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The phantom illusion

Alessandra Galmonte [a,*], Alessandro Soranzo [b], Michael E. Rudd [c], Tiziano Agostini [d]

[a] Department of Neurological, Biomedical and Movement Sciences, University of Verona, Italy
[b] Faculty of Development and Society, Sheffield Hallam University, United Kingdom
[c] Howard Hughes Medical Institute, Department of Physiology and Biophysics, University of Washington School of Medicine, Seattle, WA, USA
[d] Department of Life Sciences, University of Trieste, Italy

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ABSTRACT

It is well known that visible luminance gradients may generate contrast effects. In this work we present a new paradoxical illusion in which the luminance range of gradual transitions has been reduced to make them invisible. By adopting the phenomenological method proposed by Kanizsa, we have found that unnoticeable luminance gradients still generate contrast effects. But, most interestingly, we have found that when their width is narrowed, rather than generating contrast effects on the surrounded surfaces, they generate an assimilation effect. Both high- and low-level interpretations of this "phantom" illusion are critically evaluated.

1. Introduction

A spatial change in luminance within the retinal image can be produced by either an illumination change or by a surface reflectance change. Under many circumstances, we are able to correctly attribute the physical cause of the discontinuity. To do this, we benefit from all the information available in the retinal image. One important aspect of this information is the profile type of luminance change. When the profile of the luminance change in the retinal image is gradual, the luminance transition tends to appear as an illumination change; conversely, when the profile is sharp, the sharp edge tends to appear as a reflectance transition (Soranzo & Agostini, 2004; Soranzo, Galmonte, & Agostini, 2009).

Hering (1920/1964), for example, observed that a shadow covering a homogeneous surface appears as a dark stain if the gradual luminance transition at its edge is masked by a black ink. This demonstrates that a physical illumination edge may appear as a reflectance edge if its luminance profile is made to appear sharp rather than gradual.

Conversely, gradual luminance changes tend to be perceived as illumination edges even when they are physically generated by reflectance edges. Kennedy (1976) showed that a set of black dots grouped on a white background create the impression of radiating lines which fade towards the centre and generate the percept of a central glowing region (Fig. 1a).

Recently, a number of compelling visual illusions have been created through the use of gradients. In many cases, it is not known whether the illusion is produced because the observer interprets the gradient as arising from an illumination change. For example, Zavagno (1996, 1999) presented the illusion shown in Fig. 1b. The luminance of the central part of the cross is the same as that of the rest of the page, yet it appears quite different: a bright halo appears to cover about 3/4 of the area occupied by the cross.

Another illusory effect that is generated by luminance gradients was published by Gori and Stubbs (2006). Their display consists in a black background on which is placed a circular white spot; its boundaries are characterized by a luminance gradient that gives an impression of blur. The display produces the perception of a tunnel in depth that goes forward to the area having the highest luminance at the centre of the image (Fig. 1c).

Besides generating the perception of glares, blurs or halos, luminance gradients may also generate strong perceptual contrast effects. Agostini and Galmonte (1997, 1998, 2002) found that a 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 as being much darker than an identical middle grey region surrounded by the reversed gradient (Fig. 1d).

A different type of evidence that luminance gradients generate contrast effects has been provided by McCourt (1982). An inducing field containing a vertical sinewave luminance grating which

* Corresponding author at: University of Verona, Via Casorati 43, 37131 Verona, Italy.
E-mail address: alessandra.galmonte@univr.it (A. Galmonte).

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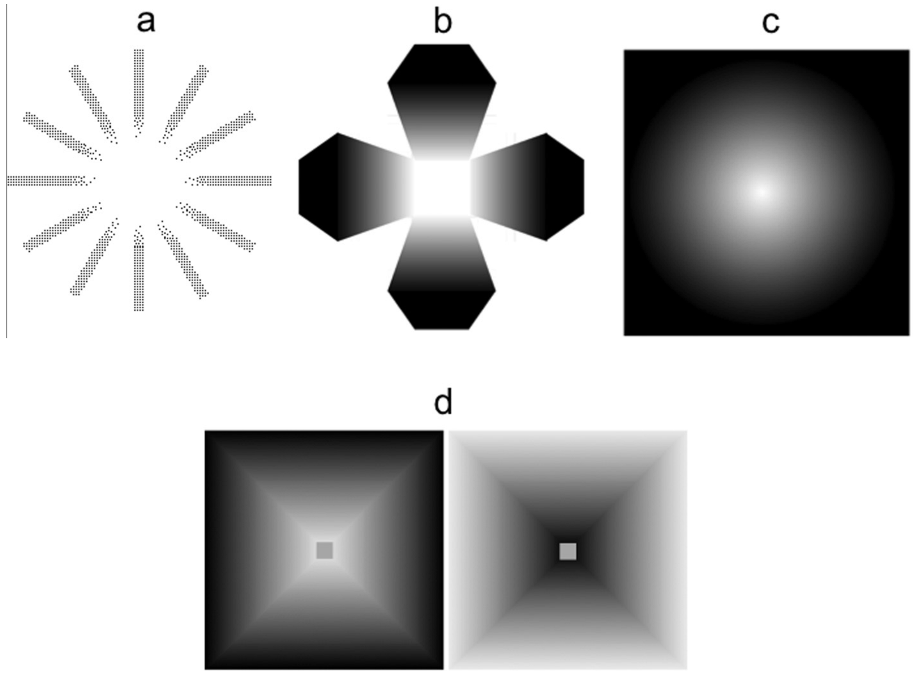

Fig. 1. Gradual luminance transition may generate the perception of glares, blurs or halos ((a) Kennedy's figure; (b) Zavagno's figure; (c) Gori & Stubbs' figure); luminance gradients may also generate contrast effects ((d) Agostini & Galmonte's figure).

surrounds a test field of similar space-average luminance induces within the homogeneous test field a contrast effect that results in the appearance of a second sinewave grating of equal spatial frequency, but of opposite phase.

Moulden and Kingdom (1991) demonstrated a low contrast version of this grating induction effect, in which a narrow homogeneous luminance stripe placed on a low contrast background sinusoidally modulated in luminance (but almost below threshold) appeared sinusoidally modulated but opposite in phase to the inducing grating. Their grating induction effect is particularly important for the purposes of the present paper because it demonstrates that luminance gradients may generate contrast effects even when their amplitude is reduced in order to be practically unnoticeable.

In summary, luminance gradients tend to appear as illumination edges, they may generate glares or halos, and they may generate strong contrast effects. Furthermore, these transitions do not need to be clearly visible: unnoticeable luminance gradients may still generate contrast effects. To underscore this point, consider a variant of the Agostini and Galmonte (2002) illusion where the steepness of the luminance gradients is reduced to be virtually unnoticeable (Fig. 2 top part). As the figure demonstrates, contrast effects persist even after the gradient's steepness has been reduced so as to make the gradient almost invisible. The two targets share the same luminance, but the one on the left appears darker. This contrast effect appears to be generated by the luminance surrounding the squares: the luminance surrounding the square to the left higher rather than that of the square itself; conversely, the luminance surrounding the square to the right is lower (refer to the luminance profile at the figure sides). This is compelling evidence that the luminance gradients do not need to be visible to generate contrast effects.

But what happens if the *width* of these luminance gradients is narrowed. Will they still generate contrast effects? Quite surprisingly, when the width of the invisible luminance gradients is narrowed, we find that they generate assimilation, rather than contrast: surfaces that are surrounded by a higher luminance appear lighter rather than equal surfaces that are surrounded by a darker luminance. Fig. 2 bottom part demonstrates this new illusion, which we call the phantom illusion because it is generated by imperceptible gradient inducers. The luminance surrounding the left target in Fig. 2 bottom part is the same as the luminance surrounding the left target in Fig. 2 top part. Similarly, the luminance surrounding the right target in Fig. 2 top part and in Fig. 2 bottom part is the same. However, the effect on targets lightness is the opposite.

To test the hypothesis that the width of luminance gradients affects the lightness of the embedded surface, we ran an experiment aimed at collecting observational data from naïve participants.

2. Experiment

2.1. Methods

2.1.1. Observers

Twenty observers participated. All had normal or corrected to normal vision. They were naïve to the purpose of the experiment. The experiment was carried out according to our institution guidelines for ethical issues and in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki). Informed consent was obtained from participants.

2.1.2. Apparatus and stimuli

The stimuli were presented on a high definition Trinitron CRT monitor (1280 $\times$ 1024 pixels) controlled by a PC. Luminance and chromaticity have been controlled.

Fig. 3 depicts the luminance profiles of the stimuli.

There were three stimulus configurations. Each configuration was composed of three pairs of displays, arranged vertically and presented simultaneously to the observers. Each display included one background and one target. The display pairs were as follows:

2.1.2.1. Display pair A-B. The display pair A-B included the square shaped backgrounds A and B subtending 6.45° each and whose