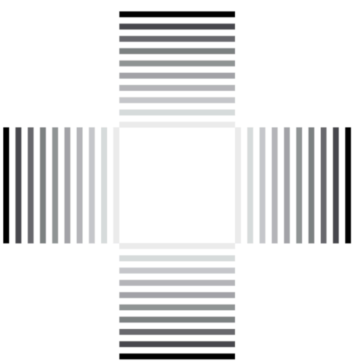

Fig. 8. Glare effect with luminance pseudo-ramps.

4. Conclusions

In their attempts to render the visual experience of light and luminosity, artists succeeded in translating into graphic terms visual indexes that are specific to the experience of light in the real world. Whether they succeeded in actually showing luminosity is still an open question. Nevertheless, a brightness illusion, published by Kennedy (1976) and precursor of the glare effect, shows how close Renaissance artists were to the solution. Those visual indexes are currently still employed to increase the perceived brightness range in virtual environments by rendering light sources.

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