1 Introduction

It was recently shown that quite a strong lightness illusion, produced by Adelson’s picture of a ‘wall of blocks’ (Adelson 1993), completely disappears for a 3-D model of this picture (Logvinenko et al 2002). In other words, when the wall is made of cardboard, it is veridically perceived, thus showing perfect background-independent lightness constancy, despite the fact that its retinal image is practically the same. This is in line with the hypothesis that simultaneous lightness contrast is solely a phenomenon of pictorial perception (Logvinenko et al, 2002 Perception 31 73 – 82). The residual lightness illusion in the 3-D model can be accounted for by the fact that this model is a hybrid display. Specifically, while it is a real object, a pictorial representation (of the illumination gradient) is superimposed on it. Thus, lightness in the 3-D display is a compromise between two opposite tendencies: the background-independent lightness constancy and the lightness illusory shift induced by the luminance gradient.

Figure 1. All the diamond shapes are physically the same, ie the six horizontal rows of diamonds are printed with the same ink. However, the diamonds in even rows look much darker than those in odd rows. This shift in lightness is in the same direction as the classical simultaneous lightness contrast effect but much stronger because of presence of the vertical luminance gradient. (After Logvinenko 1999.)

(1) This illusion is widely thought to be a version of simultaneous lightness contrast. However, we believe that Adelson’s illusion differs from the classical simultaneous lightness contrast in a few important aspects, being a visual phenomenon of essentially different type.
Here we report on an experimental study of lightness perception of a 3-D model of figure 1. Indeed, we have found that one can observe the lightness illusion for a 3-D wall of blocks with a luminance gradient, though in a rather reduced form.

2 Method

2.1 Observers
Twenty subjects (five males and fifteen females), all volunteers, with an age range of 17–40 years, undertook a lightness-matching task. They were unaware of the purpose of the experiment. All observers reported normal or corrected-to-normal vision.

2.2 Stimuli and apparatus
The subjects were presented with two stimulus displays: (i) a picture of a wall of blocks with a luminance gradient (figure 1); and (ii) a real 3-D wall of blocks made from paper with the same luminance gradient (figure 2). Lightness evaluation of the diamonds in each display was made with the Munsell 31-step neutral-value scale. The instruction given to observers was to pick out a Munsell chip that looked the same shade of grey as the diamond to be evaluated.

Both stimulus displays were presented in a viewing booth, against a white cloth background (1 m × 1 m) at a distance of 1 m from the observer. From this distance the stimulus displays subtended 20 deg (the 3-D display) and 6 deg (its pictorial prototype). The participants looked into the booth through a viewing slot (150 cm × 20 cm) which allowed them to view both objects and a set of Munsell chips. The sides of the booth were covered with the same white cloth material as above.

A chin-rest was used to ensure that the observer’s line of sight was at a right angle to the 3-D display. Observers were instructed to restrict their attention to the central (target) area of each stimulus display comprising six diamonds in two adjacent rows—three within a light surround and three within a dark surround when evaluating the lightness of the diamonds.

Illumination was produced inside the booth by four ‘natural daylight’ lamps: two were attached above and two below the viewing slot. The lamps were not directly visible.
to the observer. Illumination was arranged so as to achieve as even a light distribution as possible. Luminance measurements were taken for the target area of the 3-D display and its pictorial prototype (figure 1) from the point of observation. While diamonds in both surrounds (light and dark) were made from paper of the same reflectance, a small, though statistically significant, luminance difference between them was found for both displays. More specifically, the mean luminance for the diamonds in dark and light surrounds was 527 and 539 cd m\(^{-2}\) for figure 1, and 636 and 642 cd m\(^{-2}\) for the 3-D display, respectively. Most likely, the diamonds in the light surround were slightly lighter because of scattered light. We believe that this slight unavoidable physical difference in luminance could affect neither our results nor conclusions.

2.3 Experimental design and procedure
All observers completed five sessions, with two runs in each session. Each session lasted approximately 20 min. The lightness of a diamond in both a light and a dark surround within each object was evaluated during each run. Matches for the 3-D display were made by using both binocular and monocular vision. Monocular judgments were made to ascertain the effect, if any, of binocular cues on lightness perception of the 3-D display. The experimenter indicated (with a laser pointer) the target diamond which was to be evaluated. The order of the target diamonds was randomised for each run, as was the type of vision required for the 3-D display (monocular or binocular).

During each run, six measurements were conducted (one binocular match for the diamonds in both surrounds for both displays, and one monocular match for two surrounds in the 3-D display). Each observer completed a total of ten binocular lightness matches for the diamonds in the light surround and ten binocular lightness matches for the diamonds in the dark surround for each of two displays. In addition, ten monocular matches for each of two surrounds were made monocularly for the 3-D display.

3 Results
Histograms of the lightness matches, made for the diamonds embedded in light and dark surrounds, are presented in figure 3 (the 3-D display) and figure 4 (its pictorial prototype in figure 1). In both graphs, the frequency distribution for matches made for the light surround is horizontally shifted to the left, thus manifesting the illusory lightness shift. While being statistically significant for both displays \((p < 0.001)\) this

![Figure 3](image_url)

*Figure 3.* The distribution of the matches made for the 3-D display across the Munsell neutral-value scale (horizontal axis). The vertical axis displays the overall number of matches made for each Munsell chip by all the observers under binocular viewing. The curve with the solid line and triangular symbols represents matches made for diamonds within a light surround. The curve with the broken line and circles represents matches made for diamonds within a dark surround.
horizontal shift is considerably less for the 3-D display. Specifically, whereas the median Munsell match for the dark surround is equal to 7.75 for both displays, that for the light surround is 6.00 for the 3-D display and 4.75 for its pictorial prototype (figure 1).

No significant difference was found between monocular and binocular observations. More specifically, the signed rank (Wilcoxon) test showed no significant difference ($p = 0.59$) between viewing conditions (monocular versus binocular) for the lightness shift (figure 5).

![Figure 4](image1.png)

**Figure 4.** The distribution of the Munsell matches made for the pattern in figure 1 (binocular viewing). The curve with the solid line and triangles represents matches made for diamonds within a light surround. The curve with the broken line and circles represents matches made for diamonds within a dark surround.

![Figure 5](image2.png)

**Figure 5.** The histograms of the Munsell matches made under both viewing conditions for the 3-D display. The curves from figure 3 are combined with two histograms obtained under monocular viewing. Triangles represent matches made for diamonds within a light surround binocularly viewed. Circles represent matches made for diamonds within a dark surround binocularly viewed. Monocular judgments for diamonds within the light and dark surrounds are represented by asterisks and squares, respectively.

### 4 Discussion

While being considerably reduced, the lightness illusion still exists for the 3-D wall of blocks with a luminance gradient. Does this undermine the claim made in the previous article (Logvinenko et al 2002) that the illusion is essentially a pictorial phenomenon, and it cannot be observed for real 3-D objects? If not, as we believe, how could it be reconciled with such a claim?
It might seem strange, but it is easier to answer these questions rather than to explain why the luminance gradient induces such a strong lightness illusion in figure 1. While the effect of luminance gradient on lightness perception has been known for a long time (e.g., Mach 1865; Agostini and Galmonte 1997, 2002; Zavagno 1999), it is still unclear what mechanisms underlie this effect. Although this issue is far beyond the scope of the present report, it should be noted that these mechanisms are most likely to be sought for within a broader framework. As a matter of fact, a luminance gradient as presented in figure 1 is just a particular pattern of shading. Shading produced by an object is known to be a powerful source of information for the visual system about both the object’s lightness and its shape (e.g., Marr 1982). Strangely enough, our understanding how shape is derived from shading (Horn 1975; Zhang et al. 1999) is much better than how lightness is computed from shading. Generally, ‘lightness-from-shading’ is a topic unduly neglected in visual perception. Figure 1 shows that a pattern of shading and a pattern of lightness derived from it may differ very much. Hence, being at least as challenging a problem as ‘shape-from-shading’, ‘lightness-from-shading’ has been overshadowed by the former, and it is still waiting for researchers’ attention.

As to an account of the residual illusion observed for our 3-D display, it should be pointed out that our 3-D display is a dual object. On the one hand, it is a 3-D surface shaped as a wall of blocks. On the other hand, a pattern of a sinusoidal gradient is portrayed on its surface. Being a powerful pictorial cue for illumination, this luminance gradient induces an illusory lightness shift in the same way as the 2-D picture in figure 1. However, as distinct from the previously reported 3-D model of Adelson’s original picture of the wall of blocks, which also produced pictorial cues for illumination that are overridden by natural (real) illumination cues, the illumination cues from the luminance gradient are only weakened but not completely overridden by the natural illumination cues in the 3-D display used in the present study. As a result we observe a failure of background-independent lightness constancy for the 3-D display with luminance gradient. Thus, the difference between our previous results (Logvinenko et al. 2002) and those reported here can be accounted for by the fact, which is quite obvious though, that the pictorial illumination cues provided by the luminance gradient are relatively stronger than those presented in Adelson’s original picture of the wall of blocks.

It should also be mentioned that the luminance gradient in the 3-D display provides so strong cues for false illumination that it results in a failure of not only background-independent lightness constancy but shape constancy too. As a matter of fact, the shading on the surface of the 3-D display provides information about depth relief which is in apparent conflict with that provided by other depth cues. For instance, owing to the luminance gradient, there are, on the one hand, convex but dark corners, and, on the other hand, concave but light corners in the 3-D wall of blocks. This contradicts the shading pattern usually produced in the natural environment (convex corners are most likely to be lighter than concave ones). Therefore, the luminance gradient testifies in favour of depth relief which is the opposite to that derived from other depth cues (e.g., binocular disparity).

A perceptual conflict of the same sort can be observed in some paintings of Patrick Hughes (Slyce 1998; Wade and Hughes 1999). For instance, Hughes painted on a corrugated 3-D surface another surface the pictorial relief of which was the opposite of that of the canvas surface (Slyce 1998, page 33). As a result, a perceptual rivalry occurred: sometimes the real shape (of the canvas), sometimes the reversed relief (i.e., that of a pictorial surface) was perceived (Papathomas 2002).

An analogous depth reversal regularly takes place for our 3-D display too. Concave but highlighted corners are quite often perceived as convex, and convex but shadowed corners as concave. Moreover, such a depth reversal is accompanied with the lack of
perceptual stability of the whole perceptual image of the wall. More specifically, with an apparent depth of some corners reversed, any head movements invoke an apparent perspective distortion of the 3-D spatial relief of the wall. The wall looks as if it is ‘rubber’. Such a failure of perceptual stability following an apparent depth reversal was also reported before by many authors (eg Gregory 1970; Rock 1983; Papathomas 2002).

Under normal circumstances (ie without depth reversal), such movements also produce the same perspective distortion of the retinal images; however, we are not aware of them (it is called perceptual stability of the world). In other words, normally we perceive the objects as constant (stable) despite the perspective distortion of the retinal images induced by head movements. During depth reversal, this stability is broken down. So, conflicting with other visual cues, luminance gradient breaks down not only lightness constancy but some other types of perceptual constancies for the 3-D wall of blocks as well.

To conclude, the 3-D wall of blocks with a luminance gradient is, in a sense, a pictorial object, though quite a special one. (Its specificity is that this picture—the pattern of luminance gradient—is depicted on the surface of a 3-D, rather than on a flat cardboard object.) A pictorial content, such as a pictorial 3-D relief and lightness, is in conflict with the real 3-D shape of the wall and its lightness. As a result, what we see is a more or less successful resolution of this perceptual conflict. Therefore, some residual lightness illusion which our subjects observed in the 3-D wall of blocks with a luminance gradient does not seem to undermine the stance we have taken up recently, namely, that lightness illusions of this sort are pictorial phenomena only.

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References
Adelson E H, 1993 “Perceptual organisation and the judgement of brightness” Science 262 2042 – 2044
Logvinenko A D, 1999 “Lightness induction revisited” Perception 28 803 – 816
Logvinenko A D, Kane J, Ross D A, 2002 “Is lightness induction a pictorial illusion?” Perception 31 73 – 82
Marr D, 1982 Vision (San Francisco, CA: W H Freeman)
Zavagno D, 1999 “Some new luminance-gradient effects” Perception 28 835 – 838
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