Available online at www.sciencedirect.com
ScienceDirect
Vision Research 47 (2007) 3360–3372
Vision Research
www.elsevier.com/locate/visres

Gradient representations and the perception of luminosity

Matthias S. Keil *

Basic Psychology Department, Faculty for Psychology, University of Barcelona (UB), Passeig de la Vall d'Hebron 171, E-08035 Barcelona, Spain

Received 5 April 2007; received in revised form 19 September 2007

Abstract

The neuronal mechanisms that serve to distinguish between light emitting and light reflecting objects are largely unknown. It has been suggested that luminosity perception implements a separate pathway in the visual system, such that luminosity constitutes an independent perceptual feature. Recently, a psychophysical study was conducted to address the question whether luminosity has a feature status or not. However, the results of this study lend support to the hypothesis that luminance gradients are instead a perceptual feature. Here, I show how the perception of luminosity can emerge from a previously proposed neuronal architecture for generating representations of luminance gradients.

Keywords: Luminosity; Glow; Luminance gradients; Early vision; Brightness; Lightness

1. Introduction

Under daylight illumination conditions, looking at a television or computer screen rarely produces the sensation that displayed items are light emitting, although each pixel of the screen emits light (Zavagno & Caputo, 2001, with references).

But to perceive objects as being luminous, it is not necessary to have a physically source of light emission. Halos were used by artists since a long time as a means to create luminosity effects in their paintings (Zavagno & Caputo, 2001, with references). When a region is painted with a halo surrounding it, then one perceives this region with enhanced brightness, or even as glowing, without physical light emission being present. Thus, the perception of glow *can* be evoked on (light reflecting) paper or canvas, and text or pictures being displayed on a (light emitting) computer screen are *not necessarily* being perceived as luminous.

In other situations perception and physics are not divergent. For example, the sun is always perceived as light emitting and so are stars at night. In such situations, the strong contrast between light sources and background may provide the key factor to the perception of luminosity (Bonato & Gilchrist, 1994; Bonato & Gilchrist, 1999).

A recent fMRI study has identified a region in the brain which seems to be associated with the perception of luminosity (Leonards, Troscianko, Lazeyras, & Ibanez, 2005). In this study, different configurations of the glare effect display (Bressan, Mingolla, Spillmann, & Watanabe, 1997; Kennedy, 1976; Zavagno, 1999; Fig. 5, top row) were presented to human observers. The results of the study were indicative to that luminosity might constitute a perceptual feature much like contrast, orientation, motion, or faces.

The question about whether luminosity is a perceptual feature or not motivated a corresponding psychophysical study (Correani, Scott-Samuel, & Leonards, 2006). The study was based on the idea that perceptual features are distinguished from other object properties by being processed in a more efficient way. This means that visual features consume less attentional resources than non-features (Jospeh, Chun, & Nakayama, 1997), what is reflected in, for example, "pop out" effects. A visual search paradigm such as the one used in the study of Correani et al. (2006), therefore can serve to distinguish features from non-features.

* Fax: +34 934 021 363.
E-mail address: mats@cvc.uab.es

0042-6989/$ - see front matter
doi:10.1016/j.visres.2007.09.018

Unexpectedly, the results of Correani et al. are compatible with that *luminance gradients* instead of luminosity are a visual feature. Several authors have already formulated the hypothesis that luminance gradients are involved in the perception of luminosity (Kennedy, 1976; Zavagno, 1999; Zavagno & Caputo, 2001; Zavagno & Caputo, 2005), as there is evidence that luminance gradients can influence lightness perception under certain circumstances.

I therefore asked whether a recently proposed theory for the perception of luminance gradients ("gradient system") could account for the just-described observations. The gradient system has been successful in quantitatively predicting available data on Mach bands (Keil, Cristóbal, & Neumann, 2006). It furthermore provided an account for Chevreul's illusion in terms of luminance gradients (Keil, 2006), and in addition is capable of real-world image processing.

In this work I will show how spatial configurations of luminance gradients can interact to produce the perception of luminosity in the absence of physical illuminants. The results presented here also contribute to the further understanding of how luminance gradients interact with lightness computations and brightness perception, respectively. Specifically, representations of luminance gradients provide a straightforward explanation of "self-luminous grays" (Zavagno & Caputo, 2001, 2005), and why it is that perception of luminosity is independent from lightness anchoring.

2. Introducing the gradient system

This section provides an overview over important characteristics of the gradient system. A more detailed description of it, as well as its formal definition, can be found in Keil (2006) and Keil et al. (2006).

2.1. Motivation

The original motivation for proposing representations of luminance gradients was that they are of different utility for object recognition. It is known, for example, that they may aid to (i) recover three-dimensional information to compute surface shape (shape from shading, e.g., Mingolla & Todd, 1986; Ramachandran, 1988), (ii) to resolve the three-dimensional layout of visual scenes (e.g., Bloj, Kersten, & Hurlbert, 1999; Kersten, Knill, Mamassian, & Bülthoff, 1996), and (iii) to identify material properties of object surfaces (e.g., mat versus glossy), and are therefore complementary to lightness computations (lightness is associated with surface representations).

In situations, however, it may happen that luminance gradients rather would interfere with the goal of generating invariant surface representations, and thus disrupt lightness constancy. (Invariant surface representations are mandatory for robust object recognition.) In natural scenes, specular highlights, cast shadows, and slow illumination gradients are often superimposed on object surfaces. In such cases, luminance gradients must be suppressed in surface representations for establishing lightness constancy. Nevertheless, it has been demonstrated recently that humans use cues such as shadows, shading and highlights for segregation of object surfaces (Fowlkes, Martin, & Malik, 2007). Thus, lightness constancy implies discounting "gradient features" on the one hand, yet on the other hand they are used by humans to achieve a more reliable segregation of figural regions from the background.

Taken together, luminance gradients contain different information, which cannot be interpreted by bottom-up mechanisms. Without segregating them from surfaces, surface representations would vary as a function of illumination conditions and scene layout. Notice that such a merged representation would necessitate segregation anyway, as lightness constancy is not interrupted by specular highlights (Todd, Norman, & Mingolla, 2004), and human object recognition seems to work reliably for most illumination conditions and scenes.

2.2. How it works

The gradient systems is a hypothetical neuronal circuit, and its main processing stages are shown in Fig. 1 (see also Fig. 1 in Keil et al., 2006). The retina constitutes two pathways, which are related to brightness ("ON-channel"), and darkness ("OFF-channel"), respectively. A high-resolution boundary map is produced by processing information from both channels.[1] "High-resolution" is to say that only the finest scale is considered. At a cortical level, boundary maps are usually regarded as demarcating surface representations thus defining surface shape. Because contours define surfaces, but not gradients, they are referred to as *non-gradients* within the gradient system. Non-gradients act always inhibitory (Fig. 2).

In the first step of gradient processing, gradients are enhanced by suppressing ON- and OFF-activity at non-gradient positions. The result of this process can be conceived as "retinal activity maps with erased contours" ("gradient ON" and "gradient OFF" in Fig. 1).

In the second step, retinal ON-activity and gradient ON-activity provide excitatory input to the site labeled by "+" in Fig. 1. Analogously, OFF-activity from retina and gradients act inhibitory on the site labeled by "−".[2] Excitation and inhibition is tonic or *clamped*, what means that activity is actively generated at "+" and "−". In addition, activity spreads laterally: activity values with positive sign from "+", and negative values from "−". Silent (or shunting) inhibition (reversal potential equals resting potential that is zero) exerted by non-gradient features during activity propagation quickly suppresses boundaries, while at the

[1] In Keil (2006) and Keil et al. (2006), a simplified circuit is used to this end, which detects contours without using orientation-selective operators.

[2] For the sake of simplicity, ON- and OFF-channels interact directly for generating the gradient representations. The channels are distinguished by their respective sign, where information from the ON-channel has a positive sign, and information from the OFF-channel corresponds to negative values. See Keil (2006, p. 882) for more details.