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The roles of image decomposition and edge curvature in the 'snake' lightness illusion

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ABSTRACT

The snake illusion is an effect in which the lightness of target patches is strongly affected by the luminance of remote patches. One explanation is that such images are decomposed into a pattern of illumination and a pattern of reflectance, involving a classification of luminance edges into illumination and reflectance edges. Based on this decomposition, perceived reflectance is determined by discounting the illumination. A problem for this account is that image decomposition is not unique, and that different decompositions may lead to different lightness predictions. One way to rule out alternative decompositions and ensure correct predictions is to postulate that the visual system tends to classify curved luminance edges as reflectance edges rather than illumination edges. We have constructed several variations of the basic snake display in order to test the proposed curvature constraint and the more general image decomposition hypothesis. Although the results from some displays have confirmed previous findings of the effect of curvature, the general pattern of data questions the relevance of the shape of luminance edges for the determination of lightness in this class of displays. The data also argue against an image decomposition mechanism as an explanation of this effect. As an alternative, a tentative neurally based account is sketched.

1. Introduction

In the well-known simultaneous contrast effect, lightness or brightness of a patch depends on the luminance of its adjoining, immediately surrounding areas. As illustrated in a version of this effect in Fig. 1a, a disk placed on a high luminance surround looks darker than an equiluminant disk placed on a low luminance surround. However, the lightness of a target patch can also be significantly affected by the presence of remote elements, not adjacent to the target. The snake illusion (Adelson, 2000; Adelson & Somers, 2000; Albert, 2006; Albert, 2007; Bressan, 2001; Bressan, 2006; Logvinenko et al., 2005; Logvinenko, Petrini, & Maloney, 2008; Logvinenko & Ross, 2005) is a strong and elegant illustration of such a remote effect. In Fig. 1b, denoted as 'snake', high and low luminance patches are added to Fig. 1a, causing an increase of the lightness difference between the target disks, compared to Fig. 1a. In Fig. 1c, denoted here as 'counter-snake' (Bressan, 2001; refers to such a figure as 'articulated anti-snake'), the luminance values of the added patches are switched (high becoming low and vice versa), causing a decrease of the lightness difference between the targets. The counter-snake figure is a useful control stimulus for the snake figure because, except for the luminance switch of some elements, the two displays involve the same shapes in the same geometrical arrangement and have the same average luminance. Remote effects on lightness, such as the snake effect, are theoretically interesting because their existence directly rules out explanations of lightness illusions which rely exclusively on the luminance contrast between targets and their immediate surrounds (Kingdom, 2003).

The luminance distribution (L) arriving into our eyes from an environmental scene is the product of a pattern of illumination (I) and a pattern of reflectances (R), according to the equation $L = I * R$. It is generally accepted that the visual system is able to decompose the resulting luminance distribution into its two generating sources, in order to sort out the contribution of constant surface colors from the contribution of the variable illumination. Lightness constancy, that is, the fact that perceived reflectance of surfaces is relatively constant despite variations of illumination,

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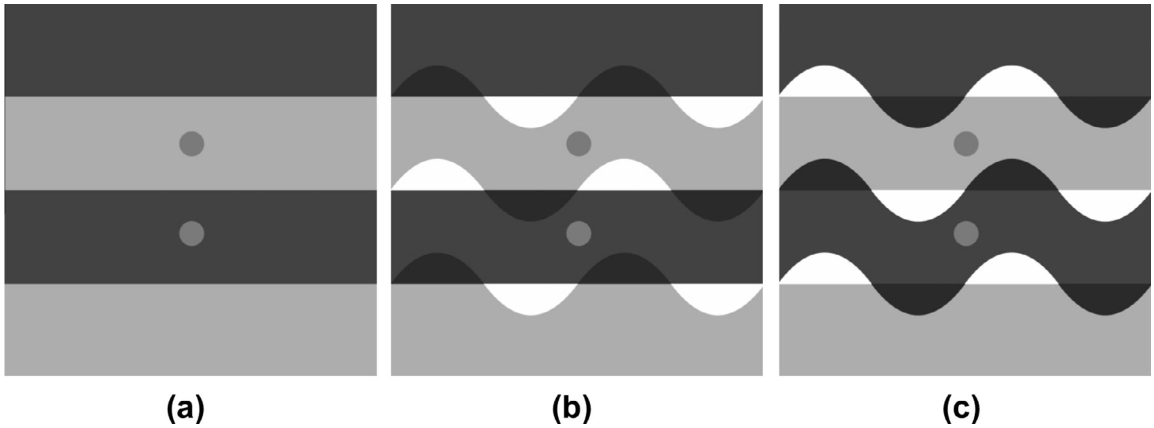

Fig. 1. Three lightness effects. (a) Simultaneous lightness contrast display: identical targets (disks) look different. (b) Snake display: difference of appearance of targets is stronger. (c) Counter-snake display: difference of appearance of targets is weaker.

could be based on a process of image decomposition followed by illumination discounting.

An interesting explanatory approach to lightness illusions is that they are due to the inappropriate application of processes of image decomposition and illumination discounting to 2D images. There are many examples of such explanations in the literature (see Kingdom, 2011; Todorović, 2006). However, the success of any general approach must be tested with individual examples of its applications. The snake display is well suited for such analyses. Fig. 2 presents, on the left, the snake image, and in its top right portion an example how it may be decomposed into a reflectance pattern and an illumination pattern. The reflectance pattern consists of alternating curved stripes of high and low reflectance patches (denoted as HR and LR), and the illumination pattern consists of alternating straight-edged portions of high and low illumination (denoted at HI and Li). The features of the image luminance distribution that support this decomposition are *X*-junctions with a characteristic structure of luminances of the four concurrent regions (Adelson & Anandan, 1990; Beck, Prazdny, & Ivry, 1984; Metelli, 1974). One of these *X*-junctions, with two diagonal edges and two horizontal edges, is circled in the snake image, and is also depicted in two blown up circles above the image; the corresponding locations in the two component patterns are also circled. In the circled portion of the reflectance pattern the open square indicates high reflectance and the solid square indicates low reflectance; in the left-hand circle above the snake image the corresponding pairs of regions are depicted with connected squares. Analogously, in the circled portion of the illumination pattern the open circle indicates high illumination and the solid circle indicates low illumination; in the right-hand circle above the snake image the corresponding pairs of regions are depicted with connected circles. Thus the two joined diagonal luminance edges of the *X*-junction correspond to a single reflectance edge in the scene, whereas the two joined horizontal luminance edges correspond to a single illumination edge in the scene. Such a structure of the *X*-junction is thus compatible with and indicative of a reflectance edge crossed by an illumination edge.

According to the image decomposition approach, based on the input luminance pattern, the visual system is assumed to arrive at reflectance values by discounting the effects of illumination, such as interpreting low-illumination portions as shadows or transparencies. What is the consequence of such an account for judgments of lightness of targets? Note that, given that the two target disks in the snake image have the same luminance L, but that the bottom disk is assumed to be exposed to lower illumination I than the top disk, according to equation $R = L/I$ it follows that the reflectance R of the shaded bottom disk must be higher than the reflectance of the normally illuminated top disk; in other

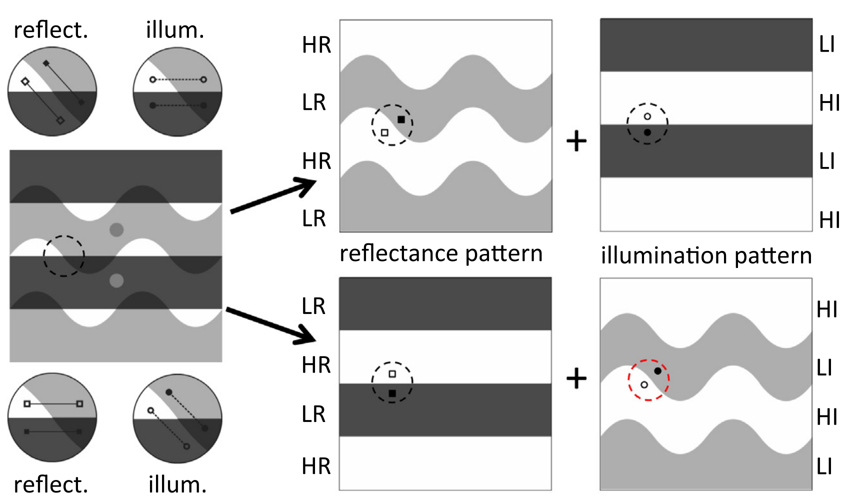

Fig. 2. Two decompositions of the snake image. Left portion: snake display. Top right portion: decomposition into a curved-edged reflectance component and a straight-edged illumination component. Bottom right portion: decomposition into a straight-edged reflectance component and a curved-edged illumination component. HR: high reflectance; LR: low reflectance; HI: high illumination; Li: low illumination. For details see text.