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ScienceDirect
Vision Research 46 (2006) 3915–3925
Vision Research
www.elsevier.com/locate/visres

Luminosity—A perceptual "feature" of light-emitting objects?

Alessia Correani [a,b], Nicholas E. Scott-Samuel [a], Ute Leonards [a,*]

[a] *Department of Experimental Psychology, Bristol University, Bristol BS8 1TN, UK*
[b] *Department of Psychology, University "La Sapienza" of Rome, Via dei Marzi 10, 00100 Rome, Italy*

Received 20 March 2006; received in revised form 24 April 2006

Abstract

Light-emitting objects are perceived as qualitatively different from light-reflecting objects, and the two categories elicit different cortical activity. However, it is unclear whether object luminosity is treated as an independent visual feature, comparable to orientation, motion or colour. Visual search tasks revealed that light-emitting targets led to efficient search when presented with light-reflecting distractors of similar luminance, but this efficiency was induced by the presence of luminance gradients producing the percept of luminosity rather than by luminosity itself. This implies that luminance gradients (not object luminosity) are encoded as features, questioning the existence of specific sensory mechanisms to detect light-emitting objects.

Keywords: Visual attention; Visual search; Brightness; Luminosity; Features

1. Introduction

Differing amounts of light coming from surfaces to the eyes can be produced either by changes in the level of illumination or by changes in the surfaces' reflecting properties. At the retinal level it is assumed that such a distinction cannot be made, since only changes in luminous flux and spectral composition are present. However, information about illumination and reflectance is recovered by the visual system at the perceptual level allowing observers, for example, to distinguish easily between light-emitting objects (light sources or objects containing luminosity) and light-reflecting objects. Under typical daytime luminance conditions, most objects relevant to our actions reflect light. In contrast, light-emitting objects such as the sun are rarely of direct interest for object selection and subsequent action upon them. This raises the question of whether the visual system treats these two object categories (only distinguished at the perceptual level) in different ways, giving task-related priority to reflecting objects. Such an object-for-action based selection mechanism would make sense, considering that the optical salience of light-emitting objects often exceeds that of simultaneously present reflecting objects by several orders of magnitude. This enormous difference in luminance might capture attention if light-emitting objects were analysed by the same mechanism as reflecting objects, and thus cost important processing time for task-relevant objects.

If the perceptual distinction of light-reflecting and light-emitting objects is related to lightness and brightness, where lightness is defined as the reflectance of the surface of an object (ranging from black to white) and brightness as illuminance ranging from dark via bright to fluorescent and luminous/light-emitting (e.g. Gilchrist et al., 1999), reflecting objects should fall into the lightness category and light-emitting objects into the brightness category. Even though, at first glance, such a distinction seems simply to link physical and perceptual luminosity and reflectance, there are situations in which perceptual and physical information do not match: for example, most objects presented on a computer screen do not appear to emit light, even though in physical terms they do. Perceptually they fall into the lightness category, but physically they fall into the brightness category.

Worse still, if such assumptions are not just restricted to object properties (light-emitting versus reflecting), but also

* Corresponding author. Fax: +44 117 928 8588.
E-mail address: ute.leonards@bris.ac.uk (U. Leonards).

0042-6989/$ - see front matter
doi:10.1016/j.visres.2006.05.001

link perceptual phenomena in general to lightness and brightness scales, it would become almost impossible to distinguish perceptually between lightness and brightness effects on object selection: first, lightness and brightness scales largely overlap with exception of those ranges of the brightness scale in which dark would be 'blacker than black' (e.g. Vukusic, Sambles, & Lawrence, 2004) and bright would be 'whiter than white' (e.g. Bonato & Gilchrist, 1994); second, the interpretation of reflectance or illuminance strongly depends on the context of a task and observer expectations (Arend & Spehar, 1993a, 1993b).

However, accepting the above-mentioned identity of perception with lightness/brightness scales for the very specific case of object quality (light-emitting versus reflecting) implies that if the object categories of luminosity and reflectance are treated differently in tasks requiring object selection, they should rely on different neural mechanisms. For example, if the perceptual quality of luminosity were treated as a visual feature, usually thought to be restricted to sensory information directly linked to physical object parameters, this would imply that luminosity-specific neurons should exist.

Despite a vast literature on brightness and lightness phenomena, surprisingly little is known about their underlying neural mechanisms, and even less about the neural mechanisms underlying the perception of light-emitting objects, i.e. brightness perception within the limits of those scales which do not overlap with lightness when attributed to an object. The few functional imaging studies in humans that tried to identify the neural mechanisms of brightness perception revealed that while activity in V1 increased with luminance, it was insensitive to brightness induction (Boucard, van Es, Maguire, & Cornelissen, 2005). In contrast, intraparietal and lateral occipital sulcus seem to be sensitive to brightness illusions (Perna, Tosetti, Montanaro, & Morrone, 2005; Troncoso et al., 2005). Only one study so far provides evidence that luminosity in contrast to the entire brightness scale might be treated as a visual feature: a recent fMRI experiment identified an area in the occipito-temporal cortex adjacent or overlapping with area V8 that was selectively activated when fixating an object that was perceived as light-emitting (Leonards, Troscianko, Lazeyras, & Ibanez, 2005); this area might be involved in the perceptual distinction between light-reflecting and light-emitting objects, irrespective of the actual luminance of the object.

When trying to identify differential behaviour of light-emitting and light-reflecting objects it is important to establish whether the perceptual quality of luminosity, when isolated from accompanying luminance differences, is in itself sufficient as a basic visual feature. This study uses the visual search paradigm to address this issue. In visual search, subjects look for a target item among a number of distractor items. If the time needed to complete the search is roughly independent of the number of distractors, the search is said to be efficient; if the search time increases linearly with the number of distractors, the search is said to be inefficient (e.g. Leonards, Rettenbach, Nase, & Sireteanu, 2002; Wolfe, 2001). Elementary features of visual perception are generally agreed to be those which, provided the contrast between target and distractors with respect to this feature is high enough, elicit efficient search in naïve subjects (e.g. Treisman & Gelade, 1980, 1988). In other words, the target seems to "pop out" from the surrounding distractors. However, this criterion alone is insufficient to guarantee status as an elementary feature of visual perception: search for the presence of a basic feature (the feature is attached to the target) must also be faster than search for its absences (the feature is attached to the distractors but not the target) (see Wolfe, 2001, for definitions of basic feature requirements). Some examples of features isolated in this way by visual search are size, luminance or contrast, line orientation, colour and motion, line termination, and even complex features such as faces (Hershler & Hochstein, 2005). Search for targets containing features is thought to involve no or very few attentional resources, and it was referred to as pre-attentive in early publications on visual search (e.g. Treisman & Gelade, 1980; but see Joseph, Chun, & Nakayama, 1997). Targets for which a search is inefficient are thought to involve attentional resources (e.g. Bravo & Nakayama, 1992; Treisman & Gelade, 1980; Wolfe, 1998). Note that we use the terms 'efficient' and 'inefficient' in this manuscript to indicate that we make no assumptions about an underlying neural search processing mode, e.g. the presence or absence of spatial shifts of attention (for reviews on this issue see Chelazzi, 1999; Palmer, Verghese, & Pavel, 2000; Townsend, 1990). Only the efficiency of the search is important to identify feature characteristics. However, given that there is a continuum between efficient and inefficient search, it is important to set explicit criteria for the boundary between the two search types. We define efficient search not only in terms of flat search slopes for target present trials (e.g. of around 10 ms/item or less), but also in terms of the original feature-defining idea of a 'pop-out' search: specifically, a search is only really efficient if target absent trials have flat search slopes too. Note that such an assumption can be made only for studies using young, healthy participants; in elderly participants, feature search for target absent trials is often impaired, possibly due to increased cortical noise or changes in response strategy (Li, Lindenberger, & Sikstroem, 2001; Rush, Panek, & Russel, 1986). Testing elderly subjects would thus require additional controls to set up appropriate baselines for feature search processing.

If luminosity is a basic feature of visual perception, targets perceived as light-emitting should pop out when presented in the context of distractors perceived as light-reflecting of similar luminance contrast; conversely, light-reflecting targets should not pop out from light-emitting distractors.

2. Experiment 1: Pop out of light-emitting objects among light-reflecting distractors of similar mean luminance, but not vice versa

Experiment 1 was conducted to determine whether target stimuli perceived as emitting light pop out when presented amongst distractor stimuli which appear to reflect