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Learning a 3-D Visual Light Field: Effects of Exploration on Lightness Constancy

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ABSTRACT
The pattern of light across a scene is determined by the lighting, the material properties of objects in the scene, and the three-dimensional (3-D) scene structure. The problem of determining the material properties of an object is therefore a complex one. To do this correctly the relationship between 3-D scene structure and lighting must be understood by the viewer. In this paper we describe experiments which evaluate how exploration of the lightfield [1] within the scene aids the estimation of surface lightness (albedo). We find that the experience of viewing a block moving throughout the 3D scene - illustrating the variations in lightfield – results in lightness constancy, i.e. viewers are able to estimate surface albedo under varying illumination. Exploration of the lightfield facilitated albedo recovery as opposed to simple brightness matching.

Categories and Subject Descriptors
D.3.3 [**Vision and Scene Understanding**]: *3D/stereo scene analysis – Shape, Perceptual reasoning, Intensity colour and thresholding.*

General Terms
Human Factors.

Keywords
Lightness perception, depth perception, stereopsis.

1. INTRODUCTION
Figure 1 (left) shows an image of a convex 'bump', sticking out from the scene. But the pattern of shading across the object is consistent with a convex object only if the light comes from above. Similarly, figure 1 (right) shows a number of identical blocks, placed at different depths within a larger box. Each block has a different luminance in the image, because the box is lit from slightly above and in front of the box. The blocks will only be perceived as identical if the visual system is able to take account of the fact that the light falling on objects in the box is different at different depths. This is referred to as lightness constancy.

Observers appear to be sensitive to the 'visual light field': even when a space is not filled with objects, they can anticipate what lightness an object should have if it were positioned at various locations within a scene [1]. In this study our aim was to explore what visual information is required in order for observers to learn a visual light field and, in so doing, obtain good lightness constancy.

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2. METHODS
We explored lightness perception in a simple scene: observers view a single test block presented at a variety of depths within a realistically-rendered box, with depth defined by perspective, lighting and binocular disparity (figure 2, left). A row of matching (Munsell) blocks were visible below the box (co-located with the front of the box). In each trial, the test block appeared at a randomly chosen location in depth, within the box. Observers were required to choose which block, from the matching row, was made of the same material as the test block. By rotating a dial the observers could choose darker (anti-clockwise) or lighter (clockwise) matching block (the matching blocks were rendered in albedo steps of 0.02).

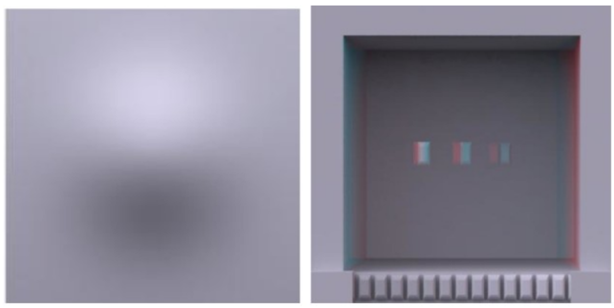

Figure 1: [left] Convex bump defined by shape from shading. [right] Blocks placed at different depths within a box, lit from the front, and above, the box – to be viewed with anaglyph glasses.

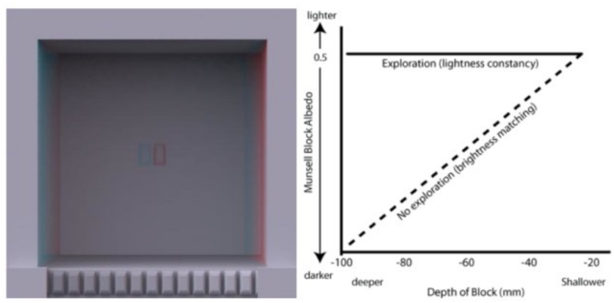

Figure 2 [left]: Test block in centre of box. Matching Munsell blocks presented below. [right] Prediction of which block will be chosen as match to the test block.

Predictions: The test block had its highest luminance at the front of the box, and its luminance decreased as it was presented further into the box in depth (as it receded into the shadow caused by the box roof and walls).

If observers matched the raw luminance of a matching block to that of the test block, as the test block was moved from the front to the back of the box (Figure 2, left, dashed line) their choice of match block would therefore have an increasingly lower albedo (darker). If observers had successfully learned the light field, and were able to compensate for the lighting at different depths within the box (achieving lightness constancy), they should always choose the same matching block, wherever the test block was located (Figure 2 right, solid line).

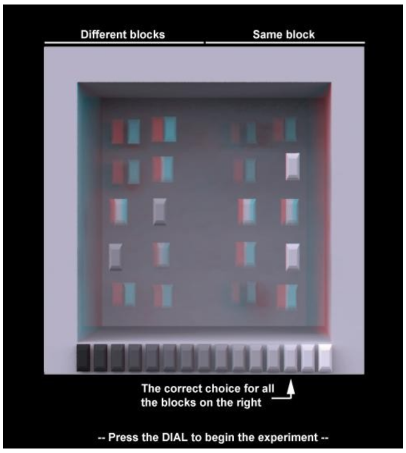

Figure 3. Static training example.

Before observers viewed the experiment, they were shown a static image that gave examples of a single test block, positioned at different locations within the box, as well as a number of test blocks made of different materials (Figure 3). Match block albedos were then recorded, in a series of experimental trials, as a function of test block depth within the box, for 4 different exploration conditions:

1. No exploration: No exploration of the light field beyond the viewing of the single static image (Figure 3) common to all conditions.

2. Passive-only exploration: observers viewed a 45-second movie of a single block moving around the box in depth.

3. Active-only exploration: For 45 seconds, observers moved the block up-down, left-right and back-and-forth in depth within the box, using button presses.

4. Full exploration: Condition 2, followed by condition 3. A total of 90 seconds exploration.

3. RESULTS

Chosen test block albedo is plotted as a function of test block depth in figure 4. When no exploration was provided (green line), observers behaved as if matching raw luminance. For each of the other three exploration conditions, performance was much closer to that expected for perfect lightness constancy (constant match regardless of test block depth). This suggests that exploration is required to learn the light field, and that viewing a static set of example blocks is not sufficient to do so.

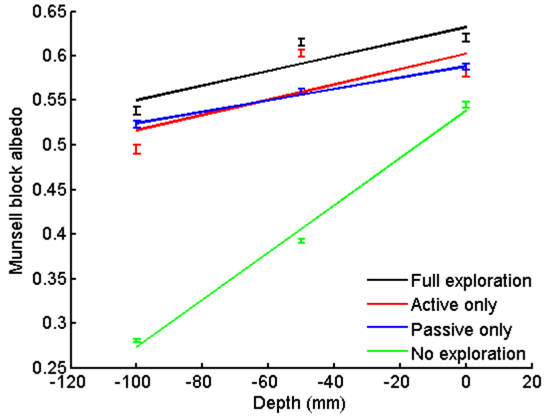

Figure 4: Match block albedo as a function of depth of test block in box.

It is possible to summarise the relationship between chosen block and test block depth by fitting the best straight line through the figure 4 data and recording the gradient of that line. In figure 5, we explore how that gradient changes as the experiment proceeds. Gradient is plotted as a function of the testing session (approx. 1hr each), again for each of the 4 exploration conditions.

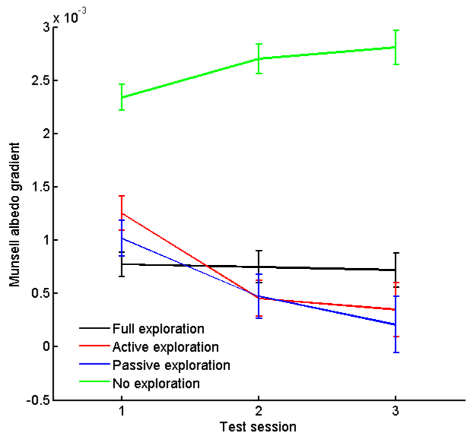

Figure 5: Match block gradients for each exploration condition over consecutive testing sessions.

For the three conditions in which observers explored the lightfield, there is a tendency for the gradient to decrease (indicating better lightness constancy) for later testing sessions. This suggests that learning of the visual light field continues throughout the experiment, not just during the training phase.

4. ACKNOWLEDGMENTS

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5. REFERENCES

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