Discriminating Material From Illumination Changes In Complex Scenes

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Abstract

In most natural visual scenes we can easily distinguish patterns of illumination resulting from shadows, highlights and shading, from patterns of object lightness and colour. How ? Shadows have certain unique physical characteristics, and we have begun to study our visual sensitivity to them using a novel psychophysical paradigm. Human test subjects were required to detect and discriminate small rectangular targets superimposed on larger, complex, 'Mondrian-like' backgrounds. The targets simulated one or more of the figural/luminance/chromatic conditions of shadows and material surfaces. We found that a combination of three factors found in natural shadows, namely X-junctions, continuity of colour across the shadow border, and consistent polarity of luminance contrast across the shadow border, maximized shadow detectability. Our simulated shadows were slightly more easily detected, but no more efficiently discriminated from material targets, when on chromatic compared to achromatic backgrounds.

Introduction

In the natural visual world, most chromatic variations arise from changes in material composition, e.g. green grass next to yellow sand. Changes in light intensity, or luminance, on the other hand arise in two ways; either from changes in material composition, such as the light stripes on a dark suit, or from the pattern of illumination, for example from shadows, highlights and shading.

Generally we do not confuse the illumination and material components of images - shadows are rarely perceived as the objects from which they arise (see Figure 1). What cues help us to do this ? In Figure 1 a number of potential cues are apparent. The change in both colour (not seen in the black and white version of this paper) and texture across the border at **a** implies a material change, whereas the continuity in both colour and texture across **b** suggests an illumination change. However, **b** could still be a material border, perhaps part of a dark painted stripe on the pavement. Another potential cue is the X-junction at **c**. X-junctions occur whenever illumination and material borders cross. That the diagonally oriented borders in Figure 1 are illumination changes is also evidenced by the fact that the contrast (i.e. ratio of luminances) across the borders are near-identical on either side of the X junction. In this study we explore to what extent the visual system is sensitive to these figural chromatic and luminance cues.

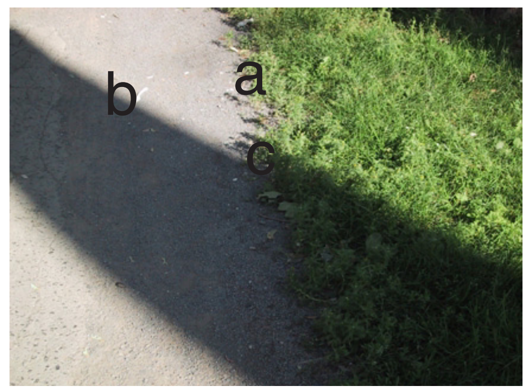

Figure 1. Natural shadow.

Methods

Stimuli

Figure 2 shows examples of the chromatic stimuli we have employed. The 'Mondrian-like' background consists of large numbers of overlapping rectangles of variable sizes, aspect ratios, luminances and colours. The achromatic version of the stimulus (not shown) consisted of the same distribution of luminances, but was a uniform grey in colour. Note that the chromatic stimuli are <u>not</u> isoluminant – they have both luminance and chromatic contrast. In Figure 2a a dark 'target' rectangle is seen near the middle of the background. The target is a simulated transparency, and as such, has many of the same properties as the shadow in Figure 1. That is, the luminance contrast across its border with the background is the same all along the border, and the background appears to run 'under' the target, producing X junctions all along the border. We term this target a 'shadow'. Figure 2b contains a 'material' target. Created first as a shadow, the target is then rotated both horizontally and vertically. Thus it has the same internal luminance composition as the shadow target, but lacks the consistency in luminance contrast and X-junctions. Figure 2c shows the 'random-colour' target. This was only employed with the chromatic background. It has identical luminance properties as the shadow target, but the colours change randomly across the target border (this will not be apparent in the black-and-white version of this paper). Figure 2d shows the 'alternating-polarity' target. The luminance contrasts across the target border alternate in polarity as one moves along the border (e.g. dark-bright, bright-dark, dark-bright etc). Thus like the shadow target it has X-junctions, but no consistent polarity of border luminance contrast.

Figure 2a. Stimulus with shadow target

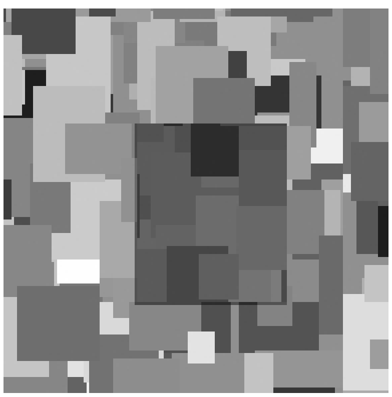

Figure 2b. Stimulus with material target

Figure 2c. Stimulus with random-colour target

Figure 2d Stimulus with alternating-polarity target

Procedure

We report here two experiments. In the first we measured the relative detectability of the four types of target in Figure 2, on both chromatic and achromatic backgrounds. In the second experiment we measured the ability of subjects to discriminate the shadow from the material targets. The independent variables in both experiments were the type of background, type of target, and target contrast. Target contrast was defined as the ratio of luminances of the background to the target across the target border. Conventional 2IFC (two-interval-forced-choice) procedures were employed. In both experiments two stimuli were presented on each trial, one containing the target. In the detection task, the subject was required to indicate by key-press the interval containing the target. In the discrimination task, the subject was required to indicate whether the target was a shadow or material. The stimuli were presented for 250 ms. The target was of fixed area, but with an aspect ratio that could vary anywhere between 1 and 3. It was randomly positioned anywhere on the background except within a narrow annulus around the edge of the background. In a given session only one type of background, and one type of target was presented, but the contrast of the target was randomly selected from six pre-determined values.

Experiment 1 - Target Detection

In this experiment the target contrasts were relatively low, such that detection rates were always less than 100%, enabling a comparison of target detectability. Figure 3 shows example results from one subject. Percent correct detections are plotted as a function of target contrast, for the shadow, material and alternating-polarity targets, on both achromatic (left graph) and chromatic (right graph) backgrounds. As the figure shows, performance systematically increases from near-chance levels as contrast is increased. The striking result is that the shadow targets are more easily detected than either the material or alternating-polarity targets, and for both types of background. Two other subjects showed a similar pattern of results. Figure 4 allows a more direct comparison of the effects of background type on the detectability of the shadow (left) and material (right) targets. This time all three subjects' data are shown, as the effect of background type is small. For all three subjects the shadow targets. and for two of the three subjects the material targets also, are more easily detected on the chromatic (filled circles) compared to achromatic (open squares) backgrounds. Finally, Figure 5 compares the data for the random-colour and shadow targets on the chromatic background. Two subject's data are shown (a third showed similar results). Performance with the shadow target is consistently superior.

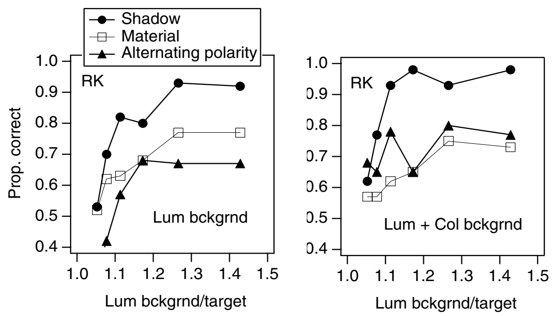

Figure 3. Target detection on achromatic (left) and chromatic (right) backgrounds for one subject

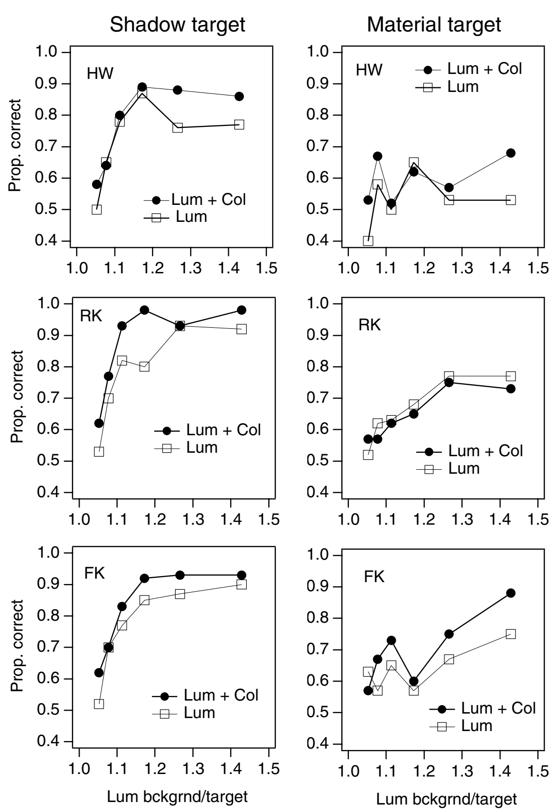

Figure 4. Comparison of target detection on achromatic (Lum) and chromatic (Lum + Col) backgrounds for three subjects. Left, shadow targets; right, material targets.

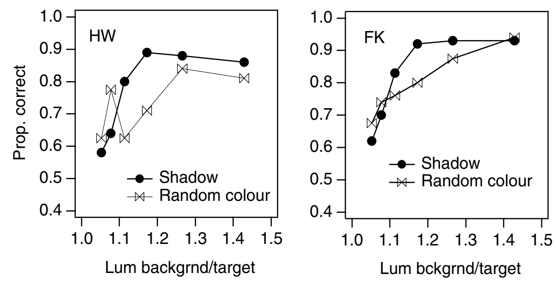

Figure 5. Comparison of detectability of shadow and random-colour targets on the chromatic background, for two subjects

Experiment 2 –Target Discrimination

In this experiment we measured the ability of test subjects to discriminate shadow from material targets, depending on the type of background. One each trial two stimuli were presented, one with and one without a target. The target was either a shadow or material. The subject first indicated in which interval the target was present, and second indicated the type of target.

Results for three subjects are shown in Figure 6. On each graph there are four sets of data points. Closed circles are for the chromatic background, open squares the achromatic background. The pairs of curves lying close to the 100% correct level are the average *detection* rates for the two types of target, and show that for the higher contrast stimuli employed in this experiment subjects easily detected all targets. The more important result for this experiment are the two lower curves on each graph, which show the *discrimination* rates. These are calculated as the average rates with which the two types of target were correctly identified. The curves for the achromatic and chromatic backgrounds more-or-less superimpose, suggesting that both types of background are equally efficient at supporting shadow-versus-material discrimination when the targets are highly visible.

Discussion

The results of this study can be summarised thus:

1. Our shadow targets were more easily detected than either the material, alternating-polarity, or random-colour targets.
2. Shadow and material targets were slightly more easily detected on chromatic compared to achromatic backgrounds.
3. Shadow and material targets were equally well discriminated on chromatic and achromatic backgrounds.

The first result, namely that our shadow targets were more easily detected than the other targets types, suggests that a combination of three figural/luminance/chromatic factors optimizes the detection of simulated illumination overlays: X-junctions, consistency in luminance contrast-polarity, and continuity in colour. With the material target, there were no X-junctions and detection rates were lower. With the alternating-polarity target, X-junctions were preserved, but the contrast polarity with respect to the background alternated along the border. Again, detection rates were lower. Finally, for the targets presented on chromatic backgrounds, introducing a colour change across the border with the background lowered detection rates. In keeping with these results on the detectability of simulated shadows/transparencies, Anderson[1] has established that a combination of X-junctions and consistent luminance polarity is the critical figural/luminance condition for phenomenal transparency.

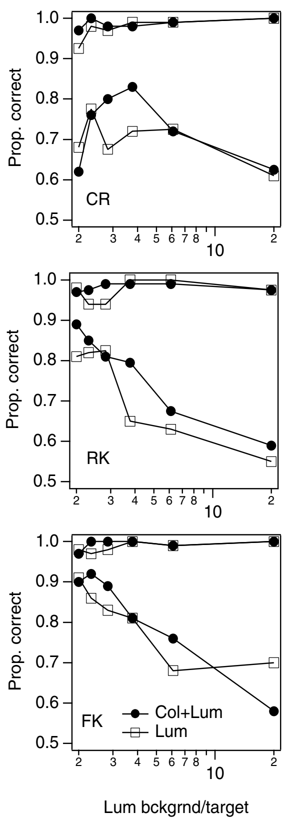

Figure 6. Data for discriminating the shadow from the material targets. Closed circles are for chromatic (Col + Lum), open squares achromatic (Lum) backgrounds. The pairs of curves close to the 100% correct level are average detection rates for the shadow and material targets. The lower pairs of curves are average shadow-versus-material discrimination rates.

The second result, that detection rates for the shadow and material targets were slightly higher on the chromatic than the achromatic background, needs careful interpretation. It has been suggested that one important function of colour vision might be to disambiguate illumination from material changes in natural scenes[2]. In our displays the addition of colour variation to the background might be expected to facilitate the detection of the shadow targets, since the continuity of colour across the shadow border is an additional cue not present in the achromatic display. However, in two of the three subjects the material target was also slightly better detected on the chromatic background. This suggests a property common to both shadow and material targets underlies their superior detection on the chromatic backgrounds. The likely common property is that they are both *decrements*. A relatively low-level process, perhaps one where the gain of the relevant mechanisms is altered when colour variation is added to the background of luminance contrasts, may underlie this effect. However, the small but significant benefit to target detectability of added background colour does not appear to be due to any disambiguating it might be expected to have.

This last conclusion is further supported by the results of Experiment 2. Here, the task was to explicitly discriminate the shadow from the material target, under conditions where both shadow and material targets were easily detectable and for which target contrast was not a cue to identification. No significant superiority was found when the discrimination was performed on the chromatic background.

Conclusion

Shadows have unique physical characteristics that in combination are highly salient for human vision. Although the continuity of colour across a shadow border is important for its detection on complex backgrounds, it does not appear to significantly help us discriminate shadows from material changes on such backgrounds.

References

1. Bart Anderson, *Perception*, **26**, 419 (1997).
2. Kathy Mullen and Frederick Kingdom , Color contrast in form perception. In *Perception of Color*, edited by P. Gouras, MacMillan, Oxford (1991).

Biography

Frederick Kingdom received his B.A. degree in Natural Sciences from the University of Cambridge in 1974, and his PhD in Visual Neuropsychology from the University of Reading in 1984. After a period of postdoctoral research at the Universities of Reading and Cambridge, he took up a faculty position at the McGill Vision Research Vision Unit in Montreal where he is now Associate Professor of Ophthalmology. His research is in human visual psychophysics, specifically the relationship between early-stage feature coding and intermediate-stage surface perception. He is a member of the Association for Research in Vision and Ophthalmology.

Reza Kasrai is a PhD student at McGill University's Montreal Neurological Institute. His research deals with the perception of achromatic transparency and its application to medical imaging.