

# THE STRENGTH OF A VISUAL ILLUSION MEASURED BY A RELATED ILLUSORY PHENOMENON

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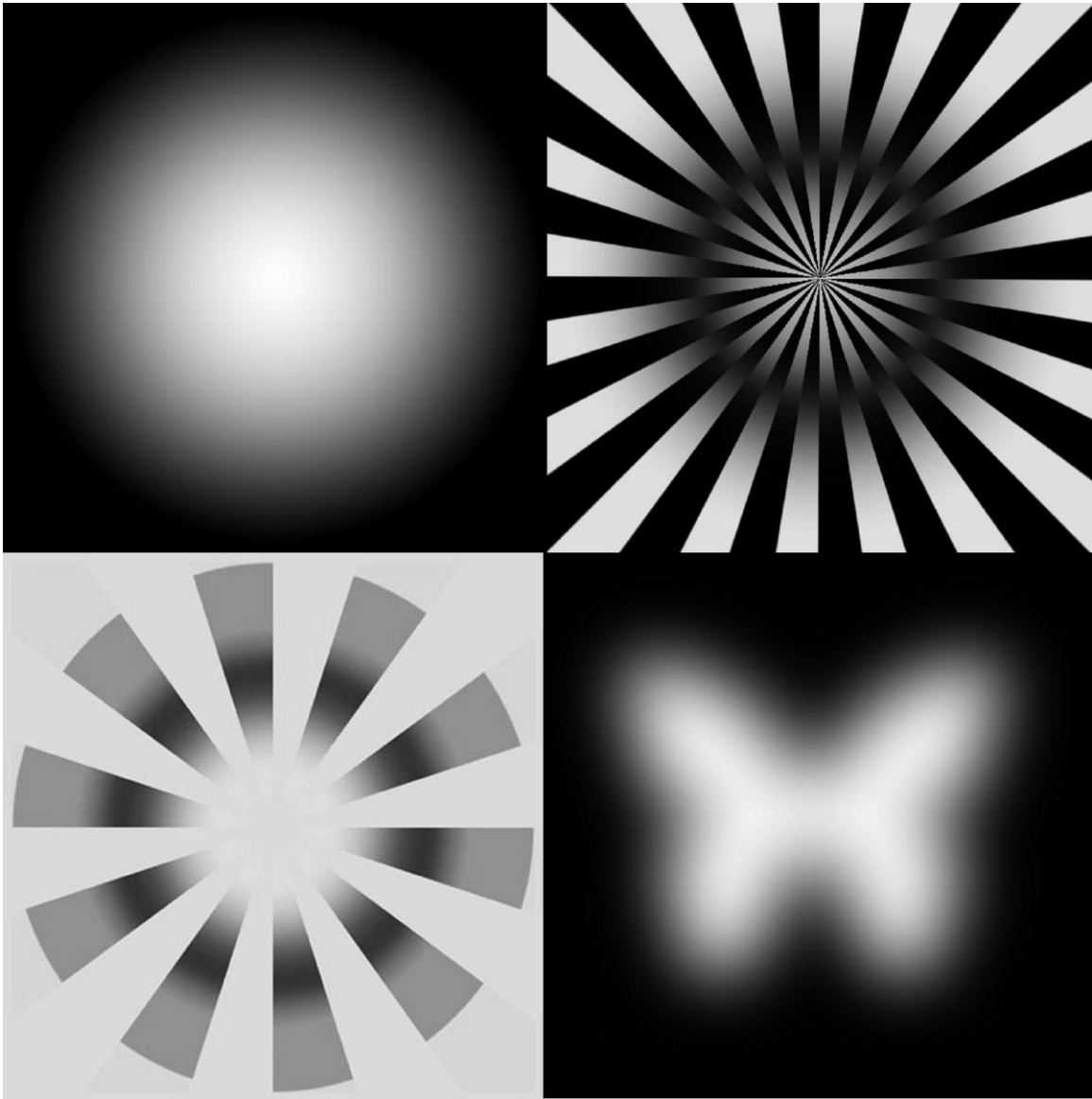
## Abstract

*Quantifying perceptual illusions leads to estimate the endogenous dynamics underlying perceptual processing. In the present research we consider the illusory enhancement in brightness occurring when one approaches a blurred white area, a phenomenon called “Breathing Light Illusion” (BLI) by Gori & Stubbs (2006). We test the strength of the brightness variation by means of a grey sharp-boundary disk superimposed on the blurred white region. When approaching the stimulus the blurred area was perceived brighter and simultaneously the grey disk darker. Two experiments demonstrate a causal relationship between the increase in brightness due to the BLI and the darkening of the superimposed disk. Importantly, the increment of achromatic contrast of the disk superimposed on the blurred area indirectly quantifies the BLI effect.*

The existence of perceptual illusions has been noted since the ancient times (Wade, 1996; Wade, 2005) and stimulated philosophical inquiries on the truth of the sensorial experience and its correspondence with reality (Boring, 1942; Masin, 1989; Vicario, 2006). Illusory phenomena are discovered when a discrepancy is experienced between what one perceives and the physical measurement of the stimulus eliciting the corresponding percept. Illusions therefore indicate that perceptual phenomena are not simply determined by the physical manipulations of a stimulus, and demonstrate instead the active work of the sensorial system in stimulus processing. Measuring illusions can appear paradoxical because of the discrepancy between the physical description of a stimulus and the respective percept (Fisher, 1967; Fisher 1973; Vicario, 2010). That measurement is nonetheless necessary to demonstrate the occurrence of an illusory phenomenon, i.e. the discrepancy between the actual perception and what expected to be perceived when considering the physical stimulus. Moreover, quantifying perceptual illusions can be a tool to estimate the endogenous dynamics underlying perceptual processing and to hypothesise their possible physiological correlates (Eagleman, 2001; Gregory, 1968; Spillmann, 2009).

The subjective nature of colour sensation was observed by the Persian natural philosopher Alhazen (circa 965-1040 AD), and thought as partly due to a mental process (Kingdom, 1997). Before the arise of experimental psychology, Renaissance painters knew empirically how to modulate the brightness by manipulating edges appearance (Zavagno & Massironi, 1997). Experimental studies have shown than a blurred boundary leads to an increment of the brightness independently of the physical luminance value (Burgh, 1964; Kennedy, 1976; Zavagno, 1999). The blurred boundaries can affect the brightness of a superimposed figure with sharp boundaries (Agostini & Galmonte, 2002). Those authors

showed that a middle-grey region placed at the centre of an area filled by a linear achromatic gradient from black (outer part) to white (inner part) is perceived to be much darker than an identical middle-grey region surrounded by a reversed gradient. This phenomenon is significantly stronger than the classical achromatic simultaneous-contrast effect. Furthermore, blurred boundaries also produce a variation of size and brightness in dynamic presentation (Gori & Stubbs, 2006). This effect, known as the “Breathing Light Illusion” (BLI), consists of a blurred white spot on a black background (Figure 1). This spot appears wider, brighter and more diffuse when it is approached, but smaller, darker and sharper when one recedes from it (Gori & Stubbs, 2006). These illusory phenomena have been explained as a superimposed negative afterimage on the physical stimulus due to the dynamic presentation (Anstis, Gori, & Wehrhahn, 2007).



**Figure 1.** A series of variations of the Breathing Light Illusion (Gori & Stubbs, 2006).

In the present research we report a quantification of the BLI strength by means of a related illusory phenomenon (Gori, Giora, & Agostini, 2008; Gori, Giora, & Agostini, 2010). We investigate the increment of the achromatic contrast of a grey sharp-boundary disk when it was superimposed on a blurred white area (BLI). The measurement of illusory achromatic contrast therefore provides an indirect quantification of the BLI.

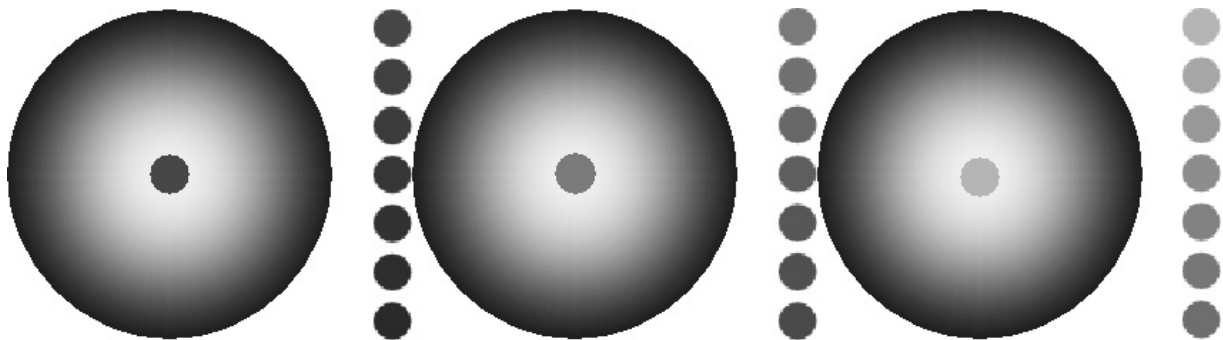
## Experiment 1

In Experiment 1 we tested three different grey disks that have a sharp boundary superimposed one by one on the centre of the BLI. We aimed to quantify the differences in perceived luminance of the disks between a *static* and a *dynamic* (i.e. when the subject approaches the stimulus) condition.

### Method

*Subjects.* Fifteen naive subjects (mean age = 22 years; SD = 6.8 years) participated in the study. All had normal or corrected-to-normal visual acuity.

*Stimuli.* A circular BLI (diameter = 20 cm) with a linear luminance profile from dark (luminance =  $1.9 \text{ cd/m}^2$ ) in the outer part to bright (luminance =  $86 \text{ cd/m}^2$ ) in the centre served as a background. Three different uniform grey disks (luminance values respectively = 8.6, 23.5, 48.4  $\text{cd/m}^2$ ) with sharp boundaries were superimposed one after the other on the BLI (Figure 2). Every stimulus was paired with a seven-step log luminance scale (scale 1 luminance values = 8.6, 7.3, 6.4, 5.4, 4.6, 4, 3.4  $\text{cd/m}^2$ ; scale 2 luminance values = 23.5, 20.1, 17.2, 14.6, 12.4, 10.7, 9.3  $\text{cd/m}^2$ ; scale 3 luminance values = 48.4, 41.6, 35.3, 30.3, 26, 22.1, 19.1  $\text{cd/m}^2$ ) displayed on a white background (luminance =  $86 \text{ cd/m}^2$ ).



**Figure 2.** Stimuli used in Experiment 1.

*Procedure.* The subjects' task was to match the brightness of one disk with that of a second disk with a seven-step log luminance scale both in static and dynamic conditions. In the static condition the subjects were seated 80 cm away from a 15 inch LG monitor (CRT). The diameter of the BLI measured 14.2 deg, while that of the superimposed disks measured 1.9 deg. The subjects observed the stimuli with central fixation, without time constraints. When the subjects were able to estimate the brightness of the disk, the stimulus disappeared and the

log luminance scale was presented on the side of the screen. The subjects had to decide which disk of the log luminance scale had an equal luminance as the disk located inside the stimulus. The same three stimuli were shown in dynamic condition. When the stimulus appeared on the screen, the subjects had to move their head quickly from 80 cm to 40 cm away from the screen. Thus, the diameter of the BLI changed from 14.2 to 28 deg and that of the superimposed disk from 1.9 to 3.6 deg. When the subjects reached the chin-rest, the stimulus automatically disappeared and the log luminance scale was shown on the side of the screen. The task was the same as that in the static condition. After the two sessions the subjects were also explicitly asked to report in which condition the disk was perceived darker. The two conditions and the stimuli were randomised in each experimental session.

## Results and Discussion

The results showed that a clear increment of illusory contrast magnitude occurs under the dynamic condition. Indeed, the disk was perceived significantly darker than under static condition at all brightness values (repeated-measures ANOVA:  $F_{(1, 14)} = 20.4$ ;  $p < 0.001$ ). The magnitude of the effect was different for the three disks. The inner disk presented in dynamic condition was always perceived darker than the one in static condition. All disks were perceived as darker than their physical value.

The results suggest that both the presence of a gradient on the background and the dynamic viewing (both responsible for the BLI effect) would be crucial factors that lead to the increment of perceived contrast. The difference in brightness between the static and the dynamic condition indicates that the increased perceived contrast in the inner circle could be due to the illusory enhancement of brightness characterising the BLI in the dynamic condition. Therefore, the decrement of the brightness of the grey superimposed disk caused by the illusory enhancement of the brightness of the background would represent a *second-order phenomenon* of illusory brightness variation (Gori, Giora, & Agostini, 2008).

Nevertheless, a crucial issue remains still uncertain: is that difference in brightness of the disk due to the variation of the BLI in the background created by motion or can it be caused just by a correlated process implied by moving toward the pattern? The next experiment will disambiguate between these two possibilities.

## Experiment 2

Experiment 2 tests whether the motion itself can explain the variation in the brightness of the inner disk between the static and dynamic condition, and, consequently, the need of the blurred boundaries of the background. If the blurred background is necessary to perceive the variation in the superimposed disk, the causal relationship between the two illusory effects can be demonstrated.

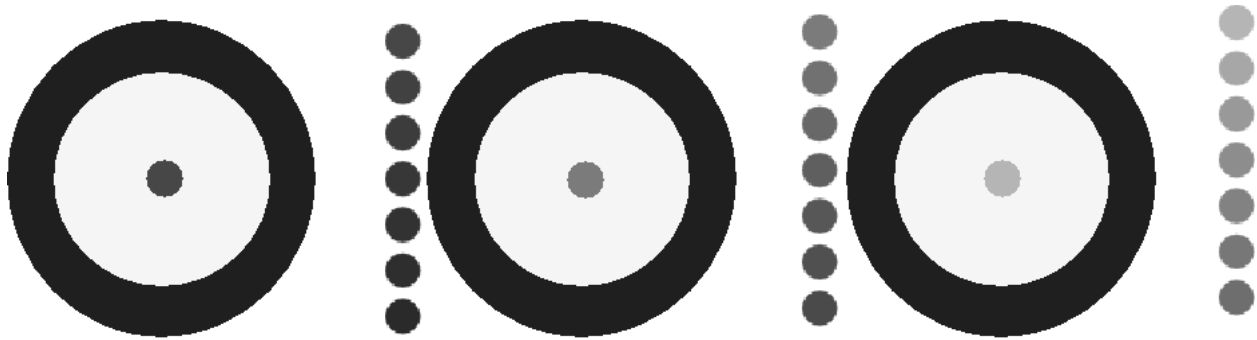
## Method

*Subjects.* Fifteen new naive subjects (mean age = 25 years; SD = 4.8 years) participated in the study. All had normal or corrected-to-normal visual acuity.

*Stimuli.* A white disk (luminance = 86 cd/m<sup>2</sup>) with a 14 cm diameter surrounded by black annulus (luminance = 1.9 cd/m<sup>2</sup>) with a 20 cm outer diameter served as background for the stimulus. The average luminance of the background was exactly the same as that of the BLI used in Experiment 1. The three different uniform grey disks used earlier were superimposed one after the other on the background described above. Each stimulus was paired with a

seven-step log luminance scale (scale 1 luminance values = 13.8, 11.7, 10.2, 8.6, 7.3, 6.4, 5.4 cd/m<sup>2</sup>; scale 2 luminance values = 37.5, 31.9, 27.2, 23.5, 20.1, 17.2, 14.6 cd/m<sup>2</sup>; scale 3 luminance values = 76.9, 65.9, 56.8, 48.4, 41.6, 35.3 cd/m<sup>2</sup>) (Figure 3). The difference in the values of the log luminance scale from those in Experiment 1 is due to the different background: without blurred boundaries no enhancement of the contrast for the disk is expected in the static condition.

*Procedure.* The procedure was the same as that used in Experiment 1, but the aforementioned stimuli were employed.



**Figure 3.** Stimuli used in Experiment 2.

## Results and Discussion

The results showed no difference between static and dynamic condition (repeated-measures ANOVA:  $F_{(1, 14)} = 1.75$ ;  $p = 0.2$ ). All three disks were perceived as equal to their physical value on the log luminance scale.

The results demonstrate that the presence of a gradient on the background (necessary for the BLI effect) is crucial to produce a brightness reduction in the disk, as found in the dynamic condition of Experiment 1. Without the brightness increment in the background, the brightness of the disk with the sharp boundary does not change. The motion itself and, consequently, the superimposition of the negative afterimage of the inner disk (produced at time t1, i.e. at an 80 cm viewing distance) on the physical inner disk (time t2, i.e. at a 40 cm viewing distance) does not significantly affect its brightness.

## Conclusion

To summarise, the two experiments demonstrate that the darkening of the grey disk superimposed on a blurred white area which appears brighter when approached by an observer (BLI), supports the existence of a causal relationship between the two phenomena (Gori, Giora, & Agostini, 2008). This augmentation of the perceived contrast in the dynamic presentation of the BLI was significantly stronger than the effect found by Agostini & Galmonte (2002) in static presentation. Measuring the increment of achromatic contrast of the disk superimposed on the blurred area provides a quantitative information on the strength of the BLI (Gori, Giora, & Agostini, 2010).

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