Sun and Sky? Probing the Default Illuminant for Human Shape-from-Shading

Andrew J. Schofield
School of Psychology
University of Birmingham
Birmingham, B15 2TT, UK
+44(0)1214145644
a.j.schofield@bham.ac.uk

Paul B. Rock
School of Psychology University of
Birmingham Birmingham, B15 2TT,
UK contact via AJS

Mark A. Georgeson
School of Life and Health Sciences
Aston University
Birmingham, B4 7ET
+44(0)1212044119
M.A.Georgeson@aston.ac.uk

ABSTRACT

People perceive smooth luminance variations as being due to the shading produced by surface undulations: shape-from-shading. To do this the visual system must simultaneously estimate the nature of the illumination and the shape of the surface. Shape-from- shading operates even when both these properties are unknown and neither can be estimated directly from the image. In such circumstances humans are thought to adopt a default illumination model. It is widely held that the default illuminant is a point source located above the observer's head, but some have argued that the default illuminant is a diffuse source. We present evidence that humans adopt an illumination model that includes both diffuse and directional (overhead) elements.

Categories and Subject Descriptors

I.3.6 [Computing Methodologies] Computer graphics – *Methodology and Technique, Ergonomics.*

General Terms

Human Factors.

Keywords

Shading, illumination, lighting-from-above, dark-is-deep.

1. INTRODUCTION

When viewing images with smooth variations in luminance, such as Figure 1, humans generally perceive a surface undulating in depth. This is so even when the image is entirely artificial and has been constructed by the simple manipulation of luminance rather than by photographing or indeed rendering a 3D object. This method has been used for many years in graphical user interfaces (GUIs) to indicate (for example) button state. The impression of depth via shape-from-shading is achieved without recourse to 3D presentation technology and is robust in the sense that most people see the intended percept. When viewing such images people form a view as to which regions are raised and which depressed. GUIs typically depict such depth features as if lit from above left such that the top (left) edge of a raised 'button' is shaded a lighter color than the main body of the button while the bottom (right) edge is given a darker color. This convention supposes typical overhead room lighting. However, humans will perceive GUI buttons in the correct state even when their environment is lit from another direction, diffusely or only by the display itself.

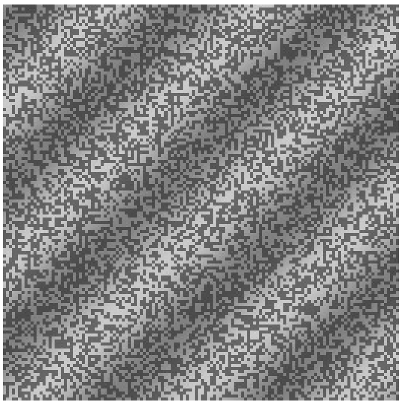

Figure 1. Example stimulus: sinusoidal luminance variation.

In principle the extraction of shape-from-shading requires knowledge of the lighting direction. However, even when there are no cues to lighting direction humans are still able to perform shape-from-shading; although they may not do so veridically (see Figure 3). In doing this people adopt a number of prior assumptions about the visual scene. One such assumption is that objects are generally lit by a directional light source from a position above our heads and slightly to the left [1-3]. This assumption is, of course, in line with the convention of above-left lighting in GUIs. However, this lighting assumption can be overridden: in Figure 2 the assumption that objects are convex overrides 'lighting-from-above' [4].

Some researchers have questioned whether the assumed illuminant for shape-from-shading is directional. Langer and Bülthoff [5] have shown that humans will see complex rendered surfaces as if lit by a diffuse source when the surfaces were rendered under such a source but are presented without explicit lighting cues. Further, Tyler [6] has show that for highly reduced scenes comprising only radial sinusoidal variations in luminance the resulting perceived shape requires that the assumed illumination be non-directional (i.e. diffuse). However, the various orientations of the 'spokes' in such radial patterns prohibit the application of a single directional lighting assumption.

Predicting Perceptions: The 3rd International Conference on Appearance, 17-19 April, 2012, Edinburgh, UK. Conference Proceedings Publication ISBN: 978-1-4716-6869-2, Pages: 172-176

We tested the default illuminant for human shape-from-shading using stimuli (similar to that of Figure 1) which promote neither a directional nor diffuse light source interpretation but which were seen as undulating by observers. To perceive undulations in our stimuli observers must adopt a lighting assumption. By measuring the nature of the perceived undulations we were able to predict the lighting assumption adopted by each observer and assess the degree of diffuseness vs directionality in this assumption.

2. METHOD

Observers were asked to view images such as those in Figure 1 and to make judgments about the perceived undulations. The stimuli comprised isotropic binary noise textures (which contain no shape cues but nonetheless help to articulate the shape percept) to which we added sinusoidal variations in mean luminance. We stress that stimuli were *not* renderings of sinusoidal surfaces. We presented these sinusoidal luminance variations at a rage of planar orientations.

We used three methods to assess the perceived shape, frequency and position of undulations (the position of perceived surface peaks were recorded relative to luminance maxima: inter-peak offsets). Our three methods were: 1) a ‘gauge figure’ task where observers had to set the perceived 3D orientation of a gauge figure to match the perceived surface orientation at a range of points on the stimulus (measuring perceived shape, frequency and relative position); 2) a feature marking task where observers had to mark the locations of visually perceived surface peaks and troughs (measuring relative position and frequency); and 3) a haptic match task in which observers had to adjust the relative position of a haptically defined virtual surface to match that of the visually perceived surface (yielding position data only). We also conducted a control experiment to verify that observers never saw the stimuli as flat surfaces. In all we tested 25 participants across the three methods.

3. RESULTS

Results from the gauge figure experiment showed that observers perceived our surfaces to be sinusoidal: sinusoidal surface profiles provided consistently better fits to the data than other candidate profiles (triangular, broad valleys with sharp peaks, and broad humps with sharp valleys). Further, the frequency of the undulations was always equal to that of the luminance profile. Finally the position of perceived surface peaks relative to the physical luminance maxima varied with stimulus orientation as depicted in Figures 2, 4&5. Inter-peak offsets were largest for horizontal stimuli and smallest for vertical stimuli.

4. ANAYSIS

A detailed analysis of physical lighting, and models of human shape-from-shading strongly suggest that if observers had assumed a directional light source assumption, close to a point or collimated in nature but with variable orientation, then the ‘gradient proportional to luminance’ rule [7] should apply producing perceived inter-peak offsets of 1⁄4 wavelength at all stimulus orientations. If such a light source assumption had a fixed orientation then offsets would still be 1⁄4 wavelengths at most orientations and when not so perceived surfaces should have half the frequency of the luminance variations. Were the assumed light source to be diffuse the dark-is-deep rule [6] would apply and we would expect no offset between perceived surface and luminance peaks at any orientation. The data support none of these interpretations. Instead we were able to model our data by assuming a mixture of point and diffuse lighting. The model allowed us to assess both the dominant direction of the light source and the relative weighting of the directional and diffuse components. The resulting parameter estimates are shown in Table 1 with data and fits shown in Figures 2,4 & 5. Model fits were good although some differences between data and model fits suggest that additional components may be required to fully predict individual data. The majority of observers adopted a mixed light source with a diffuse component and a directional element coming, largely, from above: that is, the sun in the sky.

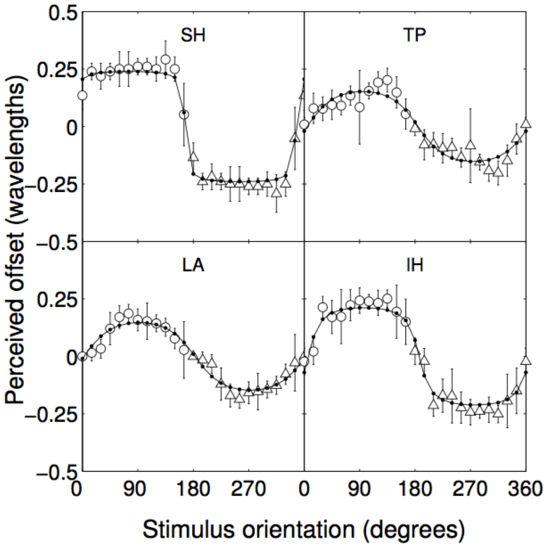

Figure 2. Data and fits for the feature marking experiment.

5. CONCLUSION

Understanding shape-from-shading in humans has implications for interface design. We have shown that in the absence of explicit cues to lighting humans may assume a mixture of diffuse and directional lighting when interpreting shape-from-shading.

6. ACKNOWLEDGMENTS

Funded by EPSRC grants GR/S07254/01 and EP/F026269/1 to AJS and GR/S07261/01 to MAG .

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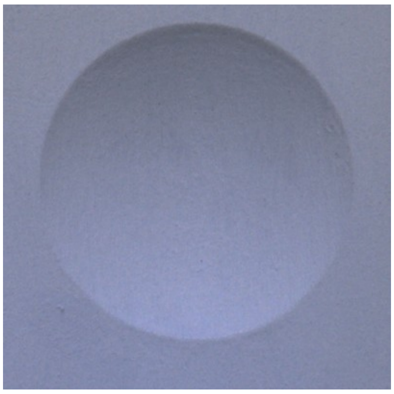

Figure 3. A photograph of a hollow lit from above is often misinterpreted as a bump lit from below.

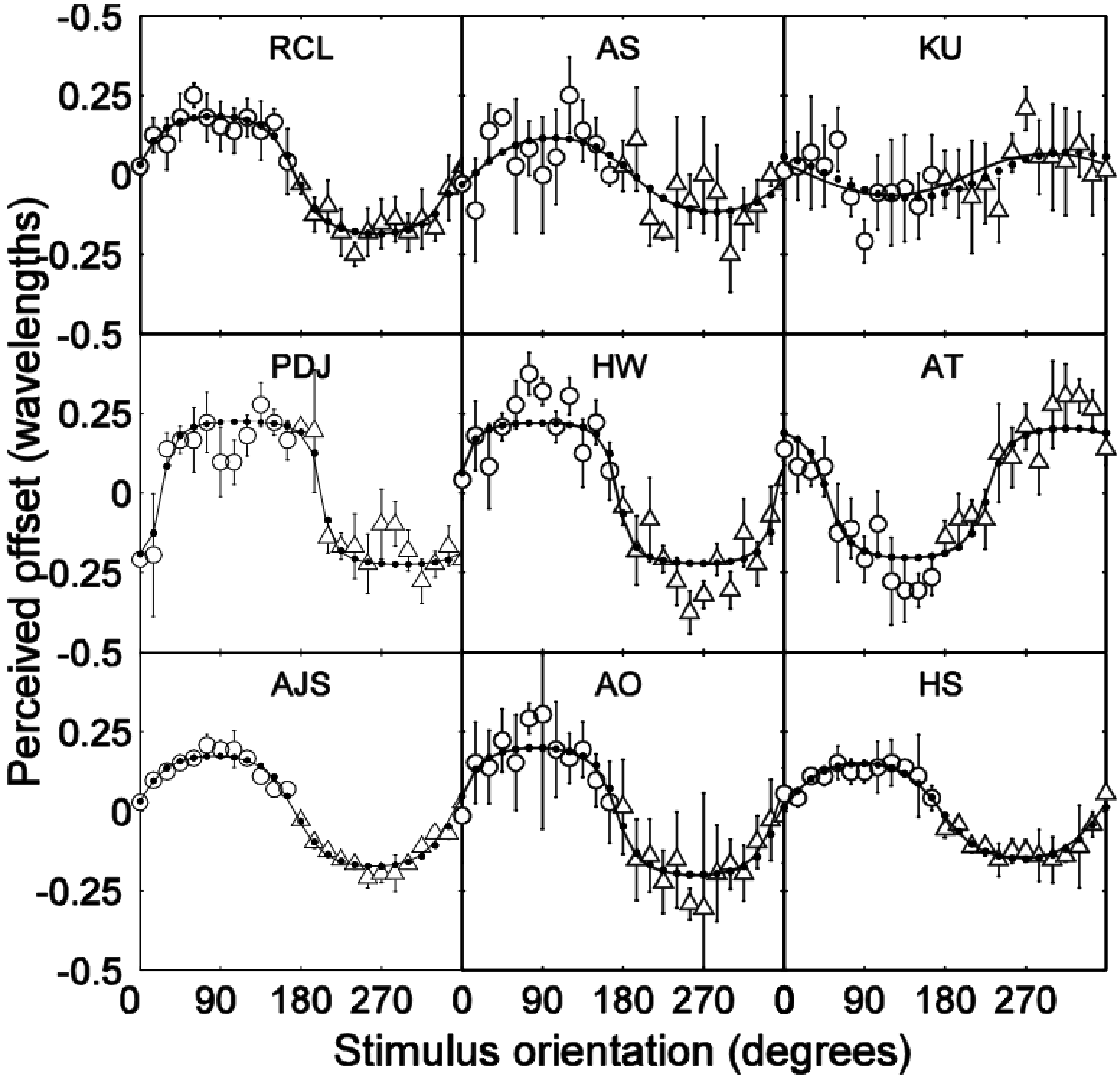

Figure 4. Results for 9 observers in the haptic match experiment showing offsets of perceived surface peaks relative to the luminance peaks. Open symbols are data; lines with solid dots are model fits.

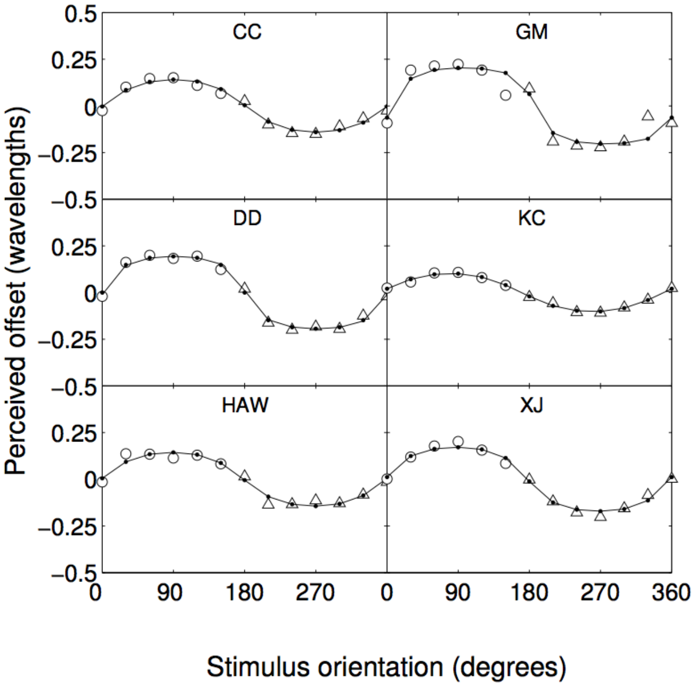

Figure 5. Results for the 6 observers in the gauge figure experiment showing offsets of perceived surface peaks relative to the luminance peaks. Open symbols are data; lines with solid dots are model fits.

Experiment	Person	SSE_A	γ	(λ)
Haptic	AJS	0.005	0.45	6
Haptic	PDJ	0.048	0.21	-25
Haptic	RCL	0.013	0.41	5
Haptic	AO	0.033	0.34	6
Haptic	HW	0.071	0.23	5
Haptic	AS	0.081	0.64	-12
Haptic	HS	0.005	0.54	3
Haptic	AT	0.061	0.33	132
Haptic	KU	0.056	0.78	151
Haptic	AC	0.004	0.69	31
Haptic	JG	0.019	0.38	-13
Haptic	PS	0.027	0.5	6
Haptic	PR	0.006	0.43	-4
Haptic	MH	0.049	0.36	-153
Haptic	SW	0.056	0.64	-46
Feature mark	SH	0.012	0.09	13
Feature mark	TP	0.019	0.53	-5
Feature mark	LA	0.009	0.54	-3
Feature mark	IH	0.015	0.28	-7
Gauge figure	CC	0.005	0.56	-1
Gauge figure	DD	0.003	0.37	-1
Gauge figure	HAW	0.007	0.55	1
Gauge figure	GM	0.037	0.32	-7
Gauge figure	KC	0.001	0.68	10
Gauge figure	XJ	0.004	0.46	2

Table 1. Sum of Squared errors, diffuse source weights (γ) and preferred direction of point source (λ, degrees from vertical) for all observers.