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Brief article

Prior knowledge on the illumination position

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Abstract

Visual perception is fundamentally ambiguous because an infinite number of three-dimensional scenes are consistent with our retinal images. To circumvent these ambiguities, the visual system uses prior knowledge such as the assumption that light is coming from above our head. The use of such assumptions is rational when these assumptions are related to statistical regularities of our environment. In confirmation of previous visual search experiments, we demonstrate here that the assumption on the illumination position is in fact biased to the above-left rather than directly above. This bias to the left reaches 26 degrees on average in a more direct shape discrimination task. Both right-handed and left-handed observers have a similar leftward bias. We discuss the possible origins of this singular bias on the illumination position.

Keywords: Shape-from-shading; Illumination position; Prior constraints

1. Introduction

The images impinging on our retinae can be interpreted in multiple ways. For instance, a circle on the retina can result from the projection of a circle drawn on a frontal plane or from an ellipse drawn on a plane slanted away from the observer. In general, however, we do not witness any of these ambiguities. Indeed, our subjective visual experience is usually stable, robust and unitary. In order to disambiguate the retinal images, the visual system must employ some extra-retinal knowledge (Rock, 1983). Recent experimental work has emphasized the study of prior knowledge and

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how this knowledge is integrated with the available retinal information (Kersten, 1999; Mamassian, Landy, & Maloney, in press).

A piece of prior knowledge that is often cited in visual science is the assumption that light is coming from above our heads (e.g. Berbaum, Bever, & Chung, 1983; Gibson, 1950; Ramachandran, 1988). The phenomenon that led to this assumption was first reported by Gmelin at the Royal Society of London in 1744 (reproduced in Brewster, 1826). When a seal was looked at through an optical tube or a microscope, convex parts were seen as concave and vice versa. The first correct interpretation of this phenomenon is credited to Rittenhouse (1786), who pointed out that the image seen through the optical tube was upside-down and consequently shadows were in the wrong place relative to the light source. The position of the shadows was thus consistent with a surface whose relief was inverted relative to the physical surface. This explanation rests on the knowledge that the light source stays at the same location whether or not one is looking through the microscope. More specifically, it remains above the observer's head (Brewster, 1826).

Several studies have started to unravel the human assumption that light is coming from above. In particular, it is important to clarify whether "above" is defined relative to the observer's head or to the gravitational direction. While early experiments suggested that the frame of reference changed in the first years of life (Yonas, Kuskowski, & Sternfels, 1979), more recent experiments have determined that adults use their head as the reference (Howard, Bergström, & Ohmi, 1990; Wenderoth & Hickey, 1993). Interestingly, one participant was discarded from the second experiment in Howard et al. (1990) because of a consistent bias to the left for the preferred illumination position. Half a century earlier, Metzger (1936) had also noticed a preference for scenes lit from the left. These observations give rise to the intriguing possibility that the visual system assumes that light is coming from above-left rather than directly above. Sun and Perona (1998) tested this proposition by asking observers to look for a convex or concave object lit from one direction among similar objects lit from the opposite direction. They found that shaded target images were detected more quickly when the illumination position was between 30 and 60 degrees to the left of overhead. While these results are consistent with a bias to the left for the illumination position, the experimental procedure utilized does not conclusively show that subjects based their responses on this information. In fact, a very different interpretation was advanced by Symons, Cuddy, and Humphrey (2000). Using a similar visual search procedure, Symons et al. (2000) argued that asymmetries in the ability to detect shaded targets could be explained by a processing advantage for concave targets regardless of left or right lighting. More specifically, they found that perceived concave targets amongst convex distractors were processed faster than convex targets amongst concave distractors (Kleffner & Ramachandran, 1992).

The idea that the preferred illumination position is above and to the left of the observer is unexpected insofar as one expects prior assumptions to be related to statistical regularities of the environment. It is indeed counter-intuitive to believe that human beings would spend more time with the light source on their left rather than on their right. One plausible explanation is that observers consistently orient their body relative to the light source while manipulating an object. If this explanation holds, then there should be a relationship between handedness and the strength of the illumination position bias. Such a relationship has been found by Sun and Perona (1998), who reported that left-handed observers had a weaker bias to the left for the illumination position.

The claim for a bias to the left for the illumination position rests upon evidence that has been gathered either informally (Howard et al., 1990; Metzger, 1936) or indirectly (Sun & Perona, 1998; Symons et al., 2000). We believe it is important to ascertain the existence of a leftward bias with a more direct approach. Because the illumination position directly affects the perceived three-dimensional shape of an object, we have designed a simple experiment in which the observer's task is to estimate the object's shape.

2. Experiment

Our experiment is based on stimuli whose shape interpretation changes with illumination position. Spheres illuminated from one side are such stimuli, with percepts alternating between convex balls and concave bowls. However, spheres provide a simple two-dimensional cue that confounds the more complex interpretation based on a three-dimensional percept: on a convex sphere, the shading gradient from bright to dark always follows the illumination direction. In addition, one has to be cautious when using a discrimination task between convexity and concavity because these judgements are usually distorted by a bias to assume that objects are convex by default (Symons et al., 2000; Woodworth & Schlosberg, 1954).

Instead of spheres, we chose stimuli that depict flat surfaces with parallel protruding strips (cf. Fig. 1). When the light source is moved from above to below, the percept changes from narrow to wide bulging strips. We display the same stimulus at different orientations in the frontal plane, thus simultaneously rotating the surface and the light source. Since the orientation of the surface is irrelevant, we directly obtain the illumination position from the orientation of the stimulus. We hypothesize that the illumination position that most consistently produces the "narrow strips" percept is the assumed illumination position for the observer.

2.1. Methods

2.1.1. Subjects

The experiment involved 20 participants (ten males and ten females) from the University of Glasgow. All participants had normal or corrected to normal visual acuity. Their mean age was 23.3 years (range 18–54 years). The participants were naive with respect to the purpose of the experiment and received a compensation fee upon its completion.

2.1.2. Apparatus

The experiment was run in a dark room. Stimuli were presented on a Sony 17 inch trinitron monitor driven by an Apple PowerMacintosh. The timing of events in each trial was controlled by the PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Head position and orientation were controlled with a chin cup and head restraint located 50 cm away from the monitor. Observers viewed the stimuli binocularly.

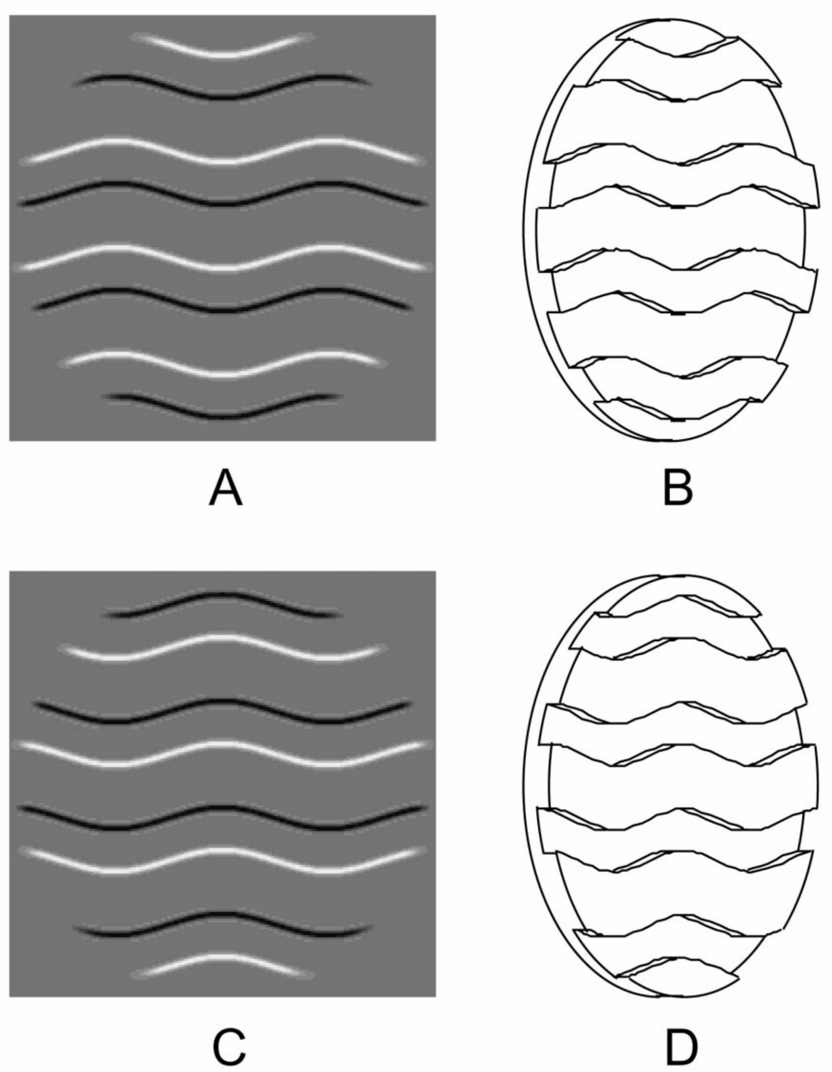

Fig. 1. Examples of stimuli used in the experiment. (A) is usually interpreted as a fronto-parallel embossed surface with narrow strips bulging out as illustrated in (B). In contrast, (C) is usually interpreted as a surface with wide strips bulging out as in (D). The difference between (A) and (C) is simply a rotation of 180 degrees in the image plane. Readers are invited to rotate the page by 180 degrees to experience the change of shape percept.

2.1.3. Stimuli

Examples of the patterns used in the experiment are shown in Fig. 1A,C. The patterns were composed of bright and dark parallel sinusoidal contours (luminance 48 and 1 cd/m^2, respectively) on a grey background (24 cd/m^2). Each pattern can be interpreted as an embossed surface with undulating strips in relief. Side renderings of such an interpretation are shown in Fig. 1B,D. The width ratio between narrow and wide strips was 1:2. In addition to the pattern shown in Fig. 1 (pattern P), another pattern was created such that the fixation point would fall in the middle of a narrow rather than wide strip (pattern Q, not shown). This manipulation which controlled for a potential bias to respond ‘narrow’ more often than ‘wide’ did not produce any significant difference in the results. Each pattern was presented at 24 orientations in the image plane in increments of 15 degrees. From the 50 cm viewing distance, the diameter of the patterns subtended 6.6 degrees of visual angle.

2.1.4. Procedure

Before starting the experiment proper, participants were tested for hand preference using the decile scale of the Edinburgh Handedness Inventory (Oldfield, 1971). Based on this inventory, participants included ten left-handers (negative scores) and ten right-handers (positive scores).

The participants were then presented with two blocks of trials consisting of a central fixation point, one figure at a random orientation and then a mask image (band-passed white noise). The presentation time was set to 120 ms; this duration was found to be a good compromise between allowing enough time to see the stimulus and avoiding natural reversals of percept that occur when the stimulus is shown for too long. The task of the observers was to report whether the strips that appeared to bulge towards them were ‘narrow’ or ‘wide’. They responded by pressing one of two keys on the computer keyboard with their left and right index fingers. No feedback was provided.

Each stimulus orientation was presented 16 times (eight repeated trials for patterns P and Q). Altogether, participants were prompted to make 384 shape judgements (24 orientations times 16 repeats). We call “narrow score” the proportion of times a stimulus at a particular orientation was interpreted as a surface with narrow bulging strips.

2.2. Results

The results for a representative observer are shown in Fig. 2. The orientation axis corresponds to the orientation of the stimulus in the frontal plane, with the origin chosen as the orientation of the pattern in Fig. 1A and positive orientations as counter-clockwise rotations. For each orientation, the “narrow score” was computed as the proportion of times the stimuli were perceived with narrow bulging strips. As described above, the illumination position assumed by the observer can be inferred from the stimulus orientation that leads to the peak narrow score. In particular, if the observer assumed that light was coming from straight above, the peak narrow score should occur at the origin. Instead, the peak narrow score is shifted to the right, indicating that the preferred illumination position was left of above.

The preferred illumination position was computed for each observer. Instead of referring only to the peak narrow score, we used all the stimulus orientations to extract the illumination bias. The narrow score was thus fitted with a raised sinewave that varied between 0 and 1. The phase of the sinewave (left or right shift) was the only degree of freedom used to fit the data and was interpreted as the bias for the illumination position. The best fit for the observer shown in Fig. 2 resulted in a bias equal to 31 degrees to the left of the vertical.

We can now look at the relationship between handedness and the magnitude of the illumination position bias. Four observers were discarded from this analysis because they failed to perceive the stimuli as three-dimensional surfaces (three left-handers and one right-hander performed at chance level). We performed a linear regression of illumination position bias against handedness based on the remaining 16 observers and found no significant correlation ($R = 0.14$, $P = 0.602$). We then separated left-handed and right-handed observers into two groups based on the sign of their

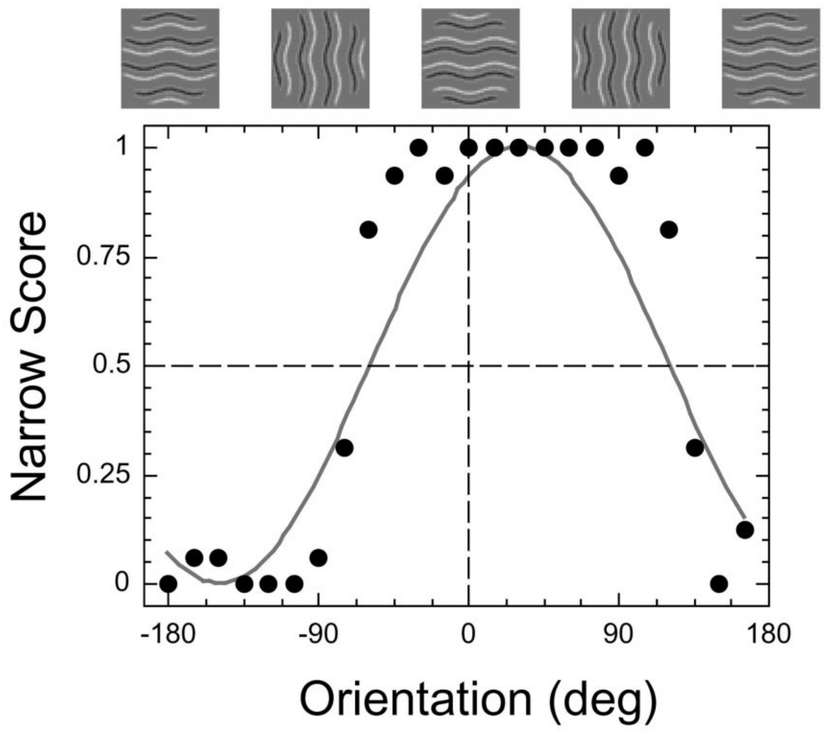

Fig. 2. Variation of narrow score with stimulus orientation for one observer. The narrow score is the proportion of times the stimulus was perceived as a surface with narrow strips bulging. The orientation origin corresponds to the orientation of the stimulus in Fig. 1A. The best fit of the narrow score with a raised sinewave (continuous line) indicates an assumed illumination position biased to the left by 31 degrees.

performance in the Edinburgh Handedness Inventory. The mean illumination position bias for left-handed and right-handed observers was 24 and 27.8 degrees, respectively. Analysis was carried out using the non-parametric Mann–Whitney test. Again, the difference between these two mean illumination position biases did not reach significance ($W = 56$, $P = 0.75$ on a two-tailed test). The mean illumination position bias across all 16 observers was 26.1 degrees. This mean illumination position bias was significantly larger than zero ($t(15) = 6.78$, $P < 0.001$ on a one-tailed t-test).

3. Discussion

The crater illusion is the phenomenon whereby a surface appears to change relief when its image is turned by 180 degrees. The explanation for this phenomenon relies on the observers' assumption that light is coming from above their head. The crater illusion has thus become a favourite demonstration in psychology textbooks because it suggests that our visual system has the ability to take into account salient regularities of its environment (e.g. Boring, 1942; Gregory, 1998). Knowing where the light is coming from can drastically disambiguate and accelerate the interpretation of natural scenes, in particular with respect to the shape of objects (Cavanagh & Leclerc, 1989; Horn & Brooks, 1989), the lightness of surfaces (Gilchrist, 1988) and the spatial layout of scenes (Mamassian, Knill, & Kersten, 1998). While early experiments have indeed suggested that human observers assumed light to come from above, it is now clear that this is only part of the story. The experiment reported here directly confirms previous findings in the visual search literature that the preferred illumination position is biased to the above-left rather than directly above (cf. Sun & Perona, 1998; Symons et al., 2000). Our results, based on a simple shape discrimination task, show that the bias to the left equals 26 degrees on average and is of similar magnitude in both left- and right-handed observers. This bias to the left is difficult to explain ecologically because observers are very often exposed to multiple sources of illumination, including strong secondary reflections and diffuse illumination such as the case when the sun shines through thick clouds. While it is true that humans are thus rarely directly under the sun, it will be difficult to prove that they orient themselves considerably more often with the light on their left side. Even if this were the case, it remains to be shown that this body orientation bias is sufficient to induce the perceptual bias reported here.

Instead of an environmental bias on the illumination position, a visual field bias might be at the origin of our results. For instance, there is evidence that observers pay attention more to the right side of a face (in the observer's left hemi-field) when they have to recognize it or identify its gender (Sergent, Ohta, & MacDonald, 1992). The right side of a face will be informative only when the light is positioned on the left of the observer (on the right of the face), since that side of the face is otherwise in shadow. A preference to attend to one side of objects could therefore be related to a bias on the illumination position. This speculation makes an interesting prediction. Patients with a right parietal injury tend to neglect the contralesional (left) side of space and objects. These hemi-neglect patients might thus assume the illuminant to be at a location different from the one found here for normal observers.

The interpretation that illumination position is related to cerebral lateralization could also partially explain our discrepancy with the results of Sun and Perona (1998). While these authors found a correlation between handedness and the magnitude of the illumination position bias, we found no evidence for such a correlation. We have already noticed major differences between the two experiments that could account for the discrepancy. In particular, we used a direct shape discrimination task rather than a visual search task and our stimuli were immune to a potential convexity bias. A final difference may be the source of the discrepancy. Because of the large variability of cerebral lateralization among left-handers (e.g. Peters, 1995), it is possible that Sun and Perona's population of left-handers included a few participants with a left cerebral dominance. The general issue of handedness versus cerebral lateralization should be addressed carefully in future studies.

Finally, if cerebral lateralization is at the origin of the illumination position bias, then this bias is likely to be witnessed very early in life as important cerebral asymmetries are present from birth (Galaburda, 1995). Evidence that illumination preference is present at birth was reported by Hershberger (1970), who showed that chickens raised in an environment lit from below still behaved as if light was coming from above. The possibility that prior assumptions about our environment are present so early in life raises some fascinating issues on the cerebral representation of this knowledge and on the genetic mechanism that hands this knowledge down.

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